PERFORMANCE ANALYSIS OF TWO-PHASE COOLING SYSTEM FOR ELECTRONIC COOLING

A project report submitted in partial fulfillment of the requirements

For the award of the Degree of

BACHELOR OF TECHNOLOGY

In

MECHANICAL ENGINEERING

By

REDDI NARSINGARAO : 315126520263
EPPILI VAMSIKRISHNA : 315126520268
KETHA STUTHI : 315126520260
MOHAMMAD AHMED : 315126520245
NIMMAKA NAVEEN : 315126520275

Under the esteemed guidance of

Sri Maddu Rama Krishna, M.Tech

Assistant Professor.

DEPARTMENT OF MECHANICAL ENGINEERING
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)
(Affiliated to A.U, approved by AICTE, Accredited by NBA and NAAC with 'A' grade)
SANGIVALASA, VISAKHAPATNAM–531162
2019

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)

(Affiliated to Andhra University)

(Sangivalasa, Bheemunipatnam (Mandal), Visakhapatnam (District)

CERTIFICATE

This is to certify that the Project Report entitled **"PERFORMANCE ANALYSIS OF TWO-PHASE COOLING SYSTEM FOR ELECTRONIC COOLING"** has been carried out by **R.Narasingarao** (315126520263), **E.VamsiKrishna** (315126520268), **Md.Ahmed** (315126520245), **K. Stuthi** (315126520260), **N.Naveen** (315126520275) under the guidance of, **Mr. M. Rama Krishna** in partial fulfillment of the requirements of Degree of Bachelor of technology of Anil Neerukonda Institute Of Technology And Sciences, Visakhapatnam.

15.4.19

APPROVED BY

(Prof.B.Naga Raju)

Head of the Department
Dept. of Mechanical Engineering
ANITS (A), Sangivalasa
Visakhapatnam.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa 531 162, VISAKHAPATNAM Dist. A.P.

PROJECT GUIDE

(Mr. M. Rama Krishna)

Assistant Professor
Dept. of Mechanical Engineering
ANITS (A), Sangivalasa
Visakhapatnam.

THIS PROJECT IS APPROVED BY THE BOARD OF EXAMINERS

INTERNAL EXAMINER: 15/4/19

15/4/19

EXTERNAL EXAMINER:

DECLARATION

We **R. Narasinga Rao, E. Vamsi Krishna, K. Stuthi, Md. Ahmed, N.Naveen** students of final semester B.Tech Mechanical Engineering from Anil Neerukonda Institute of Technology and Sciences, Visakhapatnam, hereby declare that the project work entitled **"PERFORMANCE ANALYSIS OF TWO PHASE COOLING SYSTEM FOR ELECTRONIC COOLING"** is carried out by us and submitted in partial fulfillment of the requirements for the award of **Bachelor of Technology in Mechanical Engineering,** under Anil Neerukonda Institute of Technology & Sciences during the academic year2018-19 and has not been submitted to any other university for the award of any kind of degree.

R. Narasinga Rao	315126520263
E. Vamsi Krishna	315126520268
K. Stuthi	315126520260
Md. Ahmed	315126520245
N. Naveen	315126520275

ACKNOWLEDGEMENT

We would like to acknowledge the work and help of all those who have guided us for the completion of our project on time. We take this opportunity to express our profound sense of gratitude to all those who encourage us, assisted us and cooperated with us for successful completion of this research project and without them this project would not have been possible.

We would like to express my special thanks of gratitude to my principal Prof.T.SUBRAHMANYAM who gave me the golden opportunity to do this wonderful project.

We would like to express our sincere thanks to our dean of academic affairs Prof.T.V.HANUMANTHARAO for his kind support in doing this project.

We take the privilege to thank the head of our department, Dr. B.NAGA RAJU, for permitting us in laying the first stone for success and providing the lab facilities.

With immense respect, duty bound and grateful heart, we thank our project guide Asst. professor Sri.M.RAMA KRISHNA, who encouraged a lot and has been a source of inspiration, encouragement and guidance throughout the course of project development. We are also thankful to Asst. professor Sri.P.CHANDRA SEKHAR for guiding us and for his valuable suggestions and moral support, who has spent many of his precious hours in specifying the project requirements and for all the technical support.

Last, but not least, we thank all the staff members, lab instructors and technicians of Mechanical department for their advices and kind help.

Project Member

Reddi Narsingarao	:	315126520263
Eppili Vamsikrishna	:	315126520268
Ketha Stuthi	:	315126520260
Mohammad Ahmed	:	315126520245
Nimmaka Naveen	:	315126520275

ABSTRACT

As the recent trends in electronics development and their applications pose a big challenge on heat dissipation. As the number of transistors increases with new generation of microprocessor chips, the power draw and heat load to dissipate during operation increases. As a result of increasing the heat loads and heat fluxes the conventional cooling technologies such as fan, heat sinks are unable to absorb and transfer excess heat dissipated by these new microprocessors. As a result it requires larger fans and larger heat sinks. So, new technologies are needed to improve the heat removal capacity.

In present work two phase liquid cooling system is analyzed with different refrigerants such as R-134a, R-600a and R410a at different heat inputs. As the heat absorbed during phase change will be more as the latent heat of vaporization is more than sensible heat. Refrigerants can change their phase easily at normal temperatures. A thermo siphon effect is used to circulate refrigerant through the circuit.

An experimental set-up is fabricated which is based on the thermo siphon effect. A solid heated aluminium block to simulate heat generated electronic component is used and heat is supplied to the aluminium block similar to heat generated by electronics and cooling system is placed over the heated block. The performance of cooling system is analyzed from experimental data obtained. The results obtained are compared with the results of water.

Results show that the surface temperature of aluminium block ranges from 29.5^0C to 50.6^0C, which implies that the two phase cooling system with thermo siphon effect with medium refrigerants can effectively cool down the CPU at different running status when compared to using water, ethylene glycol and calcium chloride solutions.

CONTENTS

CHAPTERS **PAGE NO**

LIST OF FIGURES

LIST OF TABLES

NOMENCLATURE

d_i = inner diameter of copper tube, m

D = Discharge, l/sec

A = Area, m^2

Q = heat transfer rate to the water, W

Q_{loss}= loss of heat energy, W

Q_{input} = heat input to the heater, W

m_{flow} = mass flow rate of water, Kg/s

C_p = Specific heat, Kj/(kg-k)

ΔT = Temperature difference, K

T_i = inlet Temperature of water, K

T_o= outlet Temperature of water, K

V = velocity of fluid, m/s

l = liters

Subscripts

i = inlet

o = outlet

w = water

Greek

ρ = fluid density [kg/m^3]

CHAPTER 1

INTRODUCTION

The electronic components have been ruling the world for few decades. They have made its way into practically every aspect of modern life, from toys and appliances to high speed computers. An electronic component depends on the passage of electric current to perform their duties, and they become potential sizes for excessive heating since the current flow through a resistance is accompanied by heat generation. Electronic devices are at the heart of almost all major industrial and military equipment. Some of these are power drives, insulated-gate bipolar transistor (IGBT) controllers, radio-frequency (RF) generators, magnetic resonance imaging (MRI) machines, traction devices for locomotives, battery chargers, UPS(uninterrupted power systems), DC-AC converters, AC-DC inverters, and army tanks (using transmission fluid already at a high temperature). The high-power, high-heat-flux demands on the cooling system cannot be met with air cooling, and advanced liquid cooling solutions are necessary.

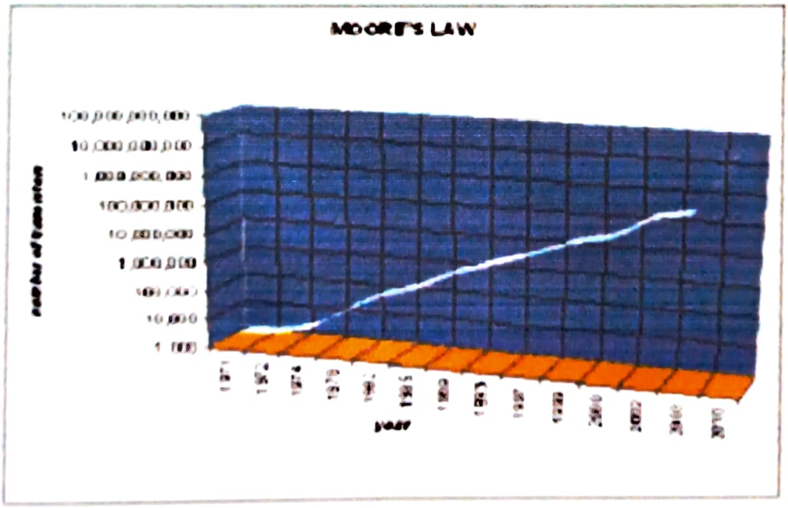

Fig: 1.1 Moore's law (number of transistors vs. year)

According to Moore's law as shown in Fig 1.1 the number of transistors mounted on a chip gets doubled for every two years. As the number of transistors increase with development of chip integration technology, the power draw and heat load to dissipate during operation increases. With the development of chip integrated circuits gradual decrease in size of the components has resulted drastic increase in the amount of heat generation per unit volume. Unless they are properly designed and controlled high rates of heat generation result in the failure of electronic component due to high operating temperature.

The failure rate of electronic components increases with increase in temperature. A hot spot created within the electronic components due to low transfer rates seems to be major failure problem. Therefore thermal control has become increasing important in the design and operation of electronic equipment. There has been a dramatic shift in cooling high-power devices in the industry during the past decade. Air cooling has sufficed for many lower power electronic devices. Although it is quite difficult to make a distinction based on total power dissipation, it seems that beyond a range of about 1500 W dissipation, there are many physical and design constraints that may dictate a shift toward liquid as the preferred medium.

Today, the energy for cooling conventional air cooled data centre systems can be significantly reduced by switching to liquid cooling. This is because the much lower thermal resistance inherent in liquid use enables cooling above the free cooling limit thus eliminating the need for coolant chillers. The free cooling limit represents the minimum temperature at which the coolant can effectively transport heat from a chip to ambient conditions without the need for an additional chiller. Additionally and perhaps more importantly, if hot water in the temperature range 50^0C-70^0C is used to cool electronic chips, direct utilization of the collected thermal energy becomes feasible.

As a result of increasing heat loads and heat fluxes conventional cooling technologies such as fan heat sink are unable to absorb and transfer the excess heat. As a result it requires large fans and large heat sinks or new techniques are needed to improve the heat removal capacity.

In order to provide greater cooling efficiency many IT systems are currently developing and employing liquid cooling systems. Liquid cooling systems are typically more compact relative to similarly rated air cooling systems and have lower power requirements due to the improved thermo-physical properties of liquids as compared to air. The liquid best suited thermally for liquid cooling is water due to its high specific heat and thermal conductivity, as well as high availability and environmental friendliness. In the present work an attempt has been made to experimentally study a liquid cooling system with water as coolant and analyze the pump power for these fluids at different flow rates.

CHAPTER 2

LITERATURE REVIEW

The following is a review of the research that has been completed especially on electronics cooling. The literature survey is arranged according to similarity to the work done in this thesis.

Moore [1] in his classical paper predicted the future of integrated electronics and the advantages of integration. Integrated circuits will lead to such wonders as home computers, automatic controls for automobiles and personal portable communication equipments. The development has been possible only due to integration of millions of transistors, but one of the problem is heat problem. According to his predictions the number of transistors will get doubled every two years and a heat transfer solution to chip is a continuous research.

Kanlikar and Grande [2] studied the increased circuit density on today's computer chips is reaching the heat dissipation limits for technology, the direct liquid cooling of chips is being as a viable alternative. This paper reviews a liquid cooling with internal flow channels in technological options and challenges. The possibilities presented here in indicate a four to increase in heat flux over the air cooled system. The road map for single phase cooling technology is presented to identify opportunities in meeting the cooling demands of future IC chips. The use of micro channels that incorporate either microstructures in the channels or grooves in the channel surface may lead to significant enhancements in single phase cooling. A simplified and well established fabrication process is described to fabricate both classes of three dimensional micro channels.

Wahib Owhaib and Bjorn Palm [3] studied the heat transfer characteristics of single phase forced convection of R – 134a through single circular micro channels with 1.7, 1.2, 0.8 mm as inner diameter were investigated experimentally. The results were compared both to correlations for the heat transfer in the macro scale channels and to correlations suggested for micro scale geometries. The results show good agreement between classical correlations and experimentally measured data in the turbulent region. Contrary, none of the suggested correlations for micro channels agreed with the data. In the laminar region the heat transfer co-efficient is almost identical for all three diameters.

Kennith and Goodson et al [4] investigated the performance of micro channel cooling system for microprocessor and found that the surface temperatures are below the air cooling techniques.

Steinkel and Kanlikar [5] studied the single phase heat transfer enhancement techniques are well established for conventional and compact heat exchangers. The major techniques include flow transition, breakup of boundary layer, entrance region, vibration, electric fields, swirl flow, secondary flow and mixtures. In the present paper, the applicability of these techniques for single phase flows in micro channels and mini channels is evaluated. The micro channels and mini channel single phase heat transfer enhancement devices will help the applicability of single phase cooling for critical applications, such as chip cooling, before more aggressive cooling techniques, such as flow boiling are considered.

Mahopatra [6] studied that cooling of electronic parts has become a major challenge in recent times due to the advancements in the design of faster and smaller components. As a result, different cooling technologies have been developed to efficiently remove the heat from these components. The use of a liquid coolant has become attractive due to higher heat transfer co-efficient achieved as compared to air cooling. Coolants are used in both single phase and two phase applications. A single phase cooling loop consists of a pump, a heat exchanger and a heat sink. The heat source in the electronics system is attached to the heat exchanger. Liquid coolants are also used in two phase system, such as heat pipes, thermo-siphons; sub cooled boiling, spray cooling and direct immersion systems.

S M Sohel Murshed[7] in his paper stated that with superior thermal properties and cooling features, nanofluids offer great promises to be used as coolants for high-tech electronic devices and industries. The emerging techniques like microchannels with these new fluids can be the next-generation cooling technologies.

The workshop[8] "Thermal Challenges in Next Generation Electronic Systems (THERMES 2007)" was held January 7 to 10, 2007, in Santa Fe, discussed the serious challenges facing thermal engineers as technology scaling continues. Design of ICs is facing difficulties in sustaining supply and threshold voltage scaling to provide the required performance increase, limit energy consumption, control power dissipation, and maintain reliability. Increased leakage power and greater variation highlight the need for electrothermal codesign of electronic systems. Various process and design techniques are currently used to provide answers to the challenges faced in IC design, particularly the high power consumption.

Yury[9] investigated experimentally the thermosiphon effect arising in the real HTS cable cooling system in the presence of elevation difference which can be used to save coolant circulation pump power. The study was carried out using 200 m DC SC PT line at the Chubu University. Experimental facility was not adapted to utilize natural circulation, but because we have achieved record low values of the pressure drop, it was allowed direct observation both the natural effect (caused by the heat penetrating through the insulation) and effect due to intentional local heating of LN2. The obtained results show that by using bypass between termination cryostats the natural circulation can occur at the flow rate of about 4 l/min.

Todd Salamon and Raffaele L. Amalfi [10] exconducted an eperimental study to analyse the thermal performance of a two-phase pump-driven loop for electronics cooling is presented, with the target application being a telecommunications equipment shelf having multiple circuit pack cards each dissipating several hundred Watts of power. The upward flow boiling heat transfer and pressure drop of R134a within an evaporator prototype fabricated with 18 individual microcooling zones to cool multiple electronics heat sources was investigated. The electronic heat sources were emulated by multiple copper heater blocks with embedded cartridge heaters, where each heat source was capable of dissipating more than 100 W, for a total power dissipation larger than 1800 W. Experimental results demonstrated the best cooling capability at a mass flow rate of 140 kg/h,

Raffaele L. Amalfi and Todd Salamo [11] conducted an experimental study to investigate the thermal performance of a two-phase thermosiphone for electronics cooling is presented in this article. In this study, the thermosiphone evaporator was connected via a riser and a downcomer to an ultra-compact condenser operating as a refrigerant-to-refrigerant counter flow heat exchanger. The secondary side of the condenser evaporated R134a from a “bus line” to condense the working fluid in the thermosiphone. Experiments were carried out for filling ratios ranging from 60% to 76%, heat loads from 102 W to 1841 W, secondary side mass flow rates from 40 kg/h to 120 kg/h, inlet subcoolings from about 0 K to 5 K, and saturation pressures from 600 kPa to 730 kPa. Robust thermal performance was observed for the entire range of operating test conditions. In particular, at the optimum filling ratio of 65%, secondary side mass flow rate of 80 kg/h, inlet subcooling close to 0 K and saturation pressure of 600 kPa, the mean temperature difference from the evaporator to inlet coolant was only 9.4 K. Experimental results demonstrated an increase of 14X in heat density dissipation, 19X increase in energy efficiency and a virtually noiseless system compared to the air-cooled thermosiphone.

Suwat Trutassanawin1 and Eckhard A. Groll [12] in his classical paper concluded that The miniature-scale vapor compression refrigeration system is one of the most promising alternative cooling techniques for high heat dissipation electronics cooling. It maintains an operating chip temperature below the ambient air temperature, increases reliability and life cycle time due to a lower and constant operating temperature, and provides high system performance. An ongoing experimental and theoretical research effort will focus on optimizing the size and performance of this technology for a variety of operating conditions and a given set of design conditions.

Kai Zhu and Xueqiang Li,[13] developed a mathematical model and was developed to simulate the operation of the electronics. Through the comparison between the simulated results and the experimental data, good agreements have been observed. Based on the validated model, the dynamic performance of LHP under the measured running status of CPU has been investigated. The highest and lowest operation temperatures of evaporator, which are 73.1 and 47.5 oC respectively, are in the safe operation temperature range. The charging ratio of working fluid is a key parameter that can clearly affect the performance of the heat pipe. There exists an optimal ratio. When keeping the charging ratio constant, a larger evaporator area is more favourite.

Mehdi Bahiraei and Saeed Heshmatian[14]carried out investigations on application of nanofluids in electronics cooling. Various aspects such as liquid block geometry, nanoparticle material, numerical approach, and second law of thermodynamics were considered. Most of the numerical and experimental studies have indicated that nanofluids result in a better thermal performance compared with conventional coolants in terms of thermal resistance of heat sinks, average temperature of heating surface, maximum temperature of heating surface, convective heat transfer coefficient, Nusselt number as well as the temperature uniformity on surface of electronic processors.

CHAPTER 3

HISTORY OF ELECTRONICS COOLING

3.1 INTRODUCTION

The field of electronics deals with the construction and utilization of devices that involve current flow through vacuum, a gas, or a semiconductor. This exciting field of science and engineering dates back to1883, when Thomas Alva Edison discovered the vacuum diode. The vacuum tube served as the foundation of the electronics industry until the 1950s, and played a central role in the development of Radio, Radar, and the Digital Computer.

The invention of the bipolar transistor in 1948 marked the beginning of the new era in the electronics industry and the obsolescence of vacuum tube technology .transistor circuits performed the functions of the vacuum tubes with greater reliability, while occupying negligible space and consuming negligible power compared with vacuum tubes. The first transistors were made from germanium. Which could not function properly at temperatures above 100°C.Soon they were replaced by silicon transistors, which could operate at much higher temperatures.

The next turning point in electronics occurred in1959 with the introduction of the integrated circuits (IC), where several components such as diodes, transistors, resistors and capacitors are placed in a single chip. The number of components packed in a single chip has been increasing steadily since then at an amazing rate, as shown in Figure 3.1.

There has been a dramatic shift in cooling high-power devices in the industry during the past decade. Air cooling has sufficed for many lower power electronic devices. Although it is quite difficult to make a distinction based on total power dissipation, it seems that beyond a range of about 1500 W dissipation, there are many physical and design constraints that may dictate a shift toward liquid as the preferred medium .Liquid cooling manages the heat loads of high watt density applications across all industries. Liquid Cold Plates are the most effective way to optimize liquid contact with hot surfaces and have the highest heat transfer. Water cooling is a method of heat removal from components and industrial equipment .As opposed to air cooling, water is used as heat conductor. Water cooling is commonly used for cooling automobile, internal combustion engines and large industrial facilities such as steam electric power plants, petroleum refineries and chemical plants and cooling heat exchangers.

The first integrated circuits contained only a few transistors. Called "Small-Scale Integration" (SSI), digital circuits containing transistors numbering in the tens provided a few logic gates for example, while early linear ICs such as the Plessey SL201 or the Philips TAA320 had as few as two transistors. The term Large Scale Integration was first used by IBM scientist Rolf Landover when describing the theoretical concept, from there came the terms for SSI, MSI, VLSI, and ULSI.

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 100,000-10,000,000 components per chip.

To reflect further growth of the complexity, the term *ULSI* that stands for "ultra-large-scale integration" was proposed for chips of complexity of more than 1 million transistors.

Wafer-scale integration (WSI) is a system of building very-large integrated circuits that uses an entire silicon wafer to produce a single "super-chip". Through a combination of large size and reduced packaging, WSI could lead to dramatically reduced costs for some systems, notably massively parallel supercomputers. The name is taken from the term Very-Large-Scale Integration, the current state of the art when WSI was being developed.

A system on a chip (SOC) is an integrated circuit in which all the components needed for a computer or other systems are included on a single chip. The design of such a device can be complex and costly, and building disparate components on a single piece of silicon may compromise the efficiency of some elements. However, these drawbacks are offset by lower manufacturing and assembly costs and by a greatly reduced power budget: because signals among the components are kept on-die, much less power is required.

A three dimensional integrated circuit (3D-IC) has two or more layers of active electronic components that are integrated both vertically and horizontally into a single circuit. Communication between layers uses on-die signaling, so power consumption is much lower than in equivalent separate circuits. Judicious use of short vertical wires can substantially reduce overall wire length for faster operation.

Today it is not usual to have a chip 3cm *3cm in size with several million components on it.

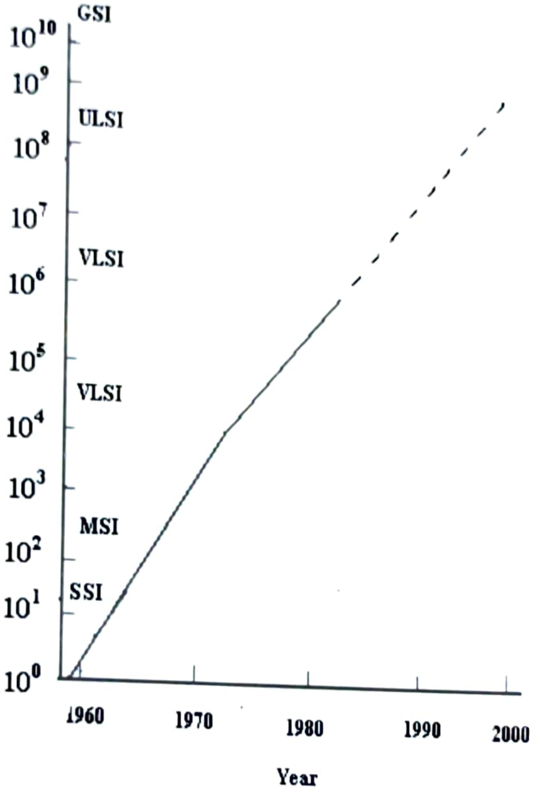

Fig: 3.1 Year V/S No. of chips

3.2 HEAT GENERATION IN ELECTRONIC COMPONENTS

Electronic equipment has made its way into practically every aspect of modern life, from toys and appliances to high-power computers. The reliability of the electronics of a system is a major factor in the overall reliability of the system. Electronic components depend on the passage of electric 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 a dramatic increase in the amount of heat generated per unit volume, comparable in magnitude to those encountered at nuclear reactors and the surface of the sun. Unless properly designed and controlled, high rates of heat generation result in high operating temperatures for electronic equipment, which jeopardizes its safety and reliability.

The failure rate of electronic equipment increases exponentially with temperature. Also, the high thermal stresses in the solder joints of electronic components mounted on circuit boards resulting from temperature variations are major causes of failure. Therefore, thermal control has become increasingly important in the design and operation of electronic equipment.

Heat is generated in a resistive element for as long as current continues to flow through it. This creates a heat buildup and subsequent temperature at an around the component. The temperature of the component will continue to rise until the component is destroyed unless heat is transferred away from it. The temperature of the component will remain constant when the rate of heat removal from it is equals to the rate of heat generation.

3.3 NECESSITY OF COOLING OF ELECTRONIC COMPONENTS

In this chapter, we discuss several cooling techniques commonly used in electronic equipment such as conduction cooling, natural convection and radiation cooling, forced-air cooling, liquid cooling, and immersion cooling. This chapter is intended to familiarize the reader with these techniques and put them into perspective. The reader interested in an in-depth coverage of any of these topics can consult numerous other sources available, such as those listed in the references.

Computer cooling is the process of removing heat from computer components. Because a computer system's components produce large amounts of heat during operation, this heat must be dissipated in order to keep these components within their safe operating temperatures. In addition to maintaining normative function, varied cooling methods are used to either achieve greater processor performance (over clocking), or else to reduce the noise pollution caused by typical (i.e. cooling fans) cooling methods (cf. ergonomics).

Components which produce heat and are susceptible to performance loss and damage include integrated circuits such as CPUs, chipset and graphics cards, along with hard drives (though excessive cooling of hard drives has been found to have negative effects). Overheated parts generally exhibit a shorter maximum life-span and may give sporadic problems resulting in system freezes or crashes.

Both integral (manufacturing) and peripheral means (additional parts) are used to keep the heat of each component at a safe operational level. With regard to integral means, CPU and GPUs are designed entirely with energy efficiency, including heat dissipation, in mind, and with each advance CPUs/GPUs generally produce less heat (though this increased efficiency is always used to increase performance, producing similar heat levels as earlier models anyway). Cooling through peripheral means is mainly done using heat sinks to increase the surface area which dissipates heat, fans to speed up the exchange of air heated by the computer parts for cooler ambient air, and in some cases soft cooling, the throttling of computer parts in order to decrease heat generation

In operation, the temperature levels of a computer's components will rise until the temperature gradient between the computer parts and their surroundings is such that the rate at which heat is lost to the surroundings is equal to the rate at which heat is being produced by the electronic component, and thus the temperature of the component reaches equilibrium.

For reliable operation, the equilibrium temperature must be sufficiently low for the structure of the computer's circuits to survive. Additionally, the normal operation of cooling methods can be hindered by other causes, such as:

- Dust acting as a thermal insulator and impeding airflow, thereby reducing heat sink and fan performance.
- Poor airflow including turbulence due to friction against impeding components, or improper orientation of fans, can reduce the amount of air flowing through a case and even create localized whirlpools of hot air in the case.
- Poor heat transfer due to a lack or poor application of thermal compounds.

Microprocessor is a device which is made up of millions of transistors of which each group of transistor works on various functions in fraction of seconds to given signal. A small microprocessor works on several instructions given and within a fraction display the results.

Due to finely packed semi conductors with in a confined space say 1 cm will obviously generate heat due to resistance thus gradually increase in temperature is observed.

The performance of the microprocessor will drop exponentially with every 10°c rise of temperature in the microprocessor as shown in Figure 3.2

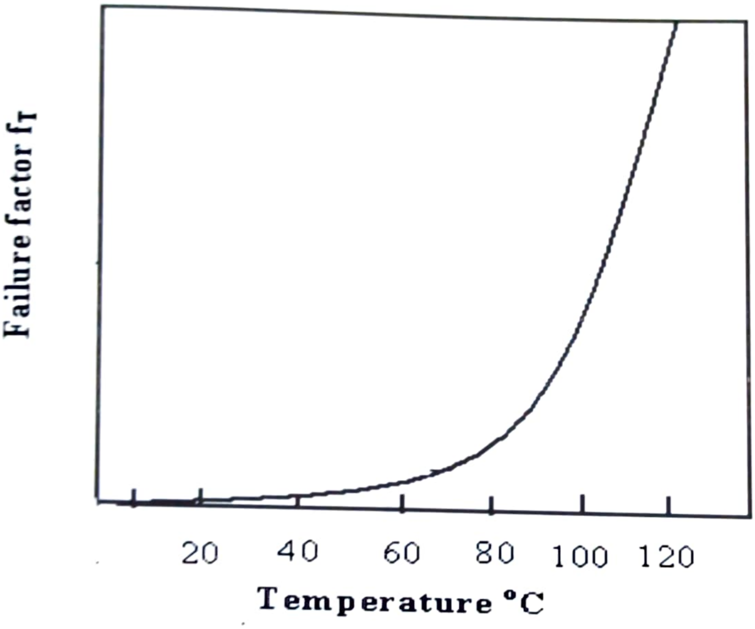

Fig: 3.2 Failure Rate Vs Temperature

3.4 COOLING LOAD OF ELECTRONIC COMPONENTS

Cooling load of electronic components is accompanied by the amount of heat dissipation. The most general way to find out the amount of heat dissipated from the electronic component is to measure the voltage applied and electric current across the component under full load condition and substitute them in relation.

$W_e = V.I = I^2R$Where, W_e is the electric power consumption of the electronic devices

3.5 PRESENT COOLING SYSTEMS

In most computers, fans do a pretty good job of keeping electronic components cool. But for people who want to use high-end hardware or coax their PCs into running faster, a fan might not have enough power for the job. If a computer generates too much heat, liquid cooling, also known as water cooling can be a better solution. It might seem a little counterintuitive to put liquids near delicate electronic equipment, but cooling with water is far more efficient than cooling with air.

Present cooling system such as air cooling, liquid cooling .submerged cooling, thermoelectric cooling and heat pipes etc., we are having good enough heat fluxes of 500 to 1000 watt/cm^2, but beyond this heat fluxes the above stated cooling may not be sufficient hence there is need for further research in the field of electronic chip cooling to create superior cooling technologies.

The main mechanism for water cooling is convective heat transfer. Cooling water is the water removing heat from a machine or system. Cooling water may be recycled through a recirculation system or used in a single pass once-through cooling (OTC) system. Recirculation systems may be open if they rely upon cooling towers or cooling ponds to remove heat or closed if heat removal is accomplished with negligible evaporative loss of cooling water. A heat exchanger or condenser may separate non-contact cooling water from a fluid being cooled or contact cooling water may directly impinge on items like saw blades where phase difference allows easy separation. Environmental regulations emphasize the reduced concentrations of waste products in non-contact cooling water.

3.6 RECENT TRENDS IN ELECTRONICS COOLING

In current electronic devices, power dissipation increases with each new design. It was already in 1965 that Dr. Gordon Moore, co-founder of Intel, postulated his "Moore's law". His law predicted that semiconductor-transistor-density and their corresponding power outputs roughly double every 18 months. Although Dr. Moore made his predictions in 1965, history seems to validate the 40 years old prediction of Dr. Moore Fig: 3.3.Moore's law is also relevant for power dissipation.

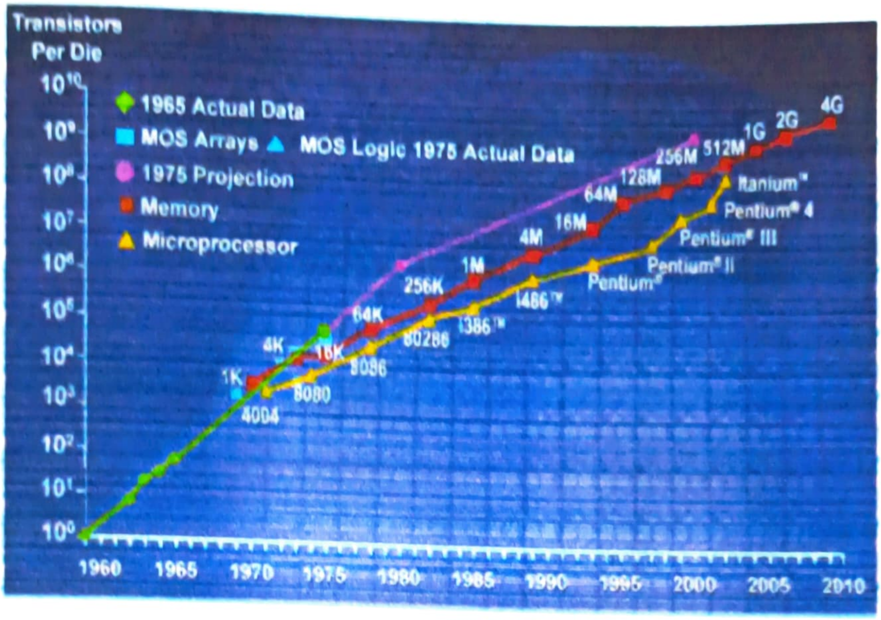

Fig: 3.3 TRANSISTORS PER DIE V/S YEAR

3.7 ELECTRONICS COOLING IN DIFFERENT APPLICATIONS

The cooling techniques used in the cooling of electronic equipment vary widely, depending on the particular application. Electronics equipment designed for airborne applications such as airplanes, satellites, space vehicles, and missiles offers challenges to designers because it must fit into odd-shaped spaces because of the curved shape of the bodies, yet to be about to provide adequate paths for the flow of fluid and heat. Most such electronic equipment are cooled by forced convection using pressurized air bled off a compressor. This compressed air is usually at a high temperature, and thus it is cooled first by expanding it through a turbine. The moisture in the air is also removed before the air is routed to the electronic boxes. But the removal process may not be adequate under rainy conditions. Therefore, electronics in some cases are placed in sealed finned boxes that are externally cooled to eliminate any direct contact with electronic components.

Electronic equipment in space vehicles is usually cooled by a liquid circulated through the components, where heat is picked up, and then through a space radiator, where the waste heat is radiated into deep space at about 0 K. Note that radiation is the only heat transfer mechanism for rejecting heat to the vacuum environment for space, and radiation exchange depends strongly on surface properties. Desirable radiation properties on surfaces can be obtained by special coatings and surface treatments. When electronics is sealed boxes are cooled by a liquid flowing through the outer surface of the electronics box, it is important to run a fan in the box to circulate the air, since there are no natural convection currents in space because of the absence of a gravity field.

The manufacturers of electronic devices usually specify the rate of heat dissipation and the maximum allowable component temperature for reliable operation. These two numbers help us determine the cooling techniques that are suitable for the device under consideration.

3.8 TYPES OF COOLING SYSTEMS FOR ELECTRONIC COMPONENTS

3.8.1 AIR COOLING

Air cooling is a method of dissipating heat. It works by expanding the surface area of or increasing the flow of air over the object to be cooled, or both. An example of the former is to add cooling fins to the surface of the object, either by making them integral or by attaching them tightly to the object's surface (to ensure efficient heat transfer). In the case of the latter, it is done by using a fan blowing air into or onto the object one wants to cool. The addition of fins to a heat sink increases its total surface area, resulting in greater cooling effectiveness. Following are the different types of air cooling.

3.8.1.1 NATURAL CONVECTION

Low-power electronic systems are conveniently cooled by natural convection and radiation. Natural convection cooling is very desirable, since it does not involve any fans that may break down. Natural convection is based on the fluid motion caused by the density differences in a fluid due to a temperature difference. A fluid expands when heated and becomes less dense. In a gravitational field, this lighter fluid rises and initiates a motion in the fluid called natural convection currents. Natural convection cooling is most effective when the path of the fluid is relatively free of obstacles, which tend to slow down the fluid, and is least effective when the fluid has to pass through narrow flow passages and over many obstacles.

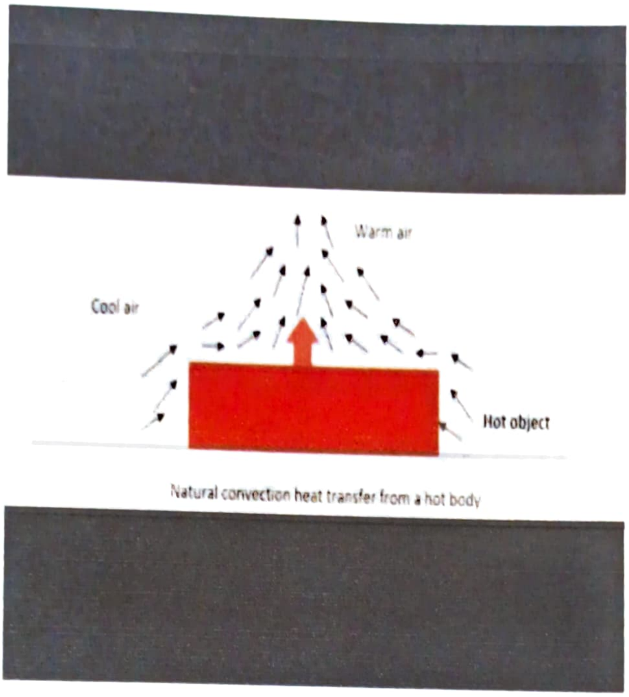

Fig: 3.4 Natural convection cooling by air

3.8.1.2 FORCED CONVECTION

We mentioned earlier that convection heat transfer between a solid surface and a fluid is proportional to the velocity of the fluid. The higher the velocity, the larger the flow rate and the higher the heat transfer rate. The fluid velocities associated with natural convection currents are naturally low, and thus natural convection cooling is limited to low-power electronic systems. When natural convection cooling is not adequate, we simply add a fan and blow air through the enclosure that houses the electronic components. In other words, we resort to forced convection in order to enhance the velocity and thus the flow rate of the fluid as well as the heat transfer. By doing so, we can increase the heat transfer coefficient by a factor of up to about 10, depending on the size of the fan. This means we can remove heat at much higher rates for a specified temperature difference between the components and the air, or we can reduce the surface temperature of the components considerably for specified power dissipation

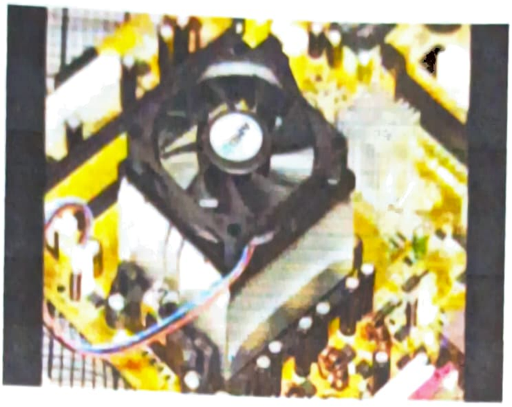

Fig: 3.5 Forced convection cooling of microprocessor by air

(1) In Desktops

Fans are generally mounted in the following locations: front, rear, top, and side. The fans on the front of the case are usually primary intakes, drawing ambient temperature air in to pass across hot components. The top and rear fans are exhausts, expelling the warm air out of the case and away from the internal components. In the past this simple air exchange was enough, but in modern systems with powerhouse (and often multiple) video cards, large banks of RAM, and over docked CPUs, more thought needs to be put into how air travels through an enclosure.

Fig: 3.6 Cooling of CPU

(ii) In High Density Computing

Data centers typically contain many racks of flat IU servers. Air is drawn in at the front of the rack and exhausted at the rear. Because data centers typically contain such large numbers of computers and other power-consuming devices, they risk overheating of the various components if no additional measures are taken. Thus, extensive HVAC systems are used. Often raised floor is used so the area under the floor may be used as a large plenum for cooled air and power cabling. Another way of accommodating large numbers of systems in a small space is blade basis. In contrast to the horizontal orientation of flat servers, blade chassis are often oriented this vertical orientation facilitates convection. When the air is heated by the hot components, it tends to flow to the top on its own, creating a natural air flow along the boards. Stack effect can help to achieve the desired air flow and cooling. Some manufacturers expressively take advantage of this effect.

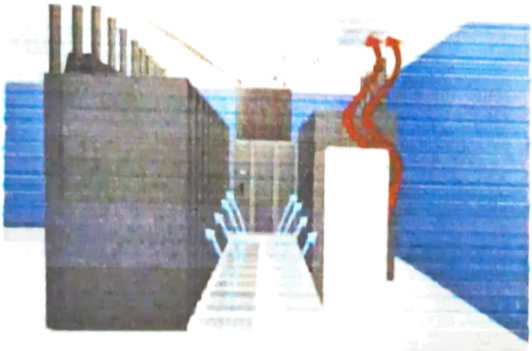

Fig: 3.7 Cooling of heavy data centers

(iii) IN LAPTOP COMPUTING

In order to keep the CPU and other components within their operating temperature range, most laptops use air cooling with a fan as shown in Fig.3.8,. Because the air is fan forced through a small port, it can clog the fan and heat sinks with dust or be obstructed by objects placed near the port. This can cause overheating, and can be a cause of component failure in laptops. The severity of this problem varies with laptop design. its use and power dissipation. With recent reductions in CPU power dissipation, this problem can be anticipated to reduce in severity.

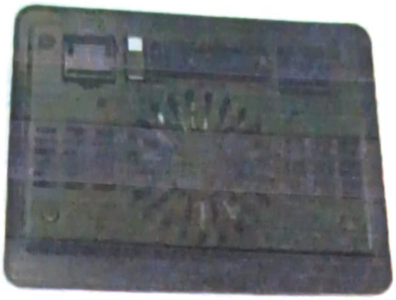

Fig: 3.8 Lap top cooling

3.8.2 LIQUID COOLING

Liquids normally have much higher thermal conductivities than gases, and thus much higher heat transfer coefficients associated with them. Therefore, liquid cooling is far more effective than gas cooling. However, liquid cooling comes with its own risks and potential problems, such as leakage, corrosion, extra weight, and condensation. Therefore, liquid cooling is reserved for applications involving power densities that are too high for safe dissipation by air cooling. Liquid cooling systems can be classified as direct cooling and indirect cooling systems.

3.8.2.1 DIRECT COOLING

Direct liquid (immersion) cooling brings the coolant in direct contact with the back of the chip. Historically, the coolant considered was a dielectric (e.g., fluorocarbon coolants or FCs) primarily because it would also be in direct contact with the chip interconnects and substrate top surface metallurgy (TSM). For this exercise, it is assumed that water can be brought in direct contact with the back of the chip. Obviously a seal or barrier preventing water from contacting the inter connects or TSM is needed. For now, it is assumed that such a seal/barrier is technically feasible.

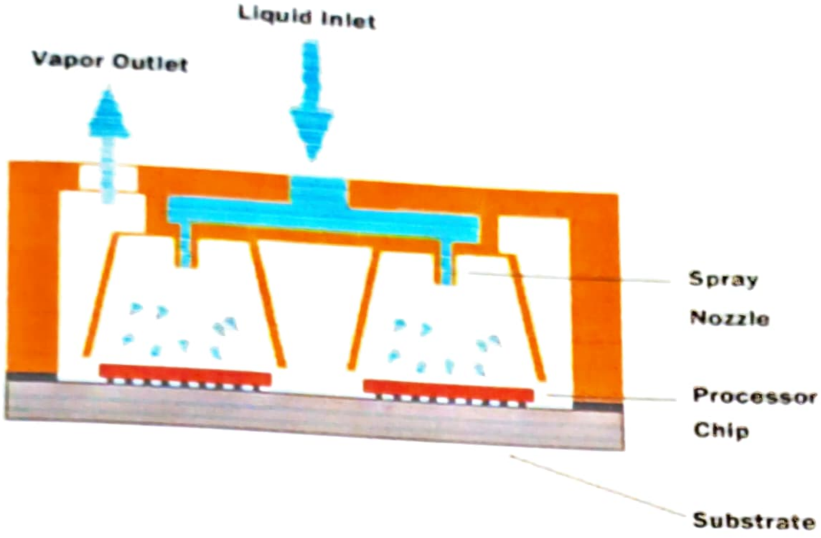

Fig: 3.9 Direct liquid cooling

3.8.2.2 INDIRECT COOLING

In indirect cooling systems, however, there is no direct contact with the components. The heat generated in this case is first transferred to a medium such as a cold plate before it is carried away by the liquid.

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, as shown in Fig.3.10. Since there is no contact with the electronics, water can be used as the liquid coolant, taking advantage of its superior thermo physical properties. Indirect liquid cooling systems of electronic devices operate just like the cooling system of a car engine, where the water (actually a mixture of water and ethylene glycol) circulates through the passages around the cylinders of the engine block, absorbing heat generated in the cylinders by combustion. The heated water is then routed by the water pump to the radiator, where it is cooled by air blown through the radiator coils by the cooling fan. The cooled water is then rerouted to the engine to transfer more heat. To appreciate the effectiveness of the cooling system of a car engine, it will suffice to say that the temperatures encountered in the engine cylinders are typically much higher than the melting temperatures of the engine blocks. In an electronic system, the heat is generated in the components instead of the combustion chambers. The components in this case are mounted on a metal plate made of a highly conducting material such as copper or aluminium. The metal plate is cooled by circulating a cooling fluid through tubes attached to it, as shown in Fig. 3.10. The heated liquid is then cooled in a heat exchanger.

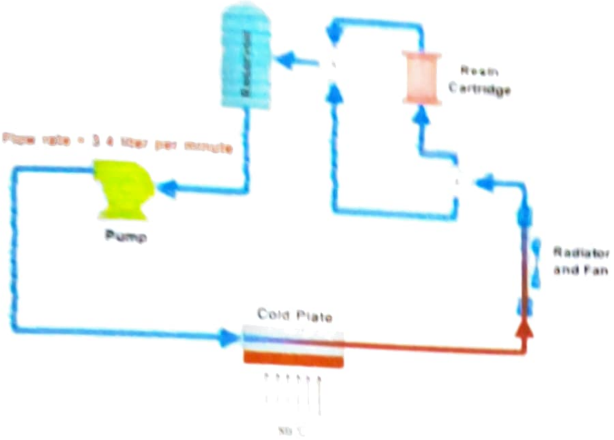

Fig: 3.10 Indirect liquid cooling

3.8.3 LIQUID SUBMERSION COOLING

An uncommon practice is to submerse the computer's components in a thermally conductive liquid. Personal computers that are cooled in this manner do not generally require any fans or pumps, and may be cooled exclusively by passive heat exchange between the computer's parts, the cooling fluid and the ambient air. Extreme component density supercomputers such as the Cray-2 and Cray T90 used additional liquid to chilled liquid heat exchangers in order to facilitate heat removal.

The liquid used must have sufficiently low electrical conductivity in order for it not to interfere with the normal operation of the computer's components. If the liquid is somewhat electrically conductive, it may be necessary to insulate certain parts of components susceptible to electromagnetic, such as the CPU. For these reasons, it is preferred that the liquid be dielectric.

Liquids commonly used in this manner include various liquids invented and manufactured for this purpose by 3M, such as Fluorinert. Various oils, including but not limited to cooking, motor and silicone oils have all been successfully used for cooling personal computers.

Evaporation can pose a problem, and the liquid may require either be regularly refilling or sealing inside the computer's enclosure. Liquid may also slowly seep into and damage components, particularly capacitors, causing an initially functional computer to fail after hours or days immersed.

Fig: 3.11 Immersed cooling

3.8.4 PASSIVE HEAT SINK COOLING

Passive heat sink cooling involves attaching a block of machined or extruded metal to the part that needs cooling. A thermal adhesive may be used, or more commonly for a personal computer CPU, a clamp is used to affix the heat sink right over the chip, with a thermal grease or thermal pad spread between. This block usually has fins and ridges to increase its surface area. The heat conductivity of metal is much better than that of air, and its ability to radiate heat is better than that of the component part it is protecting (usually an integrated circuit or CPU). Until recently, fan cooled aluminum heat sinks were the norm for desktop computers. Today many heat sinks feature copper base-plates or are entirely made of copper, and mount fans of considerable size and power.

Heat sinks tend to get less effective with time due to the buildup of dust between their metal fins, which reduces the efficiency with which the heat sink transfers heat to the ambient air. Dust build up can be countered with a gas duster by blowing away the dust along with any other unwanted excess material.

Passive heat sinks are commonly found as shown in Fig 3.7 on older CPUs, parts that do not get very hot (such as the chipset), and low-power computers.

Usually a heat sink is attached to the integrated heat spreader (IHS). It essentially is a large flat plate attached to the CPU (with conduction paste layered between). The plate is used to dissipate or spread the heat locally. Unlike a heat sink, its intent is to redistribute heat and not to remove it. In addition, the IHS offers protection to the fragile CPU. Passive cooling avoids the generation of fan noise.

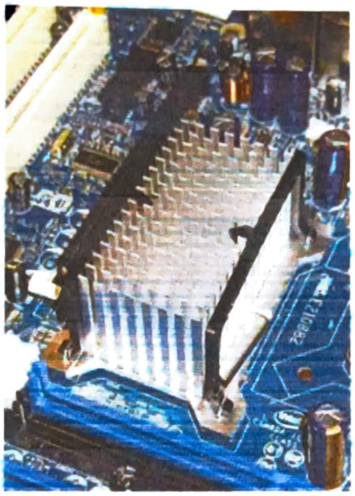

Fig: 3.12 Passive heat sink fitted on a Intel GMA graphics chip

3.8.5 ACTIVE HEAT SINK COOLING

Active heat sink cooling (Fig 3.13) uses the same principle as passive, with the addition of a fan that is directed to blow over or through the heat sink. The moving air increases the rate at which the heat sink can exchange heat with the ambient air. Active heat sinks are the primary method of cooling a modern processor or graphics card.

The build-up of dust is greatly increased with active heat sink cooling as the fan is continually taking in the dust present in the surrounding air. As a result, dust removal procedures need to be exercised much more frequently than with passive heat sink methods.

Fig: 3.13 Active heat sink with a 120mm fan located inside the unit and attached fan controller in background

3.8.6 THERMOELECTRIC COOLER

A thermoelectric cooler is an active cooling technique based on the Peltier effect which is caused by a temperature difference at the junction of two conductors, made out of a different material, when a dc current is passing through these conductors. A typical thermoelectric cooling device consists of two ceramic layers, wherein between several pairs of P-type and N-type of semiconductors are mounted. These thermoelectric pairs are electrical in series and thermal in parallel. A thermoelectric device can contain a few hundred pairs as shown in Fig 3.14.

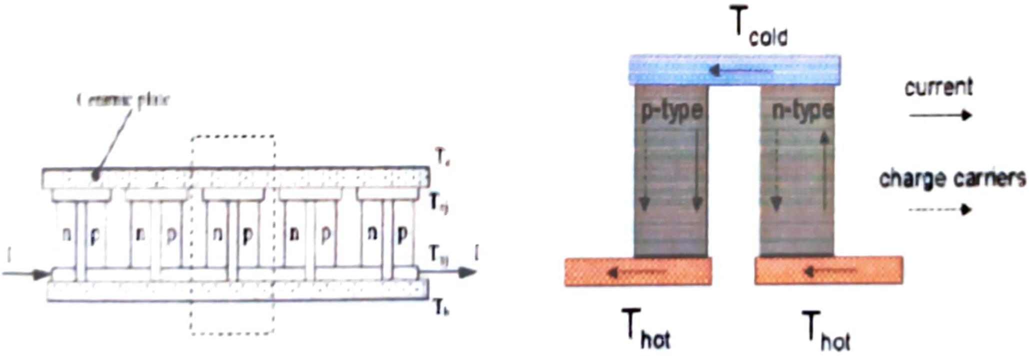

Fig: 3.14. Thermoelectric device

3.8.7 LIQUID NITROGEN

As liquid nitrogen evaporates at -196 °C, far below the freezing point of water, it is valuable as an extreme coolant for short over clocking sessions.

In a typical installation of liquid nitrogen cooling as shown in Fig 3.15, a copper or aluminium pipe is mounted on top of the processor or graphics card. After being heavily insulated against condensation, the liquid nitrogen is poured into the pipe, resulting Principle scheme of a thermoelectric cooling device. Since the charge carriers move in a different direction in each leg, each carries heat away from the cold end. A thermoelectric cooler is a solid-state cooler and thus has many advantages over conventional heat exchangers. They have the advantage of not having moving parts, or any type of fluid. Therefore, they produce no noise and can be made very compact. However, one main problem overrules all the benefits: it has a low efficiency and more power is needed than the device can cool.

By welding an open pipe onto a heat sink, and insulating the pipe, it is possible to cool the processor either with liquid nitrogen, which has a temperature below −196°C, or dry ice. However, after the nitrogen evaporates, it has to be refilled. In the realm of personal computers, this method of cooling is seldom used in contexts other than over clocking trial-runs and record-setting attempts, as the CPU will usually expire within a relatively short period of time due to temperature stress caused by changes in internal temperature.

Fig: 3.15 Liquid nitrogen may be used to cool an over clocked PC.

3.8.8 LIQUID HELIUM

Liquid helium, colder than liquid nitrogen, has also been used for cooling. Liquid helium evaporates at -269 °C, and temperatures ranging from -230 to -240 °C have been measured from the heat sink.

3.9 NEED OF TWO PHASE COOLING FOR ELECTRONIC CHIPS

In most computers, fans do a pretty good job of keeping electronic components cool. But for people who want to use high-end hardware or coax their PCs into running faster, a fan might not have enough power for the job. If a computer generates too much heat, two phase cooling can be a better solution. It might seem a little counterintuitive to put refrigerants near delicate electronic equipment, but cooling with refrigerants is far more efficient than cooling with air.

Usually air and liquid cooling is not suitable for higher capacity heat generating systems so an alternative is two phase cooling which serves the purpose to cool high heat generating systems.

- Good compatibility micro electronic circuit.
- Low auxiliary system support requirements.
- High reliability.
- Low operating and maintenance.
- Low initial cost system

3.9.1 LIMITATIONS OF THE LIQUID COOLING SYSTEM

Unfortunately there are a large number of disadvantages to liquid cooling in computer systems these days. Some of the most prominent disadvantages are size and technical skills required to install a kit.

Liquid cooling kits require a large amount of space within the computer case to work effectively. In order for the system to work properly, there must be space for items such as the impeller, the fluid reservoir and the tubing, fan and power supplies. This has a tendency to require larger desktop system cases to fit all of these parts within the computer case itself.

It is possible to have much of the system outside of the case, but then it would take up space in or around the desktop.

Since liquid cooling is a fairly new technology to PC computers, it still requires a significant level of technical knowledge to install. While there are kits to purchase from some of the cooling manufacturer's out there they still need to be custom installed into the PC case. Each case has a different layout so the tubes must be cut and routed specific to make use of the room within the system. Also, if the system is not properly installed, leaks could cause severe damage to the components inside of the system. There is also the possibility of injuring to the individual installing the system into the computer.

3.9.2 LIMITATION OF AIR COOLING

In spite of above qualities air cooling has its own limitations they are heat carrying capacity of the air is considerably low compared to liquids. Tremendous drop in the performance of air cooling system occurs when chip heat fluxes are exceeding beyond 80 W/cm^2. One cannot the electronic chips without making the size of the heat sinks bulky and fan becoming bigger.

3.9.3 IMPORTANCE OF LIQUID COOLING

Starting from the era of mainframe computers of 80s to the present day laptops and other microprocessor – based applications, the computation speed has gone up many folds. It is for sure that in coming years the microprocessor based equipment will influence the human life in a significant manner. The users of laptop computers must be aware of the fact that the computer hardware generates heat; this is due to the fact that no device works on 100 percent efficiency. Hence, some losses are bound to take place in the electronic circuit and these losses are evident in the form of heat generation in the chips. Therefore, all, the electronic devices generates heat due to dissipation of energy in the circuit.

With the advent of VLSI (very large scale integration) technology the heat dissipation in the circuit has gone up many folds with every new design. So, nowadays, the semiconductor industry is facing the problem of fast removal of heat from the chip and the system. The problem of heat removal from the electronic chips is an old one. However, recently it has become very prominent due to the increasing numbers of circuits being packed into single chip and at the same time, the dimensions of the chip are also shrinking. This is resulting in the heating up of chips and consumption of more power. In light of the ongoing developments in the area of electronics the Moore's Law still holds well today, even after forty years, as the data density has doubled approximately every 18 months. Most experts agree that the Moore's Law will hold for at least another two decades.

Today the heat dissipation rate from electronic chips is touching 100 W / cm^2, which is supposed to be very high heat dissipation rate. Further, these chips are confident in a tight place in the system and this creates serious problem of cooling these microelectronic chips. In fact, poor thermal management shortens the life of these chips. Since, high power-small size scenario is prevalent in the electronic industry for many years the microprocessor cooling system should be more and more compact, efficient and should be designed as an integrated part of the cooling system. There are a number of cooling options of electronic chips. Some of the options are discussed below in brief.

The heat absorbed during phase change will be more when compared to sensible heating makes it possible to allow greater heat dissipation. Consequently two phase cooling is much more efficient than air and water cooling and becomes even more efficient when fluid is forced to move through circuit using external agents. According to Tuckerman and Peace Unfortunately liquid cooling has some disadvantages, corrosion, high space requirement and an increase of weight in comparison with air cooled systems. In this the need of two phase cooling with thermosiphone effect is explained.

3.9.4 ADVANTAGES OF TWO PHASE THERMOSIPHONE COOLING SYSTEM

Two phase thermosiphone cooling is a much more efficient system at drawing heat away from the processor and outside of the system. This allows for higher clock speeds in the processor as the ambient temperatures of the CPU core are still within the manufacturer's specifications.

The other benefit of two phase thermosiphone cooling is the reduction of noise within the computer. Most current heat sink and fan combinations tend to generate a lot of noise for the fans that need to circulate air over the CPU and through the system. Many high performance CPUs require fan speeds in excess of 7000 rpm that generate noise of 60+ decibels of noise. Over clocking a CPU requires even more airflow over the CPU, but when a two phase thermosiphone solution, there is much less noise.

Generally there are no moving parts in this cooling system. It just consists of heat sink and condenser coil. These are generally fairly low in noise. This system doesn't need any external and supply or pumps or fans. The space retirement is very less compared to liquid cooling system.

3.9.5 THERMOSIPHONE

A thermosiphone is an indirect-contact passive liquid cooling system, where the cooling fluid is forced to perform a phase transition during its cooling cycle. Tests on prototypes have already reached heat fluxes of 150W/cm2. Different lay-outs are present: the ordinary thermosiphone, the loop thermosiphone and the pulsated two phase thermosiphones (PTPT). The ordinary thermosiphone consists only of one interconnection between the evaporator and condenser. The vapor phase and liquid phase travels through the same tube. The difference with heat pipes lays in the fact that no use is made of capillary structures, but only gravity is used to bring back the liquid phase to the evaporator. The most important limitation in this design is the traveling speed of the liquid through the hot vapor phase; this limitation is relieved in the loop thermosiphone.

The so called loop thermosiphones consist of an evaporator and a condenser, which are connected to each other in a closed loop system. In the interconnection tube from the evaporator to the condenser the heat carrier is only vapor. This vapor is transformed in the condenser back to the liquid phase which flows through the interconnection tube from the condenser back to the evaporator. This one is pictured on the right in Fig.3.16.

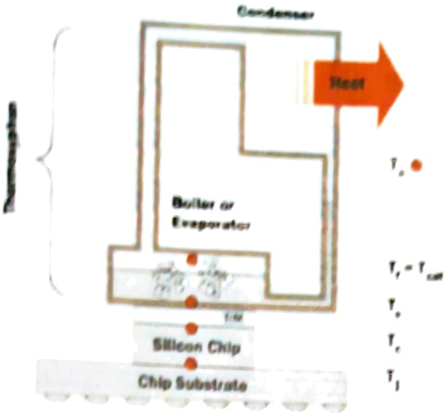

Fig: 3.16 Thermosiphone effect

The working principle of an ordinary thermosiphone and of a loop thermosiphone is such that the heat flows from the heat source through an interface in the evaporator into the cooling fluid. The interface is usually structured which benefits the boiling speed. The cooling liquid is transformed in the evaporator to its vapor phase, which will, on its turn, be transformed back to the liquid phase in the condenser. The vapor phase will rise by its thermodynamic characteristics to the higher placed condenser, where the condenser liquid will flow back to the evaporator due to gravity. Thus the main disadvantage of these first two types of thermosiphones is the necessity to place the condenser always above the evaporator which conflicts with all mobile and many stationary applications. This major disadvantage can be overcome in some other types of closed loop thermosiphones: some natural convection thermosiphones were realized where the condenser could be placed at different positions below the evaporator. In the third type of thermosiphones, the pulsated two phase thermosiphone (PTPT), this disadvantage seems to be fully solved: the condenser could be placed at any position with regards to the evaporator. The working principle of the PTPT is slightly different from a loop thermosiphone, because an additional accumulator tank is positioned in the liquid line in order to force a periodic pulsation of pressure. These devices are characterized by a periodic heat transfer regime. An example is pictured on the left in fig 3.16.

The main advantage of a thermosiphone is that no pump is needed, so no external energy has to be applied. Another advantage is the absence of moving parts in the system, which results in a high reliability. These two advantages are no longer valid for the PTPT, but this one has more design freedom than the other thermosiphones. The last advantage is the high flexibility that can be obtained: the evaporator can be very small and the interconnection tubes very long, so the condenser doesn't have to be mounted just on top of the evaporator. On the other hand a danger for leakage exists.

CHAPTER 4

REFRIGERANTS

4.1 R-134a

R134a is also known as Tetrafluoroethane (CF3CH2F) from the family of HFC refrigerant. With the discovery of the damaging effect of CFCs and HCFCs refrigerants to the ozone layer, the HFC family of refrigerant has been widely used as their replacement. It is now being used as a replacement for R-12 CFC refrigerant in the area of centrifugal, rotary screw, scroll and reciprocating compressors. It is safe for normal handling as it is non-toxic, non-flammable and non-corrosive. It exists in gas form when expose to the environment as the boiling temperature is -14.9°F or -26.1°C.

This refrigerant is not 100% compatible with the lubricants and mineral-based refrigerant currently used in R-12. Design changes to the condenser and evaporator need to be done to use this refrigerant. The use of smaller hoses and 30% increase in control pressure regulations also have to be done to the system.

4.1.1 Properties of R-134a

Table: 4.1 Physical properties of R-134a

Sl.no	Properties	R 134a
1	Boiling point	-14.9°F or -26.1°C
2	Auto ignition temperature	1418°F or 770°C
3	Solubility in water	0
4	Ozone depletion level	0.11% by weight at 77°F

		or 25°C
5	Critical temperature	252°F or 122°C
6	Cylinder colour code	Light blue colour
7	Global warming potential (gwp)	1200
8	Critical pressure	4.059Mpa
9	Specific heat	1.44KJ/Kg K

Currently it is also being widely used in the air conditioning system in newer automotive vehicles. The manufacturing industry uses it in plastic foam blowing. Pharmaceuticals industry uses it as a propellant.

R134a is also being considered as an organic solvent suitable for extraction of flavor and fragrance compounds, as a possible alternative to other organic solvents and supercritical carbon dioxide. It can also be used as a solvent in organic chemistry, both in liquid and supercritical fluid. It is used in the chamber particle in the Large Hadrons Collider. It is also used for other types of particle detectors, e.g. some cryogenic particle detectors. It can be used as an alternative to Sulphur hexafluoride in magnesium smelting as a shielding gas.

Fig: 4.1 R-134a refrigerant can

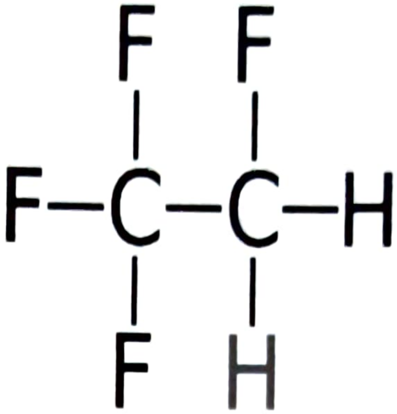

Fig: 4.2 R-134a structure

4.2 R-410a

R-410a is a zeotropic, but near-azeotropic mixture of difluoromethane (CH_2F_2, called R-32) and pentafluoroethane (CHF_2CF_3, called R-125), which is used as a refrigerant in air conditioning applications. R-410A cylinders are coloured pink. R-410A has replaced R-22 as the preferred refrigerant for use in residential and commercial air conditioners in Japan, Europe and the United States.

Unlike alkyl halide refrigerants that contain bromine or chlorine, R-410A (which contains only fluorine) does not contribute to ozone depletion, and is therefore becoming more widely used, as ozone-depleting refrigerants like R-22 are phased out. However R410a has a high global warming potential of 2088, higher than that of R-22. Since R-410A allows for higher SEER ratings than an R-22 system by reducing power consumption, the overall impact on global warming of R-410A systems will be substantially lower than that of R-22 systems due to reduced greenhouse gas emissions from power plants.

4.2.1 Physical properties

Table: 4.2 Physical properties of R-410a

Sl.no	Properties	R 410a
1	Boiling point	-48.5^{0}C
2	Auto ignition temperature	790^{0}C
3	Solubility in water	0
4	Ozone depletion level	0
5	Critical temperature	101.06^{0}C
6	Cylinder color code	Pink
7	Global warming potential (gwp)	2088
8	Critical pressure	4.86Mpa
9	Specific heat	0.3948KJ/kgK

Fig: 4.3 R-410a Refrigerant cylinder

4.3 R 600a

R 600a, also known as iso-butane, 2-methylpropane or methylpropane, is a chemical compound with molecular formula $HC(CH_3)_3$. It is an isomer of butane. It is the simplest alkane with a tertiary carbon. Isobutane is used as a precursor molecule in the petrochemical industry, for example in the synthesis of isooctane. Isobutane is obtained by isomerization of butane. Isobutane is also used as a propellant for aerosol cans and foam products. Isobutane is used as part of blended fuels, especially common in fuel canisters used for camping.

Isobutane is used as a refrigerant. The use in refrigerators started in 1993 when Greenpeace presented the Green freeze project with the German company Foron. In this regard, blends of pure, dry "isobutane" (R-600a) (that is, isobutane mixtures) have negligible ozone depletion potential and very low global warming potential (having a value of 3.3 times the GWP of carbon dioxide) and can serve as a functional replacement for R-12, R-22, R-134a, and other chlorofluorocarbon or hydrofluorocarbon refrigerants in conventional stationary refrigeration and air conditioning systems.

As a refrigerant, isobutane poses an explosion risk in addition to the hazards associated with non-flammable CFC refrigerants. Substitution of this refrigerant for motor vehicle air conditioning systems not originally designed for isobutane is widely prohibited or discouraged.

4.3.1 Physical properties.

Table: 4.3 Physical properties of R-600a

Sl.no	Properties	R 600a
1	Boiling point	-14.9°F or -26.1°C
2	Auto ignition temperature	460^{0}C
3	Solubility in water	0
4	Ozone depletion level	0-1
5	Critical temperature	134.98^{0}C
6	Cylinder colour code	Yellow
7	Global warming potential (gwp)	3.3
8	Critical pressure	3.66Mpa

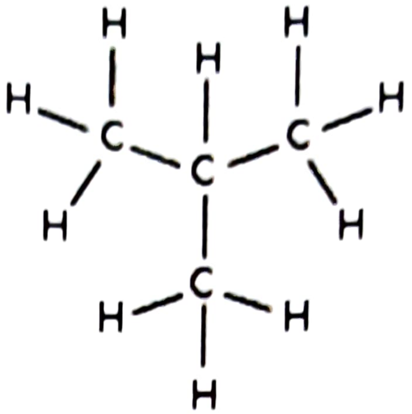

Fig: 4.4 R-600a refrigerants can **Fig: 4.5 Structure of R-600a**

4.4 DESIRED PROPERTIES OF A REFRIGERANT:

1. Vapor density:

To enable use of smaller compressors and other equipment the refrigerant should have smaller vapor density.

2. Enthalpy of vaporization:

To ensure maximum heat absorption during refrigeration, a refrigerant should have high enthalpy of vaporization.

3. Thermal Conductivity:

Thermal conductivity of the refrigerant should be high for faster heat transfer during condensation and evaporation.

4. Dielectric strength:

In hermetic arrangements, the motor windings are cooled by refrigerants vapor on its way to the suction valve of the compressor. Therefore, dielectric strength of refrigerant is important property in hermetically sealed compressor units.

5. Critical temperature:

In order to have large range of isothermal energy transfer, the refrigerant should have critical temperature above the condensing temperature.

6. Specific heat:

To have minimum change in entropy during the throttling process, the specific heat should be minimum. For this, liquid saturation line should be almost vertical.

7. Leak tendency:

The refrigerant may leak out of the system. The problems with leakage are wearing out of joint or the material used for the fabrication of the system. A denser refrigerant will have fewer tendencies to leak as compared to higher density refrigerant. The detection of leaks should be easy to loss of refrigerant. Leakage can be identified quickly if the refrigerant has distinct color or odor.

8. Toxicity:

The refrigerant used in air conditioning, food preservation etc. should not be toxic in nature as they will come into contact with human beings. Refrigerants will affect human health if they are toxic.

9. Cost of refrigerants:

The quantity of refrigerant used in industries is very less. The cost of the refrigerants is generally high when compared to other chemicals in the industry. Very low industry professional will not take necessary action to control the leaks.

10. Availability:

Refrigerants should be available near the usage point. It must be sourced and procured within a short period to enable the user in case of leaks, maintenance schedules etc.

CHAPTER 5

EXPERIMENTAL SETUP

5.1 INTRODUCTION

The main objective of our experimental investigation is to compare the effect of cooling with the present technique with that of existing technique on electric components. Cooling of Microprocessor is a hectic task which when not cooled the electronic components may fail to work. In present work two phase liquid cooling system is analyzed with different refrigerants such as R-134a, R600a and R410a at different heat inputs. The surface temperature of the heated aluminum block is tested at different heat inputs.

The Experimental Setup consists of:

1. Heat sink
2. An aluminium block
3. Condenser
4. k- Type Thermocouples.
5. Thermal interface material (TIM).
6. High density cartridge heater
7. Insulation (glass wool)
8. Temperature indicator
9. Voltage regulator

5.2 HEAT SINK

Primarily a copper sink of size 40x40x20mm which is machined precisely with fin like projections inside for enhancing the heat transfer rate to the refrigerant. It was made of copper with a lid on upper side. It was made with provisions for refrigerant to flow inside and flow outside. The sink is incorporating condenser tube. The sink is attached with copper tube to form a loop of cycle. It is made up of copper as it has good thermal conducting capacity.

Fig: 5.1 Heat sink

5.3 ALUMINIUM BLOCK

A solid aluminium block of overall dimensions 38 × 38 × 70 mm is used as heated block to simulate any electronic device. A hole was precisely machined in the heated aluminium block at the bottom surface to insert the high density cartridge heater. Any air gap between the heater and the hole would damage the heater, so heater is fitted in to the hole carefully such that there is no air gap between the two. The diameter and length of the heater is 10 mm and 40 mm respectively. The top surface of heated aluminium block and bottom surface of copper plate are polished to minimize the gaps. To measure the surface temperature of the heated aluminium block two K type thermocouples were inserted in to the top surface of the heated aluminium block.

Fig: 5.2Bottom side of aluminium block

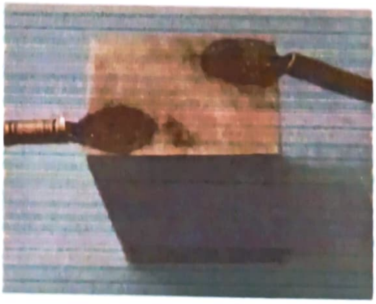

Fig: 5.3 Top surface of aluminium block

5.4 CONDENSER

For condenser a copper tube of 4.5 mm diameter is wound in circular cross section in vertical direction so that condensed refrigerant flow due to gravity. It is provided at some elevation so that condensed liquid reach the sink due to gravity. It is also made with provision for cooling with cold water for better cooling of refrigerant. The water will leave the condenser without affecting the other environments.

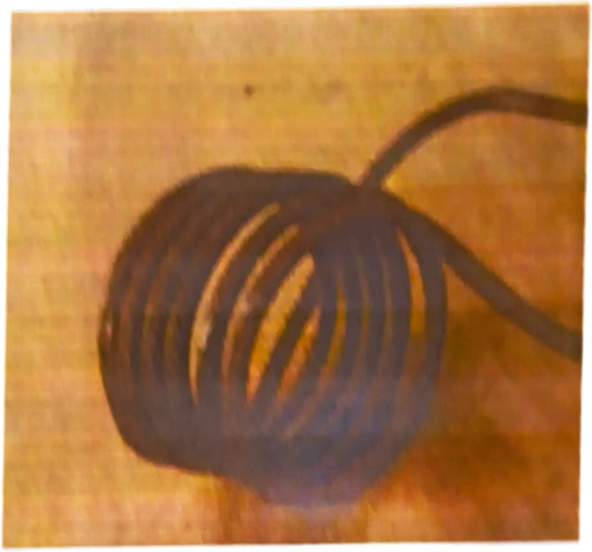

Fig: 5.4 Condenser coil

5.5 THERMOCOUPLES

A thermocouple is a sensor for measuring temperature. It consists of two dissimilar metals, joined together at one end. When the junction of the two metals is heated or cooled a voltage is produced that can be correlated back to the temperature. The thermocouple alloys are commonly available as wire.

5.5.1 How do we choose a thermocouple type?

Because a thermocouple measures in wide temperature ranges and can be relatively rugged, thermocouples are very often used in industry. The following criteria are used in selecting a thermocouple

- Temperature range

- Chemical resistance of the thermocouple or sheath material
- Abrasion and vibration resistance
- Installation requirements (may need to be compatible with existing equipment; existing holes may determine probe diameter)

Type K (chromel–alumel) is the most common general purpose thermocouple with a sensitivity of approximately 41 µV/°C, chromel positive relative to alumel. It is inexpensive, and a wide variety of probes are available in its −200 °C to +1350 °C range. Type K was specified at a time when metallurgy was less advanced than it is today, and consequently characteristics vary considerably between samples. One of the constituent metals, nickel, is magnetic; a characteristic of thermocouples made with magnetic material is that they undergo a step change in output when the magnetic material reaches its Curie point (around 354 °C for type K thermocouples).

K - Type thermocouples and the temperature indicator are shown in Fig 4.7 and 4.8 respectively.

Fig: 5.5 K-type Thermocouples

5.6 THERMAL INTERFACE MATERIALS

A Thermal Interface Material is used to fill the gaps between thermal transfer surfaces, such as between microprocessors and heat sinks, in order to increase thermal transfer efficiency. These gaps are normally filled with air which is a very poor conductor. Thermal Interface material is shown in Figure 4.9.The heated aluminium block and the heat sink after application of thermal interface material are shown in Figures 4.10 and 4.11 respectively.

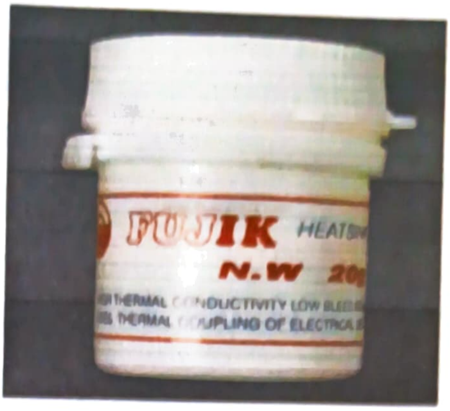

Fig: 5.6 Thermal interface material (TIM)

Fig: 5.6.1 Aluminium block after application of TIM

They take many forms. The most common is the white-colored paste or thermal grease, typically silicone oil filled with aluminum oxide, zinc oxide, or boron nitride. Some brands of thermal interfaces use micronized or pulverized silver.

Another type of TIM is the phase-change materials. These are solid at room temperature but liquefy and behave like grease at operating temperatures. They are easy to handle and are not messy.

5.6.1 Guidelines for Thermal Interface Materials

Five factors affect the choice, use, and performance of the interface material used between the processor and the heat sink.

- Thermal conductivity of the material
- Electrical conductivity of the material
- Spreading characteristics of the material
- Long-term stability and reliability of the material
- Ease of application

5.6.2 Thermal Properties:

1. Thermal and interface resistance as function of pressure.
2. Heat capacity and mass density.

5.6.3 Mechanical Properties:

1. Thermal expansion
2. Moisture diffusion
3. Generally thermal compounds contain chemical composition of ceramic materials like Na_2O, SiO_2, B_2O_3, Al_2O_3 and microscopic sintered materials like Ag, Cu, Au etc., Different interface materials used are Elastomer pads, Thermal adhesives, gels, and solders, greases, phase change materials.

5.7 HIGH DENSITY CARTRIDGE HEATER

A high density cartridge heater of 150 W is used to heat the aluminium block which simulates any electronic device. A hole was precisely machined in the aluminium block at the bottom surface to insert the high density cartridge heater. The diameter and length of the heater is 10 mm and 40 mm respectively. A dimmer stat is used to supply electric current through the high density cartridge heater at any required voltage. By using voltmeter and ammeter the supplied voltage and current to the heater is measured. The high density cartridge heater is shown in Figure 5.6.

Cartridge heaters are most frequently used for heating metal parts by insertion into drilled holes. For easy installation, the heaters are made slightly undersize relative to their nominal diameter. All cartridge heaters are rated by wattage and Watt density (Watts per square inch). In some applications it may be useful to derate the wattage by operating the cartridge heater at a lower voltage. When operating at lower voltages, the wattage is derated using the following formula

(Operating Voltage/Rated Voltage)^2 x Wattage at Rated Voltage = Derated Wattage

The tightly compacted refractory insulation provides excellent heat transfer to the heavy wall stainless steel sheath. This means the resistance wire runs at a lower temperature than competitive units with loose-fill insulation. The result is much longer life. This heavy-duty construction also provides high dielectric strength as well as shock and vibration resistance required for many industrial applications.

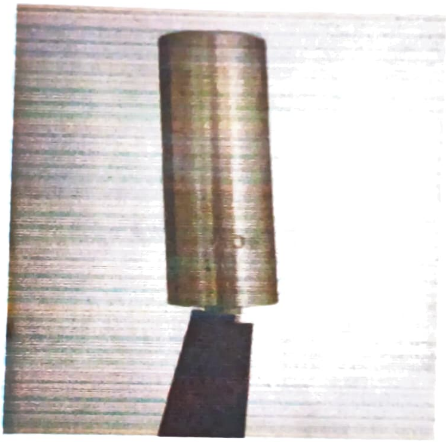

Fig: 5.7 High density cartridge heater

5.7.1 Determining Watt density

The term "Watt density" refers to the heat flow rate of surface loading. It is the number of Watts per square inch of heated surface area. The Watt density calculation would be as follows:

Watt density = W/ (π n x D x HL)

Where, W = wattage

D = diameter.

HL= heater length

5.8 INSULATION

Insulation is provided to arrest heat flow in other directions so that heat will flow in upward direction only. In our experimental setup glass wool is used as the insulator. Glass wool is an insulating material made from fibers of glass arranged using a binder into a texture similar to wool. The process traps many small pockets of air between the glass, and these small air pockets result in high thermal insulation properties

Fig: 5.8 Glass wool

5.9 TEMPERATURE INDICATOR

In our experimental setup a digital temperature indicator is used. It works with electrical input. The k-type thermocouples are attached at other end so that e.m.f induced in the thermocouple is taken by the indicator and converted into digital signal and displays the temperature value.

Fig: 5.9 Temperature indicator

5.10 VOLTAGE REGULATOR

It is used for regulating the heat input by changing the voltage of power supply. In order to give various heat inputs to the heater, it is employed. In general dimmer stat is used for voltage regulation in ac current.

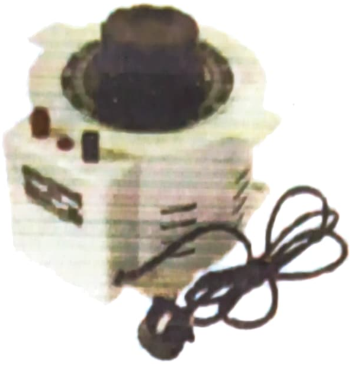

Fig: 5.10 Voltage regulator

5.11 EXPERIMENTAL SETUP

The general layout of experimental setup is shown in Fig.4.13. The major components are heated aluminium block, heat sink made with copper and copper tubes, high density cartridge heater, thermocouples and condenser coil. An aluminium block of size 40 × 40 × 70 mm which simulates the heat generated by any electronic equipment is used as the heated block. A hole is precisely machined in the aluminium block to insert the high density cartridge heater of capacity 150 W. Any air gap between the heater and the hole would damage the heater, so heater is fitted in to the hole carefully such that there is no air gap between the two parts.

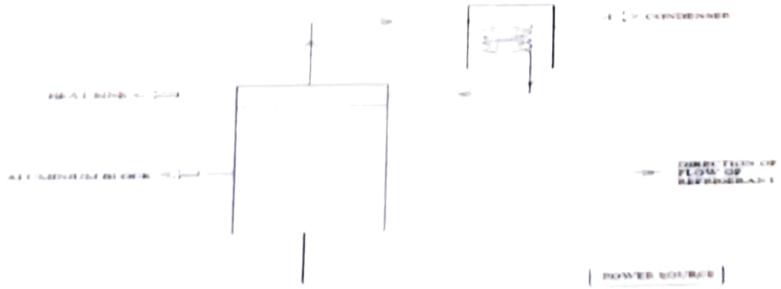

Fig: 5.11 Line diagram of experimental setup

For heat sink copper material is machines so that a chamber is created with fin like projections on the inner base to improve heat transfer rate. The copper heat sink is covered with a copper lid so that refrigerant is not exposed to atmosphere. The overall dimension of copper sink is 40*40*20mm. The top surface of aluminium block and bottom surface of copper sink are polished to minimize the gaps. Copper heat sink is placed firmly on the top surface of the aluminium block by using spring force to decrease the thermal resistance. The assembly of the aluminium heated block and heat sink is shown in Fig 4.14. To improve the thermal conductance between the heat sink and heated aluminium block, thermal interface material (TIM) is applied between aluminium block surface and heat sink.

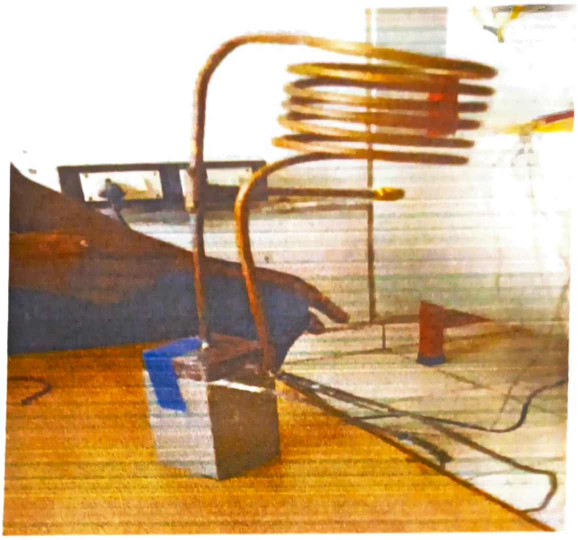

Fig: 5.12 Heat sink and aluminium block assembly

Three K-type thermocouples are inserted into the surface of the aluminium block at different locations to measure the surface temperature of the heated aluminium block.

To minimize the thermal losses to the surroundings glass wool of thickness 40mm is provided all around the heat sink and heated aluminium block assembly. The whole assembly is placed inside a wooden box of size 120×120×150 mm as shown in Fig 4.15. One more thermocouple is attached to the wooden box to find out the temperature of the insulation provided.

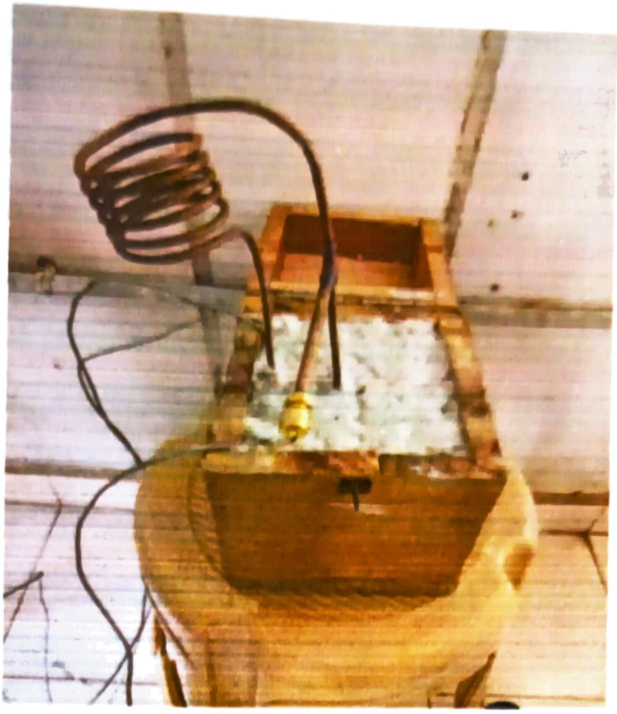

Fig: 5.13 Wooden box with glass wool

Now the heat sink is connected to condenser coil by a copper pipe. The inlet to condenser coil is on top lid and outlet of condenser coil i.e., the inlet to the copper heat sink is provided on the side wall of heat sink. So that the refrigerant enters the heat sink through its inlet and evaporates due to heat from the heat sink. Refrigerant in liquid state comes from condenser coil due to gravity. The evaporated refrigerant escapes from heat sink through the outlet due density change.

The refrigerant flow takes place due to thermo siphon effect. The evaporated refrigerant moves up due low density. The condenser is now provided on upper side that is at some level. The evaporated refrigerant now cooled and condensed by the air cooled condenser. A dimmer stat is used to supply electric current through the high density cartridge heater at any required voltage. By using voltmeter and ammeter the supplied voltage and current to the heater is measured.

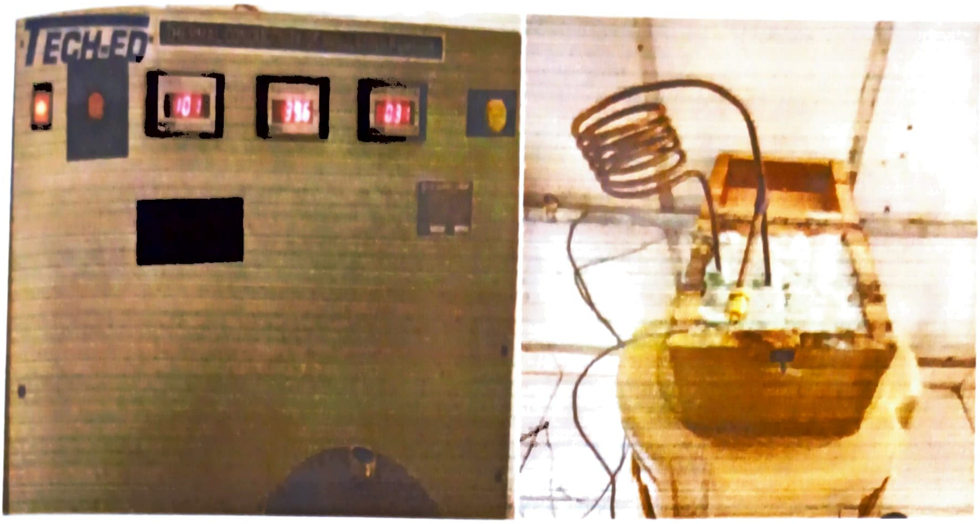

Fig: 5.14 Experimental setup

CHAPTER 6

EXPERIMENTAL PROCEDURE

6.1 EXPERIMENTAL PROCEDURE

Initially the setup is tested to ensure that there is no leak in the circuit. For this the setup is run with pure refrigerant without giving any heat flux. The refrigerant is filled at 90psi i.e., at 6.20bar using a check valve. First the suction is created by a suction pump and then refrigerant is filled from the refrigerant can. The leakage test is done by using the bubble method. Soap solution is applied to entire circuit. Any escaping refrigerant produces bubbles at the leak points. By using dimmer stat constant heat flux is applied to high density cartridge heater. The voltmeter, ammeter, wattmeter and dimmer stat are used for electrical measurement.

The heater is then calibrated by heating a certain amount of water for a given time. The efficiency if cartridge heater is obtained at different heat inputs.

For each heat input from cartridge heater, surface temperature of heated aluminium block and surface temperature of wooden box are taken periodically by using digital temperature indicator. The readings are taken till the system reaches steady sate. For each heat input the surface temperature of the aluminium block is measured.

The refrigerants are now changed by repeating same procedure and the results are taken for different heat inputs. The refrigerants used are R134a, R-600a and R410a.

6.2 CALCULATIONS

6.2.1 Calibration of heater:

From the energy balance equation the heat loss is calculated. Heat energy carried away by water is given by $Q = m_{flow}\ C_p\Delta T = mC_p(T_0\text{-}T_1)/\text{time}$ ----- (1)

Heat loss is calculated by using

$$Q_{loss} = Q_{input} - Q$$

Volume of water taken = 1 liter

Density of water = 1000kg/m^3

Specific heat of water C_p = 4.18 kJ/Kg k

Mass of water = density * volume

= 1000*1liter

= 1000*0.001

= 1kg

Mass of water taken (m) = 1 kg

Input given to the heater Q= $mC_p(t_1-t_2)$/time

=1*4.18*1000*(23.2-20)/600

=22.29 joules

Heat input given Q_{input} = V*I

= 83*0.38

=31.54 joules

Heat loss Q_{loss} =Q_{input} –Q = 31.54-22.29

= 9.25 joules

Efficiency = Q_{input} –Q/Q = 9.25/31.54

=0.707

CHAPTER-7

RESULTS & DISCUSSIONS

The surface temperature of heated aluminium block which stimulates the electronically component is the indication of performance of the cooling system. The experiments were conducted with utmost care and readings were tabulated. The values obtained from the experiments with water at different heat inputs and with different refrigerants are plotted on graphs and compared with the air, deionized water, calcium chloride ethylene glycol and peltier cooling. The convection heat transfer co-efficient is calculated at each flow rate of water on different heat sinks and the effect of convection heat transfer co-efficient on surface temperature of the heated aluminium block is plotted on graph

The tables 7.7, 7.8 and 7.9 gives the surface temperatures of aluminium block for two phase thermosiphone cooling with R-134a, R-600a and R-410a respectively. When compared to each other R-134a is giving better cooling for electronics.

When two phase cooling system is compared with the results of other fluids such as deionized water, ethylene glycol and calcium chloride, it is giving better cooling. From the Figure7.11 it is clear that two phase cooling with refrigerants is better performance when it is compared with peltier.

The water cooling and thermosiphone cooling are performing similar i.e., giving similar surface temperatures but the construction of thermosiphone cooling is very simple, easy to install and doesn't need any external power input for circulation of refrigerant.

Table: 7.1 Heat input and surface temperature for conventional air cooling

Sl.no	Heat input(watt)	Surface temperatur^{0}C
1	25	53.5
2	50	78
3	100	114.5

Table: 7.2 Heat input and surface temperature for peltier cooling

Sl.no	Heat input(watt)	Surface temperatur^{0}C
1	25	43.3
2	50	67.4
3	100	94.6

Table: 7.3 Surface temperature for water cooling for different flow rates at different heat inputs

Sl.no	Flow rate (lt/min)	Surface temperatur^{0}C		
		25W	50W	100W
1	1.1	34.5	39.7	48
2	1.4	32.5	38.5	46
3	1.7	32.3	37.5	45.3
4	1.8	30.2	36.7	44
5	2.2	31.2	36.5	43.3
6	2.7	31	35.5	42

Table: 7.4 Surface temperature of aluminium block by two phase cooling for R-134a

Sl.no	Heat input(watt)	Surface temperature^{0}C
1	10	29.5
2	20	32.6
3	30	35.9
4	40	41.3
5	50	44.6

Table: 7.5 Surface temperature of aluminium block by two phase cooling for R-600a

Sl.no	Heat input(watt)	Surface temperature^{0}C
1	10	31.2
2	20	34.6
3	30	42.0
4	40	44.7
5	50	46.3

Table: 7.6 Surface temperature of aluminium block by two phase cooling for R-410a

Sl.no	Heat input(watt)	Surface temperature^{0}C
1	10	35.0
2	20	39.1
3	30	41.1
4	40	45.9
5	50	50.6

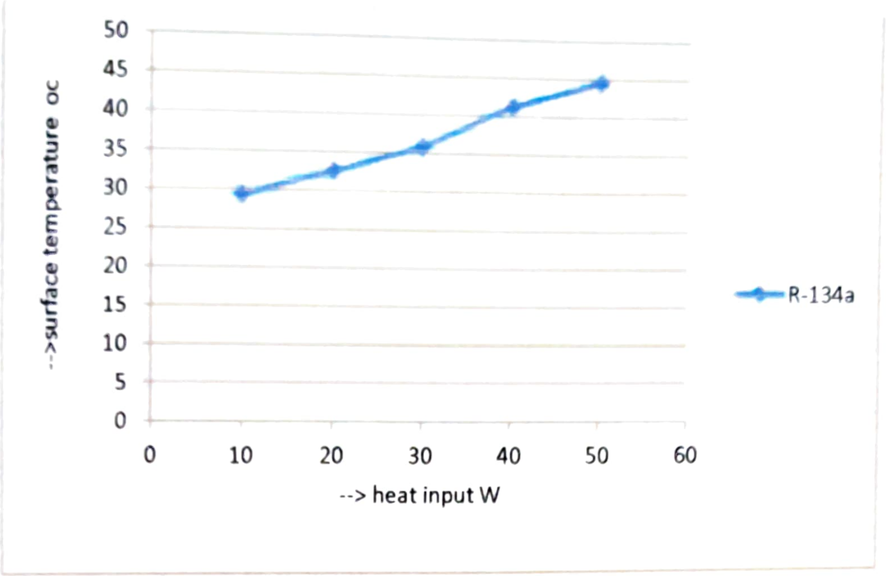

Fig: 7.1 Effect of different heat inputs on surface temperature for R-134a by two phase thermosiphone cooling

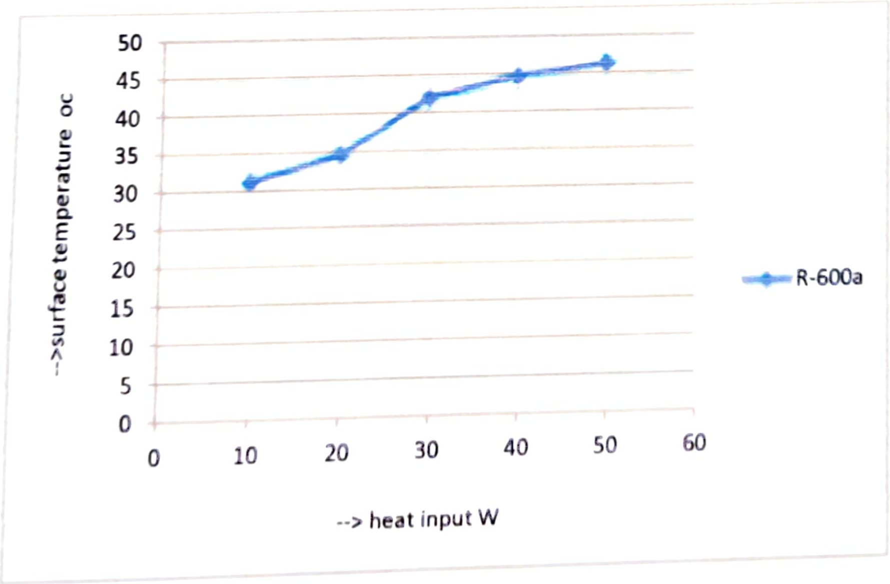

Fig: 7.2 Effect of different heat inputs on surface temperature for R-600a by two phase thermosiphone cooling

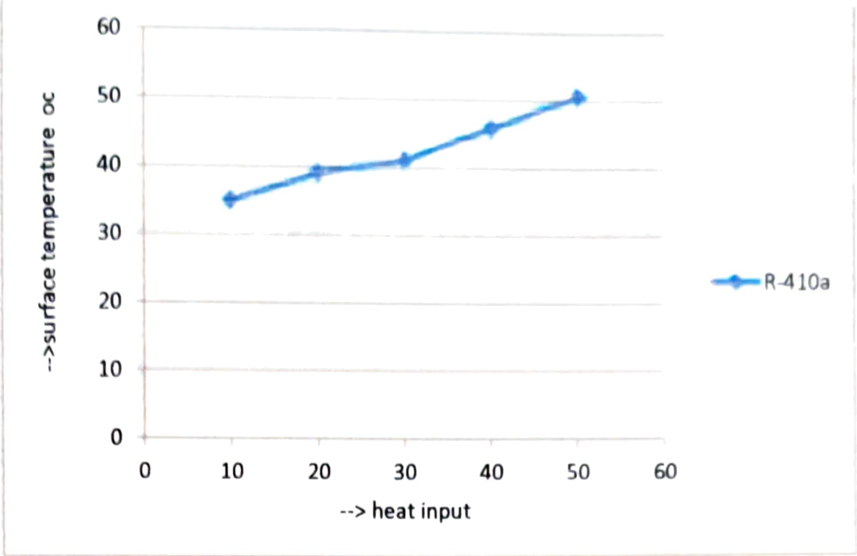

Fig: 7.3 Effect of different heat inputs on surface temperature for R-410a by two phase thermosiphone cooling

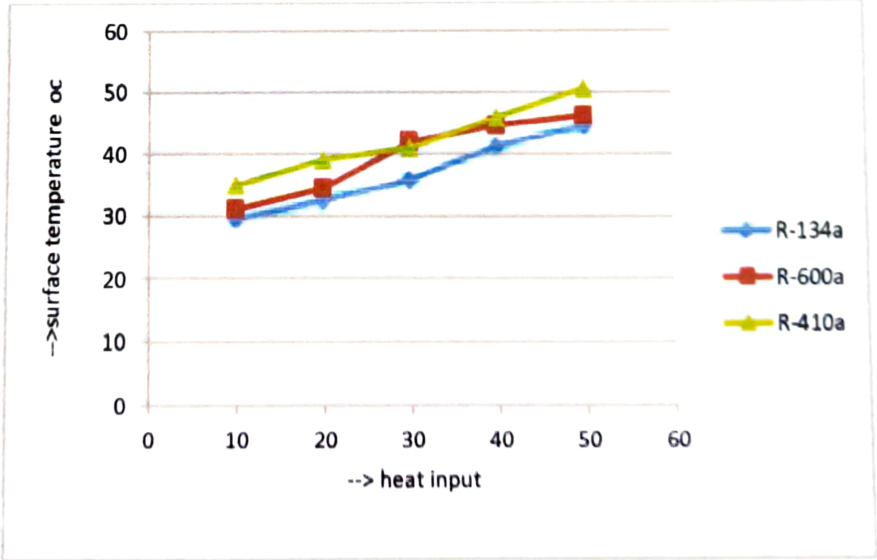

Fig: 7.4 Comparison of R-134a, R-600a and R-410a for different rates of heat inputs

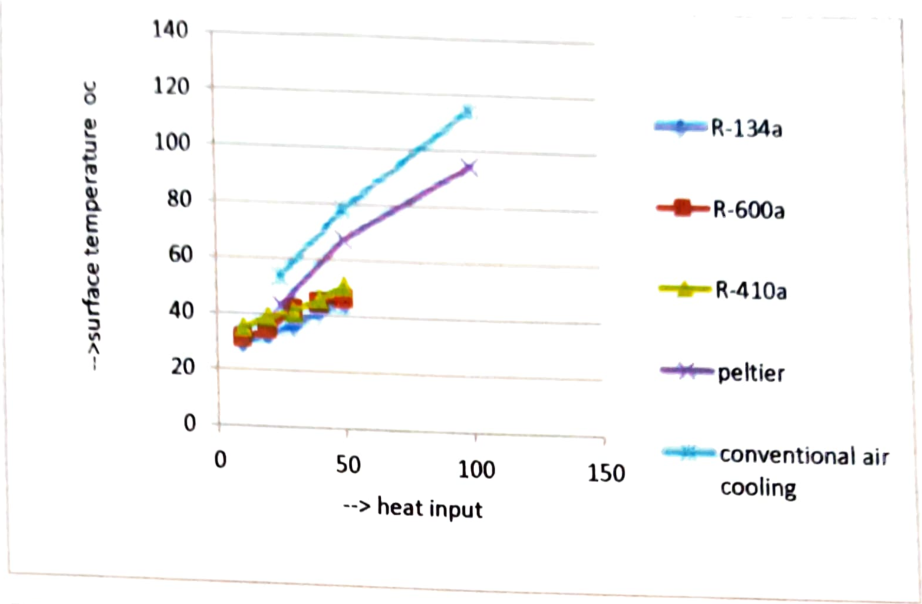

Fig: 7.5 Comparison of R-134a,R-600a, R-410a, peltier and conventional air for different rates of heat inputs

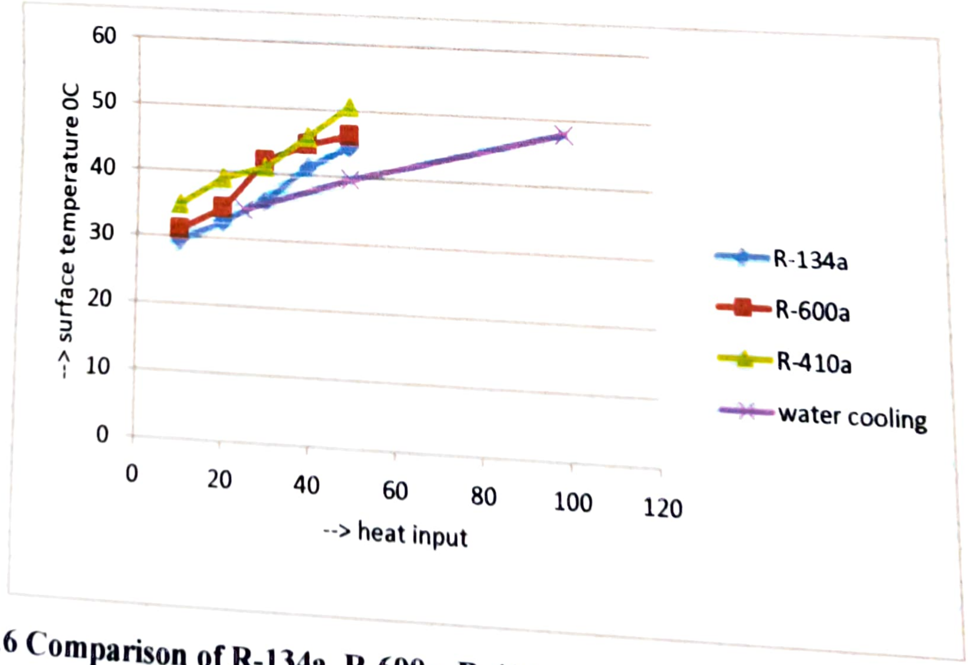

Fig: 7.6 Comparison of R-134a, R-600a, R-410a and water for different rates of heat inputs

CHAPTER 7

CONCLUSIONS

Two phase thermosiphone cooling system is designed for cooling of electronic components with different refrigerants. Experiments are carried out at various heat inputs with these refrigerants and from the results obtained, the performance of Two phase thermosiphone cooling system are analyzed. From the obtained results following conclusions were made.

1. Heat source surface temperature will go beyond safe limit even for small heat flux, if no heat sink is used.
2. When the heat input is 10W and refrigerant R-134a is used, the minimum surface temperature of 29.5°C is attained and which is almost equal to that of ambient temperatures.
3. When each refrigerant is compared with each other, R-134a is giving low temperatures at same heat inputs given.
4. For maximum heat input considered i.e., at 50W, R-134a, R-600a and R-410a given surface temperatures 44.6, 46.3and 50.6 respectively.
5. The refrigerant R410a is giving better values at maximum heat inputs as its boiling point is high when compared to other refrigerants compared.
6. It is observed that the two phase cooling system with refrigerants is cooling the electronics very efficiently compared with other cooling systems.

REFERENCES

REFERENCES

1. Yinfeng Wanga,c, Xiaoyuan Wanga, Haijun Chena, Hongtu Fanb, Robert A Taylorc,d, Yuezhao Zhua, CFD simulation of an intermediate temperature, two-phaseloop thermosiphon for use as a linear focus solar receiver Energy Procedia 105 (2017) 230 – 236.
2. Mehdi Bahiraei, Saeed Heshmatian Electronics cooling with nanofluids: A critical review Energy Conversion and Management 172 (2018) 438–456.
3. S M Sohel Murshed Electronics Cooling — An Overview · June 2016 DOI: 10.5772/63321.
4. Raffaele L. Amalfi1,2, Todd Salamon2, Nicolas Lamaison1,2, Jackson B. Marcinichen1, John R. Thome1 Two-phase liquid cooling system for electronics, part 3: Ultra-compact liquidcooled condenser DOI: 10.1109/ITHERM.2017.7992553.
5. Yury Ivanova*, Hirofumi Watanabea, Makoto Hamabea, Toshio Kawaharaa, Jian Suna, Satarou Yamaguchia,b Observation of the thermosiphon effect in the circulation of liquid nitrogen in HTS cable cooling system Physics Procedia 27 (2012) 368 – 371.
6. Suwat Trutassanawin1 and Eckhard A. Groll Review of Refrigeration Technologies for High Heat Dissipation Electronics Cooling 2004 (765) 495-7515.
7. Dipankar Bhanjaa,b,*, Balaram Kundub , Pabitra Kumar Mandala Thermal analysis of porous pin fin used for electronic cooling IConDM 2013.
8. Suresh V. Garimella, Amy S. Fleischer, Jayathi Y. Murthy, Ali Keshavarzi, Ravi Prasher,, Chandrakant Patel, Sushil H. Bhavnani, R. Venkatasubramanian, Ravi Mahajan, Y. Joshi, Bahgat Sammakia, Bruce A. Myers, Len Chorosinski, Martine Baelmans, Prabhu Sathyamurthy, and Peter E. Raad.Thermal Challenges in Next GenerationElectronic Systems. DOI: 10.11.09/TCAPT.2008.2001197.
9. Todd Salamon1, Raffaele L. Amalfi1,2, Nicolas Lamaison1,2, Jackson B. Marcinichen2, John R. Thome2 Two-Phase Liquid Cooling System for Electronics, Part 1: Pump-Driven Loop DOI: 10.1109/ITHERM.2017.799255.

10. 9th International Conference on Applied Energy, ICAE2017, 21-24 August 2017, Cardiff, UK.Dynamic performance of loop heat pipes for cooling of electronics Kai Zhua Xueqiang Lia,b, Yabo Wanga, Xiaoqing Chena, Hailong Lia,c,*aTianjin Key Laboratory of Refrigeration technology, Tianjin University of Commerce, Tianjin 300134, China School of Environmental Science and Engineering, Tianjin University, 300350, Tianjin, China c School of Sustainable Development of Society and Technology, Malardalen University, SE 721 23 Västrås, Sweden.
11. system Arulmurugan Loganathan ⇑, Ilangkumaran Mani.A fuzzy based hybrid multi criteria decision making methodology for phase change material selection in electronics cooling Rough surfaces with enhanced heat transfer for electronics cooling by direct metal laser sinteringLuigi Ventola a, Francesco Robotti a, Masoud Dialameh a.
12. Flaviana Calignano b, Diego Manfredi b,Eliodoro Chiavazzo a, Pietro Asinari .a Multi-Scale ModeLing Laboratory (SMaLL), Energy Department, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy b Center for Space Human Robotics IIT@Polito, Istituto Italiano di Tecnologia, Corso Trento 21, 10129 Torino, Italy.
13. Heat and Mass Transfger Data Book by C.P.Kothandarama and S.Subramanyam, New Age International Publishers.
14. Physical and chemical properties of refrigerant R-410A by National Refrigerants, INC.
15. Thermodynamic properties of refrigerant HFC-134a by the Dupont oval logo, The miracles of sciences.
16. Thermal properties of refrigerant R600a (Iso-Butane) by industrial pumps.

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES (A)

(Affiliated to Andhra University)

(Sangivalasa, Bheemunipatnam (Mandal), Visakhapatnam (District)

CERTIFICATE

This is to certify that the Project Report entitled **"PERFORMANCE ANALYSIS OF TWO-PHASE COOLING SYSTEM FOR ELECTRONIC COOLING"** has been carried out by **R.Narasingarao** (315126520263), **E.VamsiKrishna** (315126520268), **Md.Ahmed** (315126520245), **K. Stuthi** (315126520260), **N.Naveen** (315126520275) under the guidance of, **Mr. M. Rama Krishna** in partial fulfillment of the requirements of Degree of Bachelor of technology of Anil Neerukonda Institute Of Technology And Sciences, Visakhapatnam.

15.4.19

APPROVED BY

(Prof.B.Naga Raju)

Head of the Department
Dept. of Mechanical Engineering
ANITS (A), Sangivalasa
Visakhapatnam.

PROJECT GUIDE

(Mr. M. Rama Krishna)

Assistant Professor
Dept. of Mechanical Engineering
ANITS (A), Sangivalasa
Visakhapatnam.

PROFESSOR & HEAD
Department of Mechanical Engineering
ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY & SCIENCES
Sangivalasa-531 162 VISAKHAPATNAM Dist. A.P.