EXPERIMENTATION ON PERFORMANCE OF STRAIGHT AND SPLAYED PIN FINS FOR ELECTRONICS COOLING

A project report submitted in partial fulfilment of the requirements for the Award of the Degree of

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IN

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ABSTRACT

As the number of transistors increases with new generation of microprocessor chips, the power drawn and heat dissipated during the operation increases. As a result of increasing the heat loads and heat fluxes the Conventional cooling techniques like fan, heat sinks are unable to absorb and heat transfer excess heat dissipated by these new microprocessor. As a result it requires larger fans and larger heat sinks. So, new techniques are needed to improve the heat removal capacity.

In the present work fins with straight and splayed are analysed by taking the parameters of velocity and heat transfer rates are investigated. Pin fins are chosen as to provide higher heat transfer co-efficient than conventional cooling methods.

Copper and aluminium pins of 3mm diameter and 30 mm length are chosen to fabricate heat sinks. A fan is used to cool the pins under forced convection medium.

A solid heated aluminium block to simulate heat generated electronic component is used and electrical input is supplied to the heated aluminium block and cooling system is placed over the heated block. The performance of the cooling system form the experimental data is obtained.

It is experimentally observed that the pin fin heat sinks with fan as cooling system has better performance compared to other cooling systems. The effect of the convective heat transfer co-efficient on surface temperature of the heated aluminium block for these pin fins are obtained.These heat sink designs promises to keep electronic circuits 20 to 40% cooler than standard pin-fin heat sinks.

Heat dissipation techniques are the prime concern to remove the waste heat produced by Electronic Devices, to keep them within permissible operating temperature limits. Heat dissipation techniques include heat sinks, fans for air cooling, and other forms of cooling such as liquid cooling. Heat produced by electronic devices and circuitry must be dissipated to improve reliability and prevent premature failure. Integrated circuits such as CPUs, chipset, graphic cards, and hard disk drives are susceptible to temporary malfunction or permanent failure if overheated. As a result, efficient cooling of electronic devices remains a challenge in thermal engineering.

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NOMENCLATURE

R_1=Radius of the fan from the centre of the fan to start of the fan blades (m)

R_2= Radius of the fan from the centre of the fan to end of the fan blades (m)

n= Speed of the fan (rpm)

V_1=Velocity of the fan at the start of fan blade (m/s)

V_2=Velocity of the fan at the end of the fan blade (m/s)

V_{avg}=Average velocity of air (m/s)

V_{max}=Maximum velocity of air (m/s)

m_{water}=Mass of water (kg)

$Re_{D,max}$=Maximum Reynolds number

D= Diameter of fin (m)

ν=Kinematic Viscosity (m^2/s)\

L_f=Length of fin (m)

S_T=Transverse distance between the fins (m)

S_L=Longitudinal distance between the fins (m)

$\overline{Nu}$=Nusselt number

C_1, m=constants of equation

C_2=correction factor

K_{air}=Thermal conductivity of air (W/mK)

$K_{aluminium}$=Thermal conductivity of aluminium (W/mK)

K_{copper}=Thermal conductivity of copper (W/mK)

$\bar{h}$=Convective heat transfer co-efficient (W/m^2K)

N= Total number of fins

N_T=Number of transversal rows

C_p=Specific heat constant at constant pressure (J/kgK)

ρ=Density of air (kg/m^3)

P=Perimeter of fin (m)

A=Cross sectional area of fin (m^2)

T_i=Inlet temperature of air (^0C)

T_o=Outlet temperature of air (^0C)

T_∞=Ambient temperature (^0C)

T_b=Base temperature (^0C)

T_S=Average Surface temperature (^0C)

ΔT_{Lm}=Log mean temperature difference (^0C)

M=constant

Q=Rate of heat transfer (W)

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 General

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 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 charges, UPS(Uninterrupted Power Systems), DC-AC inverters, and army tanks (using transmission fluid at high temperatures). The high-power, high-heat flux demands on the cooling system cannot be met with air cooling, and advanced liquid cooling solutions are necessary.

According to Moore's law as shown in Fig.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 drawn 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.

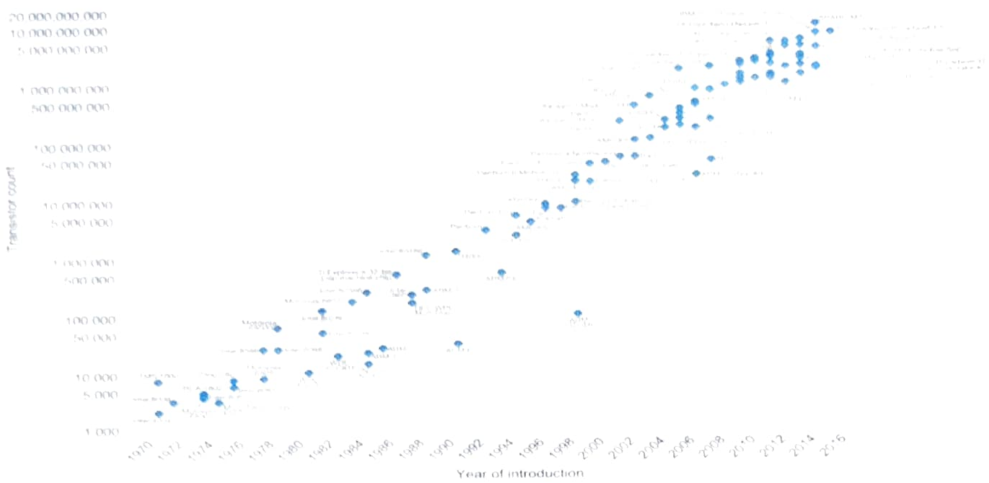

Fig 1.1 Moore's law

According to the Moore's law "the no. of transistor on a chip increases double after each 18 months" so we have to maintain temperature below specific temperature (e.g. 85oc) of the electronic component so that reliability will increase & chances of failure of that part will be minimized.

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 drastic shift in cooling high 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 150W dissipation, there are many physical and design constraints that may dictate a shift toward liquid as the preferred medium.

Today, the energy for cooling is conventional air cooled data centers systems. Energy use 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 cooled 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 heat transfer excess. As a result it requires large fans and larger heat sinks or new techniques are needed to improve the heat removal capacity.

Heat sinks are the most common thermal management hardware used in electronics. They improve the thermal control of electronic components, assemblies, and modules by enhancing their surface area through the use of pin fins. Applications utilizing pin fin heat sinks for cooling of electronics have increased significantly during the last few decades due to an increase in heat flux densities and product miniaturization. Today's cutting edge electronic circuits dissipate substantially heavier loads of heat than ever before. At the same time, the premium associated with miniaturized applications has never been greater, and space allocated for cooling purposes is on the decline. These factors have forced design engineers to seek more efficient heat sink technologies. One of the more powerful cooling technologies that have emerged in recent years is the pin fin technology. The unique pin fin design generates significant cooling power and is highly suitable for "hot" devices and applications that have limited space for cooling.

Pin fin heat sinks for surface mount devices are available in a variety of configurations, sizes and materials. Pin fin heat sinks, which contain an array of vertically oriented round pins made of copper or aluminium, deliver significantly greater performance than standard heat sinks with flat fins. The aerodynamic nature of the round pins and their omnidirectional configuration enable pin fin heat sinks to transfer heat very efficiently from the heat generating device to the ambient environment. As a result, this superior heat sink style is used in a wide range of applications and industries, wherever difficult cooling challenges takes place.

Even though standard pin fin heat sinks as shown in Fig.2 provide significant levels of cooling, there are applications in which even greater cooling power is required. With these applications in mind, two pioneering derivatives of the pin fin heat sink were developed.

Splayed pin fins as shown in Fig. 3 possess the round pins associated with the standard pin fin heat sink. But as result of their structural and metallurgical enhancements, these two new heat sink styles drive heat sink performance to advanced levels.

Splayed pin fin heat sinks are relatively new derivatives of the standard pin fin heat sink. Unlike standard pin fin heat sinks, which contain an array of vertically oriented pins, splayed pin fins features pins that gradually bend outward. Curving the pins in this way increases the spacing between the pins and allows surrounding air streams to enter and exit the pin array more efficiently without sacrificing surface area. The impact of increased pin spacing on heat sink performance is magnified at lower air speeds because weak air streams have less power to penetrate the array of pins.

In low airspeed environments and in natural convection, the increased spacing between the pins reduces the heat sink's thermal resistance by up to thirty percent versus a standard pin fin heat sink. As a result, splayed pin fins are recommended for low and moderate airspeed environments and for natural convection cooling.

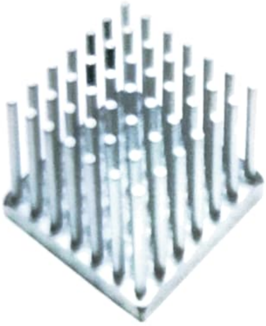

Fig.1.2 Straight Pin fin

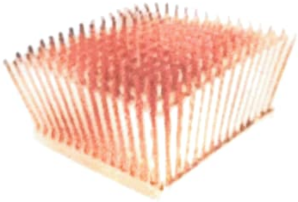

Fig.1.3 Splayed Pin Fin

In order to provide greater cooling efficiency may IT systems are currently developing and employing air cooling systems. In the present work an attempt has been made to experimentally study air cooling system with pin fin at different velocities.

CHAPTER 2

LITERATURE REVIEW

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 the 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 heat transfer solutions to chip is a continuous research.

Kanlikar and Grande [2] studied the increased circuit densityon todays computer chips is researching 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 oppurtunities in meeting the cooling demands of future IC chips. The use of micro channels surafce 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 convention of R-134a through single circular micro channels with 1.7, 1.2, 0.8mm 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 transfer show good agreement between classical correlations and experimentally measured data in the turbulent region. Contary, 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.

Abdulah and Kua [4] experimentally the thermal contact resistance to investigate the effect of machined surface roughness at different heat rates. The interface materials have been used in order to reduce thermal contact resistance between two mild steel bars with different surface roughness. It is demonstrated that the use of heat sink compound as an interface material significantly reduce the thermal contact resistance. However the use of Aluminium foil increased the thermal contact resistance unexpectedly.

Kennith and Goodson et al [5] investigated the performance of microchannel cooling system for microprocessor and found that that the surface temperatures are below the air cooling techniques.

Yang and Peng [6] have demonstrated the numerical simulation of the compound heat sink and have provided physical insight into the flow and heat transfer characteristics. The governing equations are discretized by using a control-volume-based finite-difference method with a power-law scheme on an orthogonal nonuniform staggered grid. The coupling of the velocity and the pressure terms of momentum equations are solved by the SIMPLEC algorithm. The well-known RNG k - two-equations turbulence model is employed to describe the turbulent structure and behaviour. The compound heat sink is composed of a plate fin heat sink and some pins between plate fins. The objective of this investigation is to examine the effects of the types and the arrangements of the pins. It is found that the compound heat sink has better synthetical performance than the plate fin heat sink. Moreover, the compound heat sink which is composed of a plate fin heat sink and circular pins performs better than the square ones.

Seyf and Layeghi [7] have carried out a numerical analysis to determine flow and heat transfer characteristics of an elliptical pin fin heat 50 sinks with and without metal foam inserts. The effects of metallic foam properties at various Reynolds numbers are studied numerically. Different metallic foams with various porosities and permeabilities are used in the numerical analysis. The Darcy–Brinkman– Forchheimer and classical Navier– Stokes equations, together with corresponding energy equations are used in the numerical analysis of the flow field and heat transfer in the heat sink with and without metal foam inserts, respectively. A finite volume code with point implicit Gauss–Seidel solver in conjunction with algebraic multigrid method is used to solve the governing equations. The code is validated by comparing the numerical results with available experimental results for a pin fin heat sink without porous metal foam insert. The effects of air flow Reynolds number and metal foam porosity and permeability on the overall Nusselt number, pressure drop, and the efficiency of the heat sink are investigated. The results indicate that the structural properties of metal foam insert can significantly influence both flow and heat transfer in a pin fin heat sink.

Gingras and Gosselin [8] have presented a conceptual design of a heat sink combining a porous medium whose matrix is highly conductive and a fin. A simplified model is presented to estimate the performance of the system, relying on Darcy law and local thermal 49 equilibrium. The objective is to minimize the hot-spot temperature under global mass constraint by using an optimization procedure based on genetic algorithms. The design variables are the porosity and material of each layer of the porous medium, the fin material, height, and width, the aspect ratio of the heat sink, and the shape of a weightless upper corner deflector which reduces the width of the inlet and outlet air slots which remove the less useful mass. Results show that the optimal porous layers have been generally of copper, independent of the mass constraint. However, the fin is mostly beneficial for heavier designs, while the deflector becomes more important when lightness is required. These two special features show their efficiency by allowing a mass reduction of 95% with a decrease of only 24% in the cooling performance.

Tien and Huang [9] have investigated the feasibility and effectiveness of air impingement cooling on pin-fin heat sinks applied in personal computers numerically. The effects of fin height, fin width, base plate thickness of the heat sink, and the ratio of the vertical spacing between the nozzle and the heat sink to jet diameter (z/D) have been discussed. For a PC with 68.4 W CPU, it has been found that the cooling effect by using air impingement on a heat sink with $z/D = 4$ and fin width 4.13 mm for the jet Reynolds number (Re) between 20000 to 25000 is comparable with the cooling effect achieved by using traditional coolers. When the fin width is increased to 5.3 mm, the performance by jet impingement is improved significantly. Specifically, the cooling performance by jet impingement for $Re = 15000$ and fin width 5.3 mm surpasses that by using a fan-heat sink coolers. Moreover, by changing the design of the PC chassis, the fin height and z/D is increased from 32.75 mm to 38.05 mm and from 4 to 8, respectively. It is found that the cooling effect is further enhanced. When handling CPU's with higher power (> 80 W), jet impingement cooling along with proper heat sink design and PC chassis design offer another possible choice.

Fisher and Torrance [10] presented the analytical solutions relevant to the limits of free convection for pin fin cooling. They suggested that the design of pin fin heat sink could be optimized by properly choosing the pin fin diameter and the heat sink porosity. Also, for conventional heat sinks, the minimum thermal resistance was about two times greater than that in an ideal limit according to the model of inviscid flow with idealized local heat transfer.

Aihara experimentally [11] studied 59 arrays with a population density of 1.08–10.58 pins/cm^2. He uses the modified Nusselt and Rayleigh numbers; an empirical correlation for characterized performance heat transfer performance of round pin fin arrays is established.

Balaram Kundu [12] studied the thermal analysis and optimizations of longitudinal and pin fins of uniform thickness subject to fully wet, partially wet and fully dry surface conditions and made a comparative study between the longitudinal and pin fin for a wide range of design parameters. He made a comparative study on the fin performance between the longitudinal and pin fins. The optimization analysis has been presented in a generalized form such that either heat transfer duty or fin volume can be treated as a constraint. The optimality criteria have been derived using the Lagrange multiplier technique. In addition, the method for optimization of partially wet surface fins has also been established.

Heat and Mass Transfer data book [13] by C.P. Kothandaram and S. Subramanyam, New Age International Publishers is a collection of various properties of fluids and formulae in the field of heat and mass transfer. Property values for various materials at different temperatures are also specified in this book.

CHAPTER 3

HISTORY OF ELECTRONICS COOLING

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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.

3.1 INTRODUCTION

The field of electronics deals with the construction and utilization of devices that involve current flow through a vacuum, a gas, or a semiconductor. This exciting field of science and engineering dates back to 1883, when Thomas Edison invented 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, TV, radar, and the digital computer. Of the several computers developed in this era, the largest and best known is the ENIAC (Electronic Numerical Integrator and Computer), which was built at the University of Pennsylvania in 1946. It had over 18,000 vacuum tubes and occupied a room 7 mX14 m in size. It consumed a large amount of power, and its reliability was poor because of the high failure rate of the vacuum tubes. The invention of the bipolar transistor in 1948 marked the beginning of a 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 in 1959 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 Fig.3.1. The continued miniaturization of electronic components has resulted in medium-scale integration (MSI) in the 1960s with 50 to 1000 components per chip, large-scale integration (LSI) in the 1970s with 1000 to 100,000 components per chip, and very large-scale integration (VLSI) in the 1980s with 100,000 to 10,000,000 components per chip. Today it is not unusual to have a chip 3 cm X 3 cm in size with several million components on it.

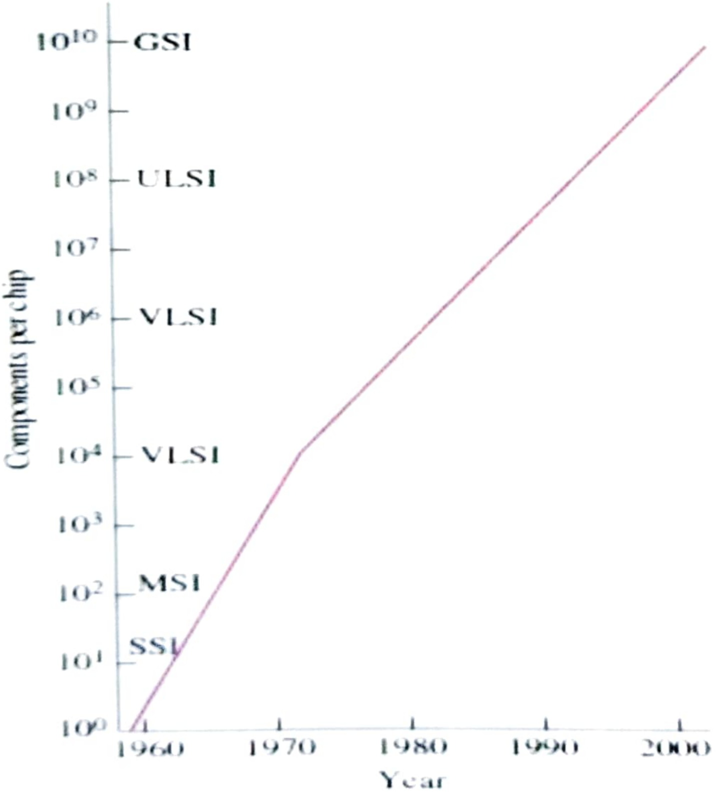


Fig: 3.1 Increase in the number of components packed on a chip over the microprocessor

The development of the microprocessor in the early 1970s by the Intel Corporation marked yet another beginning in the electronics industry. The accompanying rapid development of large-capacity memory chips in this decade made it possible to introduce capable personal computers for use at work or at home at an affordable price. Electronics has made its way into practically everything from watches to household appliances to automobiles. Today it is difficult to imagine a new product that does not involve any electronic parts.

3.2 HEAT GENERATION IN ELECTRONIC CHIP

The current flow through a resistance is always accompanied by heat generation in the amount of I^2R, where I is the electric current and R is the resistance. When the transistor was first introduced, it was touted in the newspapers as a device that "produces no heat." This certainly was a fair statement, considering the huge amount of heat generated by vacuum tubes. Obviously, the little heat generated in the transistor was no match to that generated in its predecessor. But when thousands or even millions of such components are packed in a small volume, the heat generated increases to such high levels that its removal becomes a formidable task and a major concern for the safety and reliability of the electronic devices. The heat fluxes encountered in electronic devices ranges from less than 1 W/cm^2 to more than 100 W/cm^2.

Heat is generated in a resistive element for as long as current continues to flow through it. This creates a heat build-up and a subsequent temperature rise at and around the component. The temperature of the component will continue rising 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 equals the rate of heat generation.

3.3 FAILURE OF ELECTRONIC COMPONENT

Individual electronic components have no moving parts, and thus nothing to wear out with time. Therefore, they are inherently reliable, and it seems as if they can operate safely for many years. Indeed, this would be the case if components operated at room temperature. But electronic components are observed to fail under prolonged use at high temperatures. Possible causes of failure are diffusion in semiconductor materials, chemical reactions, and creep in the bonding materials, among other things. The failure rate of electronic devices increases almost exponentially with the operating temperature, as shown in Fig. 3.2. The cooler the electronic device operates, the more reliable it is. A rule of thumb is that the failure rate of electronic components is halved for each 10°C reduction in their junction temperature.

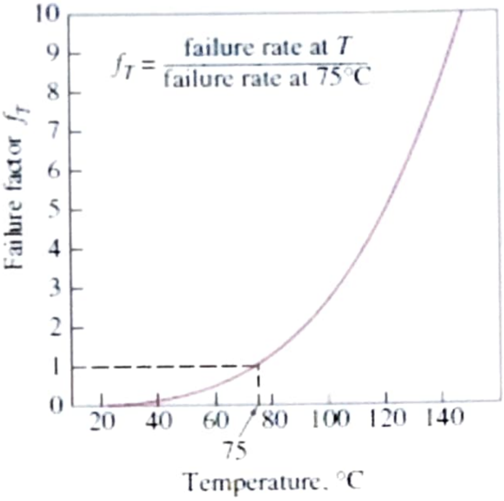


Fig. 3.2 Failure Factor vs Temperature

3.4 NECESSITY OF COOLING OF ELECTRONIC COMPONENTS

Computer cooling is the process of removing heat from computer components. Because a computer systems 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 (ergonomics).

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 modes 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 component 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 computers 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 impending airflow, thereby reducing heat sink and fan performance.
- Poor airflow including turbulence due to friction against impending 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 the display results. Due to finely packed semiconductors with in a confined space say 1cm will obviously generate heat due to resistance thus gradually increase in temperature is observed.

The performance of the microprocessor will drop exponentially with every 10^0c rise of temperature in the microprocessor as shown in Fig. 3.3

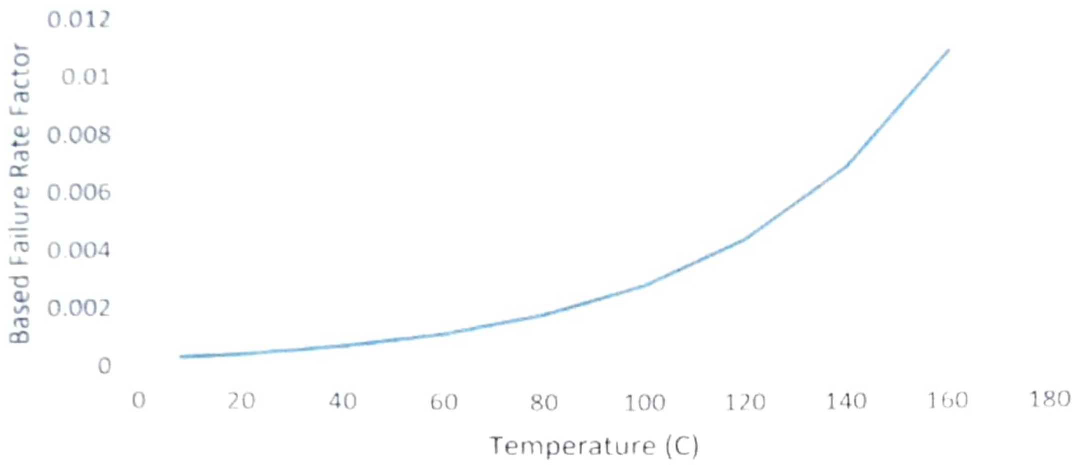


Fig. 3.3 Failure rate vs Temperature

3.5 COOLING LOAD OF ELECTRONIC COMPONENTS

The first step in the selection and design of a cooling system is the determination of the heat dissipation, which constitutes the cooling load. The easiest way to determine the power dissipation of electronic equipment is to measure the voltage applied **V** and the electric current (I) at the entrance of the electronic device under full-load conditions and to substitute them into the relation

$$W_e = V.I = I^2R$$

Where We is the electric power consumption of the electronic device, which constitutes the energy input to the device.

3.6 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 generated 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, thermo-electric cooling and heat pipes etc., we are having good enough heat fluxes of 500 to 1000 w/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 recycles 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 reduce concentrations of waste products in non-contact cooling water.

Air cooling is a method of dissipating heat. It works by expanding the surface area 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.

3.7 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:3.4 Moore's law is also relevant for power dissipation.

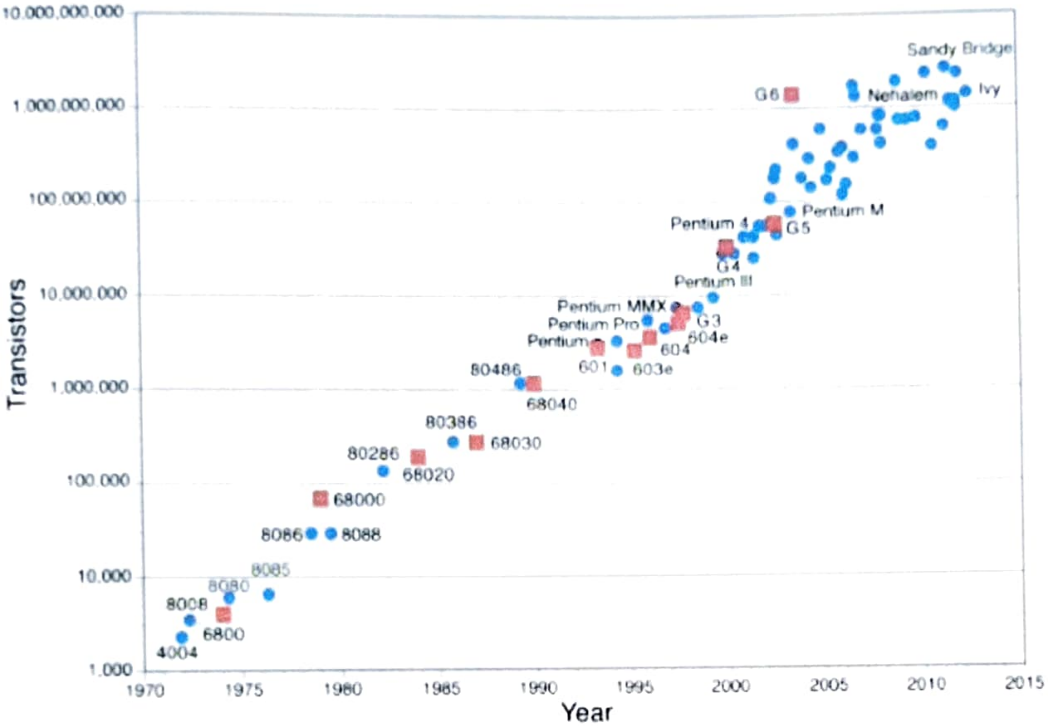


Fig 3.4 Number of transistors per die as function of time. This figure validates Moore's assumption of 1965

Miniaturization, integration of functionality, and the increase of clock speed are recognized business drivers in the electronics industry today. Consequences are the fast increase in power dissipation leading to higher heat fluxes, higher temperatures and larger temperature gradients. Handling these effects makes it more difficult to stay cost competitive, because expensive cooling solutions are needed. Therefore, reducing power dissipation will be a competitive advantage.

3.8 ELECTRONICS COOLING IN DIFFERENT APPLICATIONS

The cooling techniques used in the cooling of electronic equipment vary widely, depending on the particular application. Electronic equipment designed for airborne application. Electronic 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 be able to provide adequate paths for the flow of fluid and heat. Most such electronic equipment is 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 scaled 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 of 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 in scaled 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 temperatures for reliable operation. These two numbers help us determine the cooling techniques that are suitable for the device under consideration.

Supersonic gas turbine engines pose unique thermal management challenges not encountered in subsonic engines. In both cases, compressor bleed air is used to cool various downstream engine components such as turbine blades and afterburner walls. In subsonic engines, compressor bleed air is cool enough to be used directly for downstream cooling purposes. However, in supersonic engines, compressor bleed air temperature is quite high and therefore a heat exchanger is needed to precool the air before it can effectively cool the downstream engine components.

Compressor bleed air can be cooled by rejecting heat to either engine fan's bypass air or fuel. In some cases, depending on engine cycle requirements and thermal management architecture, using fuel as heat sink may allow a more compact and lightweight heat exchanger design than using air.

3.9 NEED OF AIR COOLING FOR ELECTRONIC CHIPS

The need for new cooling techniques is driven by the continuing increases in power dissipation of electronic parts and systems. In many instances standard techniques cannot achieve the required cooling performance due to physical limitations in heat transfer capabilities. These limitations are principally related to the limited thermal conductivity of air for convection and copper for conduction.

Fig 3.5 shows a comparison of various cooling techniques as a function of the attainable heat transfer in terms of the heat transfer coefficient. To accommodate a heat flux of 100 W/cm^2 at a temperature difference of 50 K requires an effective heat transfer coefficient (including a possible area enlarging factor) of 20,000 W/m^{2}K. From Figure 1 it can be concluded that there will be a need for liquid cooling in the future of thermal management. This article briefly discusses a number of promising thermal management technologies that are emerging for possible electronics applications.

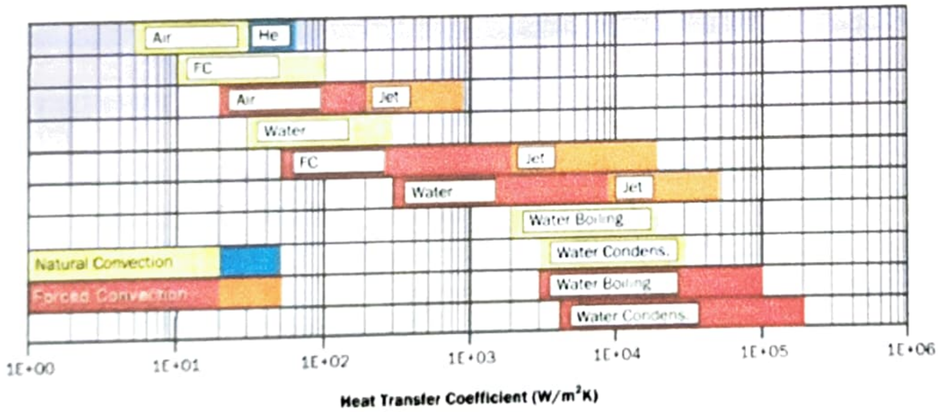


Fig 3.5 Comparison of various cooling techniques as a function of the attainable heat transfer in terms of the heat transfer coefficient

Air Cooling: It is generally acknowledged that traditional air-cooling techniques are about to reach their limit for cooling of high-power applications. With standard fans a maximum heat transfer coefficient of maybe 150 W/m^{2}K can be reached with acceptable noise levels, which is about 1 W/cm^2 for a 60°C temperature difference. Using 'macro jet' impingement, theoretically we may reach 900 W/m^{2}K, but with unacceptable noise levels. Non-standard fans/dedicated heat sink combinations for CPU cooling are expected to have a maximum of about 50 W/cm^2, which is a factor of 10 higher than expected 15 years ago. However, some new initiatives have emerged to extend the useful range of air-cooling such as piezo fans, 'synthetic' jet cooling and 'Nano lightning'.

Piezo Fans:

Piezoelectric fans are low power, small, relatively low noise, solid-state devices that recently emerged as viable thermal management solutions for a variety of portable electronics applications including laptop computers and cellular phones. Piezoelectric fans utilize piezo ceramic patches bonded onto thin, low frequency flexible blades to drive the fan at its resonance frequency. The resonating low frequency blade creates a streaming airflow directed at electronics components. A group at Purdue reports up to a 100% enhancement over natural convection heat transfer.

3.9.1 LIMITATIONS 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 performance of air cooling system when chip heat fluxes are exceeding 80 W/Cm^2. One cannot make the electronic chips without making the size of the heat sinks bulky and fan becomes bigger.

3.9.2 IMPORTANCE OF AIR COOLING

Today the heat dissipation rate from electronic chips is touching 100 W/Cm^2, which is supposed to be very high 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 higher convective heat transfer coefficients of liquids compared to air make it possible to allow greater heat dissipation. Consequently liquid cooling is much more efficient than air cooling and becomes even more efficient when fluid is forced to move through channles with very small dimensions.

3.10 TYPES OF COOLING SYSTEMS FOR ELECTRONIC COMPONENTS

3.10.1 AIR COOLING

Air cooling is a method of dissipating heat. It works by expanding the surface area 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.

In all cases, the air has to be cooler than the object or surface from which it is expected to remove heat. This is due to the second law of thermodynamics, which states that heat will only move spontaneously from a hot reservoir (the heat sink) to a cold reservoir (the air). Following are the different types of air cooling.

3.10.1.1 NATURAL CONVECTION

Natural convection is a mechanism, or type of heat transport, in which the fluid motion is not generated by any external source (like a pump, fan, suction device, etc.) but only by density differences in the fluid occurring due to temperature gradients.

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. 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.

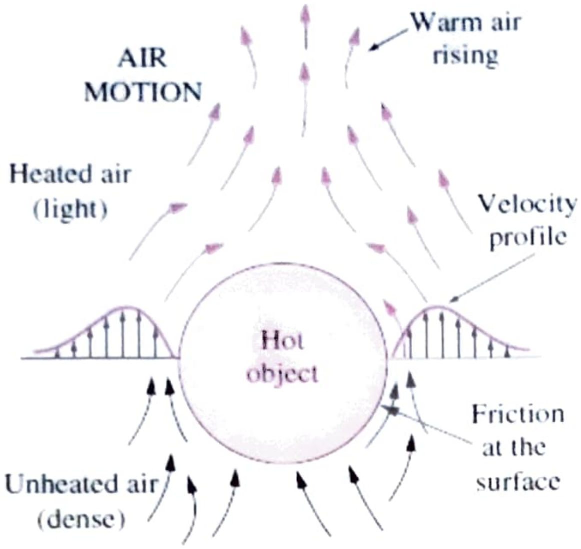


Fig 3.6 Natural convection currents around a hot object in air.

The magnitude of the natural convection heat transfer between a surface and a fluid is directly related to the flow rate of the fluid. The higher the flow rate, the higher the heat transfer rate. In natural convection, no blowers are used and therefore the flow rate cannot be controlled externally. The flow rate in this case is established by the dynamic balance of buoyancy and friction. The larger the temperature difference between the fluid adjacent to a hot surface and the fluid away from it, the larger the buoyancy force, and the stronger the natural convection currents, and thus the higher the heat transfer rate.

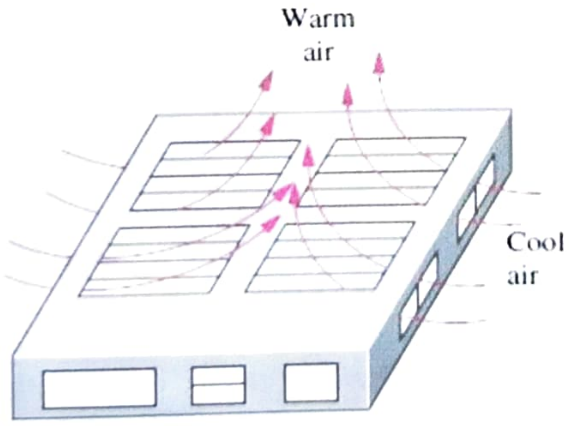


Fig 3.7 Natural convection through vent holes

3.10.1.2 FORCED CONVECTION

Forced convection is a mechanism or type of transport in which fluid motion is generated by an external source (like a pump, fan, suction device, etc.). It should be considered as one of the main methods of useful heat transfer as significant amounts of heat energy can be transported very efficiently. We mentioned earlier that convection heat transfer between a solid surface and a fluid is proportional to the velocity of 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 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.

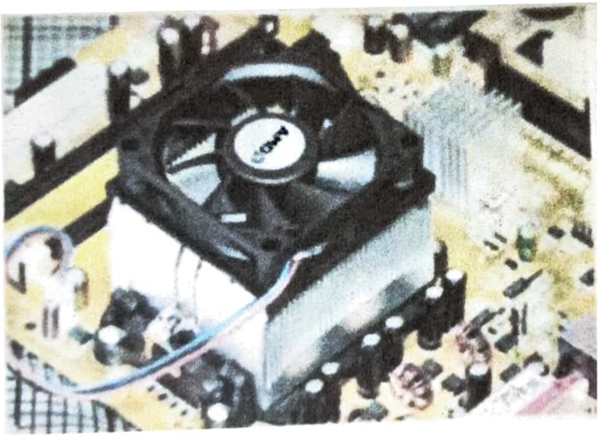


Fig 3.8 Forced convection through cooling fins

(i). 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 power house (and often multiple) video cards, large banks of RAM, and over locked CPUs, more thought needs to be put into how air travels through an enclosure.

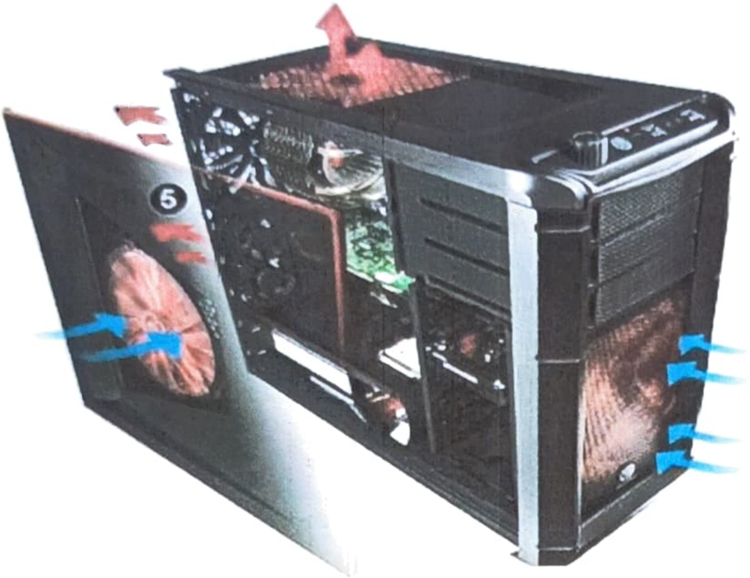


Fig 3.9 Typical airflow through a desktop ATX case

(ii). In High Density Computing

Data centres 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 centres typically contain such large numbers of computers and other power consuming devices, they risk overheating of various components if no additional measures are taken. Thus, extensive HVAC systems are used. Often a 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 place is blade chassis. In contrast to the horizontal orientation of flat servers, blade chassis is often oriented vertically. This vertical orientation facilitates convection. When the air is heated by hot components, it tends to flow to the top on its own, creating a natural air flow along the boards. This stack effect can help to achieve the desired air flow and cooling. Some manufacturers expressively take advantage of this effect.

Fig 3.10 Cooling of large data severs

(iii) In Laptop computing

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

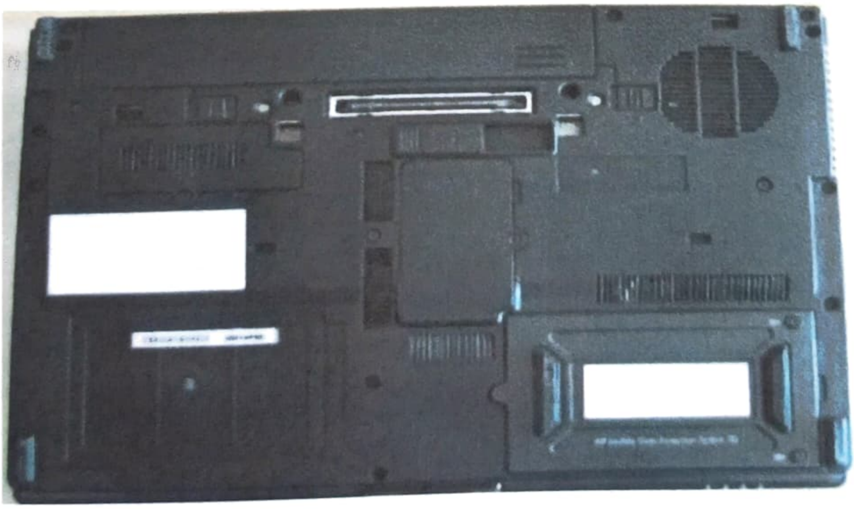


Fig 3.11 Laptop cooling

3.10.2 LIQUID COOLING

Liquids normally have much higher thermal conductivity than gases, and thus much higher heat transfer co efficient 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.

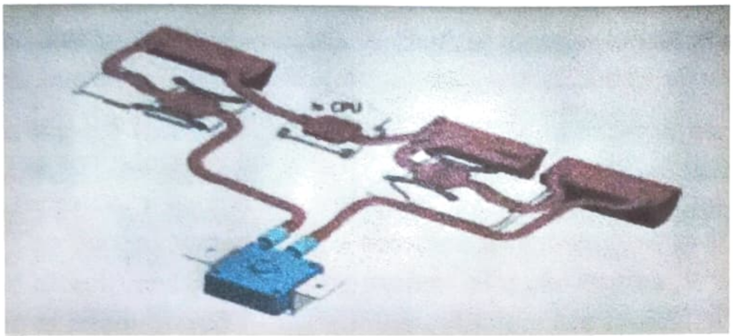


Fig 3.12 Desktop PC liquid cooling system

3.10.2.1 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 interconnects or TSM is needed. For now, it is assumed that such a seal/barrier is technically feasible.

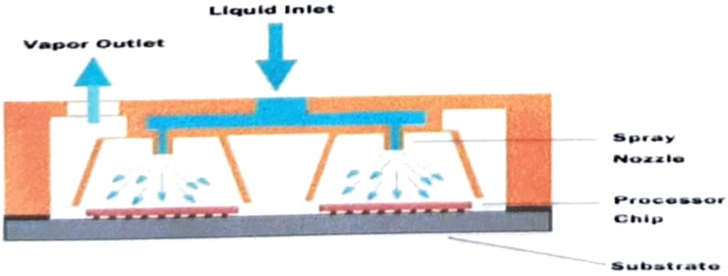


Fig 3.13 Direct liquid spray cooling of chips on an MCM

3.10.2.2 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. Since there is no contact with 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 the air blown to 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 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 points of the engine blocks. In an electronic system the heat is generated in the components instead of combustion chambers. The components in this case are mounted on a metal plate made of highly conducting material like copper or aluminium. The metal plate is cooled by circulating a cooling fluid through tubes attached to it, as shown in fig 3.14 The heated liquid is then cooled in a heat exchanger, usually by air (or sea water in marine applications), and is recirculated by a pump through the tubes. The expansion and storage tank accommodates any expansions and contractions of the cooling liquid due to temperature variations while acting as a liquid reservoir. The heat sinks or cold plates of an electronic enclosure are usually cooled by water by passing it through channels made for this purpose or through tubes attached to the cold plate. High heat removal rates can be achieved by circulating water through these channels or tubes. In high performance systems, a refrigerant can be used in place of water to keep the temperature of the heat sink at sub-zero temperatures and thus reduce the junction temperatures of the electronic components proportionately.

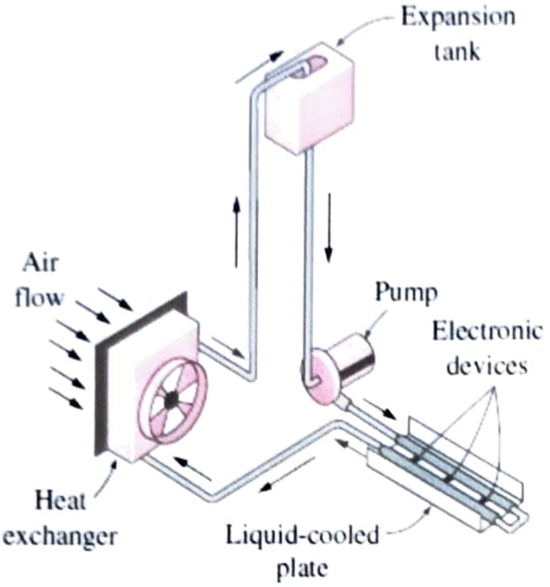


Fig 3.14 Schematic of an indirect liquid cooling system

3.10.3 IMMERSION COOLING

Immersion cooling has been used since the 1940s in the cooling of electronic equipment, but for many years its use was largely limited to the electronics of high powered radar systems. The miniaturization of electronic equipment and the resulting high heat fluxes brought about renewed interest in immersion cooling, which has been largely viewed as an exotic cooling technique.

From thermodynamics, at a specified pressure, the fluid boils isothermally at the corresponding saturation temperature. A large amount of heat is absorbed during the boiling process, essentially in an isothermal manner. Therefore, immersion cooling also provides a constant temperature bath for the electronic components and eliminates hot spots effectively.

The simplest type of immersion cooling system involves an external cooling reservoir that supplies liquid continually to the electronic enclosure. The vapour generated inside is simply allowed to escape to the atmosphere, as shown in fig. A pressure relief valve on the vapour vent line keeps the pressure and the temperature inside at the preset value, just like the petcock of the pressure cooker. Note that without a pressure relief valve, the pressure inside the enclosure would be atmospheric pressure and the temperature would have to be the boiling temperature of the fluid at the atmospheric pressure.

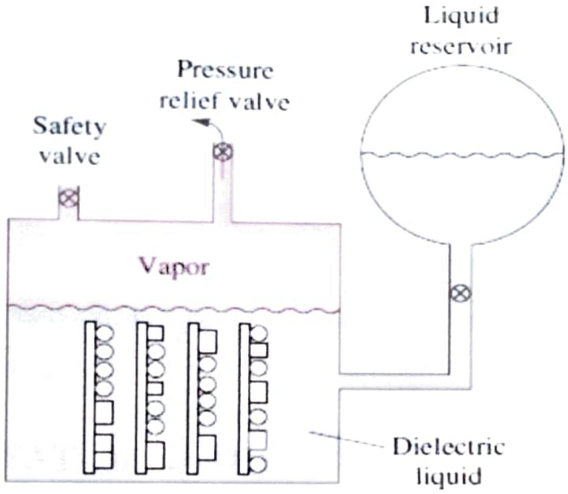


Fig 3.15 A simple open-loop immersion cooling system

3.10.4 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 in between. This block usually has fins or ridges to increase its surface area. The heat conductivity of metal is much better that 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 the CPU). Until recently fan cooled aluminium heat sinks were the norm for desktop computers. Passive heat sinks are commonly found as shown in fig. 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 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.

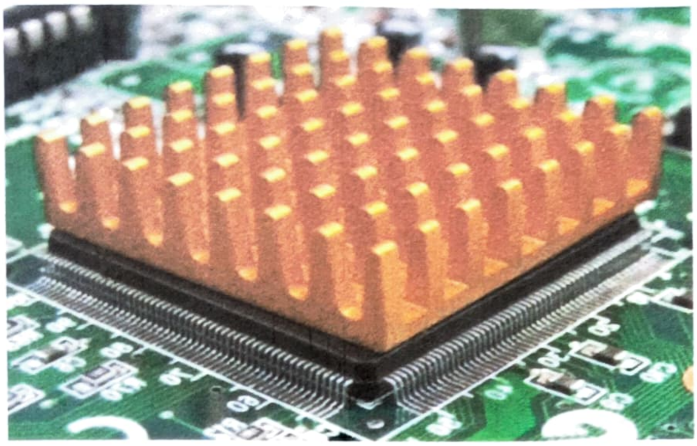


Fig 3.16 Passive heat sink fitted on an Intel GMA graphics chip

3.10.5 ACTIVE HEAT SINK COOLING

Active heat sink cooling uses the same principle as that of a fan that is directed to blow over or through the heat sink. The more the surface the higher the rate at which heat sink can exchange heat with ambient air. Active Heat sink is a method of cooling a modern processor or graphics card.

The build-up of dust is greatly increased with active heat sink continually taking in 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.

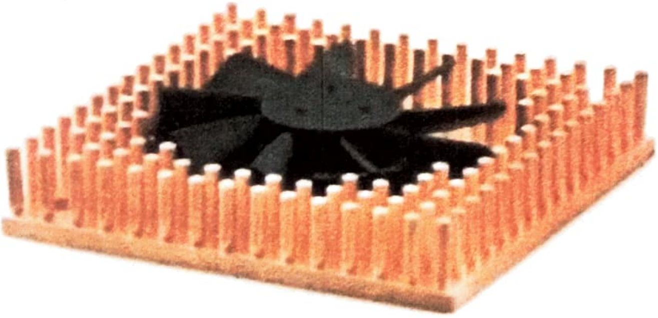


Fig 3.17 Active heat sink with a 120mm fan located inside the unit and attached fan controller in background

CHAPTER 4

COOLANTS

A coolant is a fluid which flows through or around a device to prevent the device from overheating, transferring the heat produced by the device to the other devices that either use or dissipate it.

The coolant can either keep its phase and stay liquid or gaseous, or can undergo a phase transition, with the latent heat adding to the cooling efficiency. The latter, when used to achieve below ambient temperature, is more commonly known as refrigerant.

4.1 REQUIREMENTS FOR A COOLANT FOR ELECTRONICS

There are many requirements for a liquid coolant for electronics applications. The requirements may vary depending on the type of application. Following is a list of some general requirements:

- Good thermo-physical properties (high thermal conductivity and specific heat; low viscosity; high latent heat of evaporation for two phase applications)
- Low freezing point and burst point(sometimes burst protection at -40°C or lower is required for shipping and/or storage purposes)
- High atmospheric boiling point(or low vapor pressure at the operating temperature) for single phase system; a narrow desired boiling point for a two phase system
- Good chemical and thermal stability for the life of electronic system
- High flash point and auto ignition temperature(sometimes non combustibility is a requirement)
- Non corrosive to materials of construction(metals as well as polymers and other non-metals)
- No or minimal regulatory constraints(environmentally friendly, non-toxic, and possibly biodegradable)
- Economical

4.2 TYPES OF COOLANTS

4.2.1 GASES:

Air is a common form of a coolant. Air cooling uses either convective air flow (passive cooling), or a forced circulating using fans.

Hydrogen is used as a high-performance gaseous coolant. Its thermal conductivity is higher than all other gases; it has high specific heat capacity, low density and therefore low viscosity, which is an advantage for rotary machines susceptible to windage losses. Hydrogen-cooled turbo generators are currently the most common electrical generators in large power plants.

4.2.2 LIQUIDS:

The most common coolant is water. Its high heat capacity and low cost makes it a suitable heat transfer medium. It is usually used with additives like corrosion inhibitors and anti-freeze. Anti-freeze, a solution of a suitable organic chemical (most often ethylene glycol, di ethylene glycol, or propylene glycol) in water, is used to when the water based coolant has to withstand temperatures below 0°C, or when its boiling point has to be raised. Betaine is a similar coolant, with an exception that is made from pure plant juice, and is therefore non-toxic or difficult to dispose off ecologically.

Very pure deionized water, due to its relatively low electrical conductivity, is used to cool some electrical equipment of and high power transmitter and high power vacuum tubes.

4.2.2.1 MOLTEN METAL AND SALTS:

Liquid fusible allows can be used as coolants in applications where high temperature stability is required, e.g., some fast breeder nuclear reactors. Sodium (in sodium cooled fast reactors) or sodium-potassium alloy NaK are frequently used; in special cases Lithium can be employed. Another liquid metal used as a coolant is Lead, e.g. lead cooled fast reactors, are a lead-bismuth alloy. Some early fast neutron reactors used mercury.

4.2.2.2 LIQUID GASES:

Liquefied gases are used as coolants for cryogenic applications, including, over clocking of computer processors, applications using super conductors, or extremely sensitive sensors and very low noise amplifiers.

Carbon Dioxide is used as a coolant replacement for cutting fluids. CO_2 can provide controlled cooling at the cutting interface such that the cutting tool and the work piece are held at ambient temperatures. The use of CO_2 greatly extends tool life, and on most materials allows the operation to run faster. This is considered a very environmentally friendly method, especially when compared to the use of petroleum oils as lubricants; parts remain clean and dry which often can eliminate secondary cleaning operations.

Liquid Nitrogen, which boils at -196°C (77K), is the most common and least expensive coolant in use. Liquid air is used to a lesser extent, due to its liquid oxygen content which makes it prone to cause fire or explosions when in contact with combustible materials.

4.2.2.3 NANO FLUIDS:

Emerging and new classes of coolants or Nano fluids which consist of a career liquid, such as water, dispersed with tiny Nano-scale particles known as Nano-particles. CuO, Alumina, Titanium Dioxide, Carbon Nanotubes, Silica, or metals (e.g. Cu, or Silver Nano-rods) dispersed into the career liquid enhance the heat transfer capabilities of the resulting coolant compared to the career liquid alone. The enhancement can be theoretically as high as 350%. The experiments however did not prove so high thermal conductivity improvements, but found significant increase of the critical heat flux of the coolants.

4.2.3 SOLIDS:

In some applications, solid materials are used as coolants. The materials require high energy to vaporize; this energy is then carried away by the vaporized gases. This approach is common in space flight, for ablative atmospheric re-entry shields and for cooling of rocket engine nozzles. The same approach is also used for fire protection of structures, where ablative coating is applied. Dry ice and water ice can be also used as coolants, when in direct contact with the structure being cooled. Sublimation of water ice was used for cooling the project Apollo space suit.

4.3 COOLANTS BASED ON CONDUCTIVITY:

4.3.1 DIELECTRIC COOLANTS:

A liquid dielectric is a dielectric material in liquid state. Its main purpose is to prevent or rapidly quench electric discharges. Dielectric liquids are used as electrical insulators in high voltage applications, e.g. transformers, capacitors, high voltage cables, and switchgear (namely high voltage switch gear). Its function is to provide electrical insulation, suppress corona and arcing, to serve as a coolant.

A good liquid dielectric should have high dielectric strength, high thermal stability and chemical inertness against the construction materials used, non-flammability and low toxicity, good heat transfer properties, and low cost.

4.3.1.1 AROMATICS:

Synthetic hydrocarbons of aromatic chemistry (i.e. di ethyl benzene (DEB), di benzyl toluene, di aryl alkyl, partially hydrogenated terphenyl) are very common heating and cooling fluids used in a variety of applications. However, these compounds cannot be classified as non-toxic. Also, some of these fluids (i.e. alkylated benzene) have strong odors, which can be irritating to the personnel handling them.

4.3.1.2 SILICATE-ESTERS:

This chemistry (i.e., Coolanol 25R) was widely used as a dielectric coolant in Air Force and Navy airborne radar and missile systems. These fluids have caused significant and sometimes catastrophic problems due to their hygroscopic nature and subsequent formation of flammable alcohols and silica gel. Therefore, these fluids have been replaced by more stable and dielectric aliphatic chemistry (polyalphaolefins or PAO).

4.3.1.3 ALIPHATICS

Aliphatic hydrocarbons of paraffinic and Iso-paraffinic type (including mineral oils) are used in a variety of direct cooling of electronics parts as well as in cooling transformers. Many petroleum based aliphatic compounds meet the Food and Drug Administration (FDA) and United States Department of Agriculture (USDA) criteria for incidental food contact. These petroleum based fluids do not form hazardous degradation byproducts. Most of these fluids have a non-discernible odor and are nontoxic in case of contact with skin or ingestion. As mentioned before, aliphatic PAO based fluids have replaced the silicate ester fluids in a variety of military electronics (and avionics) cooling applications in the last decade.

4.3.1.4 FLUOROCARBONS

Fluorinated compounds such as perfluoro carbons (i.e., FC72, FC77) Hydro fluoro ethers (FIFE) and perfluoro carbon ethers (PFE) have certain unique properties and can be used in contact with the electronics. First of all, these fluids are noncombustible and nontoxic. Some fluorinated compounds have zero ozone depleting potential and other environmental properties. Secondly, some of these fluids have low freezing points and low viscosities at low temperatures. However, these fluids are very expensive, have poor thermal properties, some of them have global warming potential (greenhouse effect), and, due to the extremely low surface tension, leaks can develop around fittings. The following table 4.1 shows various properties of dielectric fluids.

Coolant Chemistry	Freezing point (^{0}C)	Flash Point (^{0}C)	Viscosity ($kg.m^{-1}s^{-1}$)	Thermal conductivity $W.m^{-1}K^{-1}$	Specific Heat $J.Kg^{-1}K^{-1}$	Density $Kg.m^{-3}$
Aromatic (DEB)	< -80	57	0.001	0.14	1700	860
Silicate-Ester (coolanol 25R)	< -50	>175	0.009	0.132	1750	900
Aliphatic	< -50	>175	0.009	0.137	2150	770
Silicone (Syltherm XLT)	< -110	46	0.0014	0.11	1600	850
Fluorocarbon (FC-77)	< -100	None	0.0011	0.06	1100	1800

Table 4.1Various properties of dielectric fluids

4.3.2 NON-DIELECTRIC COOLANTS:

Non-dielectric liquid coolants are often used for cooling electronics because of their superior thermal properties, as compared with the dielectric coolants. Non-dielectric coolants are normally water-based solutions. Therefore, they possess a very high specific heat and thermal conductivity.

4.3.2.1 DEIONIZED WATER

Deionized water (DI water, DIW or de-ionized water), often confused with mineralized water / DM water, is water that has had almost all of its mineral ions removed, de h as cations like sodium, calcium, iron, and copper, and anions such as chloride and sulfate.

4.3.2.1.1 USES

Purified water is suitable for many applications, including autoclaves, hand-pieces, laboratory testing, laser cutting, and automotive use. Purification removes contaminants that may interfere processes, or leave residues on evaporation. Although water is generally considered to be a good electrical conductor—for example domestic electrical systems are considered particularly hazardous to people if they may be in contact with wet surfaces—pure water is a poor conductor. The conductivity of sea-water is typically 5 S/m, drinking water is typically in the range of 5-50 mS/m, while highly purified water can be as low as 5.5 pS/m (0.055 pS/cm), a ratio of about 1,000,000:1,000:1.

4.3.2.1.2 PURIFICATION METHODS

(i). Distillation

Distilled water is produced by a process of distillation and has an electrical conductivity of not more than 11 pS/cm and total dissolved solids of less than 10 mg/litre. Distillation involves boiling the water and then condensing the vapor into a clean container, leaving solid contaminants behind. Distillation produces very pure water

(ii). Double Distillation

Double-distilled water (abbreviated "ddH$_2$0", "Bidest. water" or "DDW") is prepared by slow boiling the uncontaminated condensed water vapor from a prior slow boiling. Historically, it was the de facto standard for highly purified laboratory water for biochemistry and used in laboratory trace analysis until combination purification methods of water purification became widespread.

(iii). Deionization:

Deionization is a chemical process that uses specially manufactured ion-exchange resins, which exchange hydrogen and hydroxide ions for dissolved minerals, and then recombine to form water. Because most non-particulate water impurities are dissolved salts, deionization process a high purity water that is generally similar to distilled water, and this process is quick and without scale buildup.

4.3.2.1.3 PROPERTIES OF DEIONIZED WATER

- Water has a high specific heat. Specific heat is the amount of energy required to change the temperature of a substance. Because water has a high specific heat, it can absorb large amounts of heat energy before it begins to get hot. It also means that water releases heat energy slowly when situations cause it to cool. Water's high specific heat allows for the moderation of the Earth's climate and helps organisms regulate their body temperature more effectively.

- Water in a pure state has a neutral pH. As a result, pure water is neither acidic nor basic. Water changes its pH when substances are dissolved in it. Rain has a naturally acidic pH of about 5.6 because it contains natural derived carbon dioxide and sulfur dioxide.

- Water conducts heat more easily than any liquid except mercury. This fact causes large bodies of liquid water like lakes and oceans to have essentially a uniform vertical temperature profile.

- Water molecules exist in liquid form over an important range of temperature from 0 - 1000 Celsius. This range allows water molecules to exist as a liquid in most places on our planet.

- Water is a universal solvent. It is able to dissolve a large number of different chemical compounds. This feature also enables water to carry solvent nutrients in runoff, infiltration, groundwater flow, and living organisms.

- Water has a high surface tension . In other words, water is adhesive and elastic, and tends to aggregate in drops rather than spread out over a surface as a thin film. This phenomenon also causes water to stick to the sides of vertical structures despite gravity's downward pull. Water's high surface tension allows for the formation of water droplets and waves, allows plants to move water (and dissolved nutrients) from their roots to their bodies of some animals.

The freezing of water molecules causes the mass to occupy a larger volume. When water freezes it expands rapidly adding about 9% by volume. Fresh water has a maximum density at around 4° Celsius. Water is the only substance on this planet where the maximum density of its mass does not occur when it becomes solidified.

4.3.2.2 ETHYLENE GLYCOL ($C_2H_60_2$):

Commonly used as antifreeze in automotive engine cooling, EG also has found use in many industrial cooling applications. Common applications include process cooling at lower as a raw material in the manufacture of polyester fibers and fabric industry, and polyethylene temperatures.

Ethylene glycol (IUPAC name: ethane-1,2-diol) is an organic compound primarily used terephthalate resins (PET) used in bottling. A small percent is also used in industrial applications like antifreeze formulations and other industrial products.

4.3.2.2.1 COOLANT AND HEAT TRANSFER AGENT:

The major use of ethylene glycol is as a medium for convective heat transfer in, for example, automobiles and liquid cooled computers. Ethylene glycol is also commonly used in chilled water air conditioning systems that place either the chiller or air handlers outside, or systems that must cool below the freezing temperature of water.

In geothermal heating/cooling systems, ethylene glycol is the fluid that transports heat through the use of a geothermal heat pump, The ethylene glycol either gains energy from the source (lake, ocean, water well) or dissipates heat to the sink, depending if the system is being used for heating or cooling.

4.3.2.2.2 PHYSICAL PROPERTIES:

Physical Properties Ethylene glycol is a clear, colorless, odorless, liquid with a sweet taste. It is hygroscopic and completely miscible with many polar solvents such as water, alcohols, glycol ethers, and acetone. Its solubility is low however, in nonpolar solvents, such as benzene, toulene, and dichloro ethane and chloroform. Following table shows the physical properties of ethylene glycol.

Boiling Point at 101.3 Kpa	197.6^0C	Critical pressure	6515.73Kpa
Freezing point	-13^0C	Flash Point	-13^0C
Density at 20^0C	1.1135 g/cm^3	Ignition temperature	410^0C
Heat of Combustion	19.07 MJ/Kg	Viscosity at 20^0C	19.83 mPa-s
Critical temperature	372^0C	Cubic expansion coefficient at 20^0C	$0.62*10^{-3}K^{-1}$

Table 4.2 Various properties of Ethylene Glycol

4.3.2.2.3 CHEMICAL PROPERTIES

The ethylene glycols (commonly called diols) are dihydirc alcohols that have an aliphatic carbon chain. The two hydroxyl groups result in high water solubility and hygroscopicity and provide reactive sites. The heavier glycols exhibit some of the properties of ethers because of the ether linkage in their molecular structure. The reaction of the ethylene glycols are similar to those of the monohydric alcohols in which the hydrogen group is replaced by halogens, is esterified of forms ethers, etc. Organic acids react with ethylene glycol to produce mono- and diesters, the relative yields of which are dependent on the molar ratio of the acid to the glycol. Typical reactions, which are of industrial importance, are as follows.

$(CH_2OH)_2 + RCOOH \rightarrow RCOOCH_2\text{-}CH_2OH + H_2O$ $(CH_2OH)_2 + 2RCOOH \rightarrow RCOOCH_2\text{-}CH_200CR + H_2O$

Polyesters are formed by the reaction of ethylene glycol with polybasic acids or their derivatives, Bishydroxyethyl terephthalate, which is used to produce polyethylene terephthalate, is made from the condensation of ethylene glycol with dimethyl terephthalate or terephthalic acid.

4.3.2.3 METHANOL/WATER

Methanol, also known as methyl alchohol, wood alchohol, wood naphtha, methyl hydrate, or wood spirit, is a chemical with the formula CH_3OH(often abbreviated MeOH). Methanol acquired the name wood alchohol because it was once produced cheaply as a byproduct of the distructive distillation of wood. Aqueous solutions of calcium chloride find wide use as circulating coolants in food plants. It is non flammable, non toxic, and thermally more efficient than the glycol solutions. This is a low cost anti freeze solution, finding use in refrigeration services and ground source heat pump. Similar to glycol, this can be inhibited to stop corrosion.

4.3.2.4. CALCIUM CHLORIDE ($CaCl_2$):

Calcium chloride is a chemical compound made up of the elements, calcium and chlorine. It contains two atoms of chlorine and one atom of calcium. Thus, its chemical formula is $CaCl_2$. It is also known as a common salt, as referred to in chemistry.

Calcium Chloride $CaCl_2$ is an inorganic salt, which exists in a solid form or as a liquid solution. Solid calcium chloride is a white, crystalline substance in the form of flake, granule or powder. Depending on the crystallized water contents, it can be dehydrate or anhydrous. Liquid calcium chloride is a colorless liquid. The diverse physical and chemical properties of calcium chloride make it a very useful compound for various industries.

Calcium chloride can be prepared by various methods. When calcium carbonate or calcium oxide is dissolved in hydrochloric acid, this compound is produced. Calcium chloride is obtained on a large scale as a byproduct of the Solvay process or the ammonia-soda process. In this process, when calcium carbonate reacts with sodium chloride, sodium carbonate and calcium chloride are formed.

4.3.2.4.1 PHYSICAL PROPERTIES OF CALCIUM CHLORIDE

Calcium chloride can be found in solid state at room temperature, and is available as takes, granules, and in the powdered form. Calcium chloride is salty to taste. Hence, it is added to many food products like canned vegetables, pickles etc. In the solid form, this compound is white in color, while in the liquidated form, it is colorless. This is an odorless compound. The density 0f calcium chloride is 2.15gm/cm. It is soluble both in inorganic solvents like water, as well as organic solvents like ethanol.

4.3.2.4.2 CHEMICAL PROPERTIES OF CALCIUM CHLORIDE

(I). Exothermic:

Calcium Chloride is exothermic in nature, that is it realeases heat during any chemical reaction.

(ii). Reaction with water:

When Calcium Chloride is exposed to water it dissolves to form aqueous ions. The reaction depicting the process is given below:

$CaCl\ (S) + H_2O(l) \rightarrow Ca(aq) + 2Cl(aq) + H_2O(l)$

(iii). Reaction with metals:

Calcium chloride is a non-inflammable substance. However, when it comes in contact with metals like zinc or sodium, it produces hydrogen, which is highly inflammable. For this reason, we should ensure that calcium chloride is kept away from these metals. We should also avoid storage of calcium chloride in containers made of any of these substances. Despite being a valuable chemical substance, calcium chloride has some harmful side effects. It can cause mild to severe itching when it comes in contact with our skin. So, one should handle it carefully. The following table 4.3 shows various properties of dielectric fluids. The following table 4.3 shows various properties of dielectric fluids.

Coolant Chemistry	Freezing Point (^{0}C)	Flash Point (^{0}C)	Viscosity Kg.m^{-1}s^{-1}	Thermal conductivity Wm^{-1}K^{-1}	Specific heat J.Kg^{-1}K^{-1}	Density Kgm^{-3}
EG/water (50:50 v/v)	-37.8	None	0.0038	0.37	3285	1087
PG/Water %0:50(v/v)	-35	None	0.0064	0.36	3400	1062
Methanol/ Water 40:60(wt/wt)	-40	29	0.002	0.4	3560	935
Ethanol/water 44:56(wt/wt)	-32	27	0.003	0.38	3500	927
Potassium Formate/Water 40:60(wt/wt)	-35	None	0.0022	0.53	3200	1250

Table 4.3 Various Properties of dielectric fluids

CHAPTER 5

PIN FIN

CHAPTER 5
PIN FIN

Fins are surfaces that extend from an object to increase the rate of heat transfer to or from the environment by increasing convection. The amount of conduction, convection, or radiation of an object determines the amount of heat it transfers. Increasing the temperature gradient between the object and the environment, increasing the convection heat transfer coefficient, or increasing the surface area of the object increases the heat transfer. Sometimes it is not feasible or economical to change the first two options. Thus, adding a fin to an object increases the surface area and can sometimes be an economical solution to heat transfer problems.

A Pin Fin heat sink is a normal heat sink, but it differs from other heat sinks as it consists of pins that are extended from its base. These pins are in various shapes including elliptical, cylindrical and square shapes. It is the most common heat sink available in the market nowadays.

5.1 FACTORS TO BE CONSIDERED WHILE DESIGNING HEAT SINK

- Power that needs to be dissipated.
- Maximum allowable component temperature.
- Available space/volume for heat sink.
- Power density.
- Air Flow parameters.
- Pressure Drop.
- Manufacturability.
- Cost.

5.2 FACTORS AFFECTING THE PERFORMACE OF HEAT TRANSFER

1) Arrangement of pin fin array.
2) Shape of pin fin (cross-section of fin).
3) Geometric parameters (diameter, length, aspect ratio, void fraction).
4) Pitch between adjacent fins (transverse & longitudinal).
5) Number of fins.

6) Material of pin fin.
7) Shroud clearance (bypass factor).
8) Nature of fluid flow (natural or forced).
9) Location of fan/Blower in case of forced convection i.e. velocity of flowing fluid.
10) Type of flowing fluid.
11) Surface finish of the fins.
12) Inclination of fins.

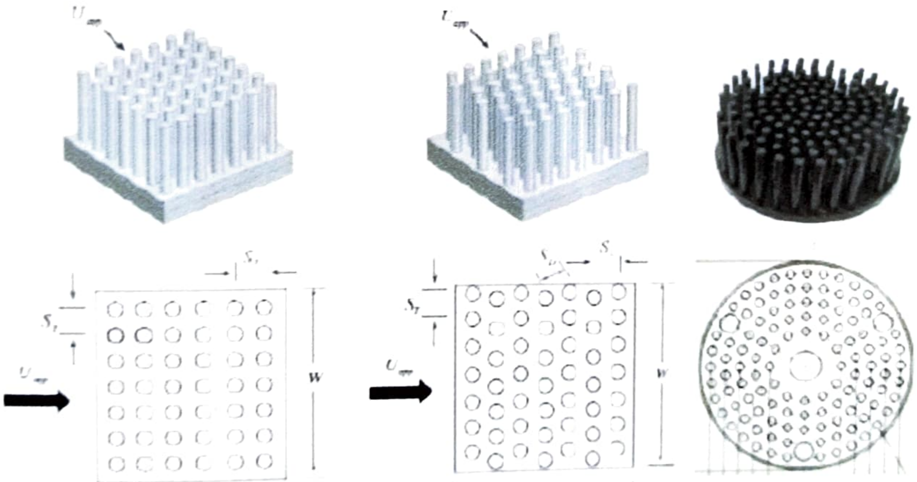
5.2.1 ARRANGEMENT OF PIN FINS

According to arrangement of pin fins they are classified as

a) Inline pin fin array –in these, each pin fins are in straight line horizontally& vertically in a rectangular channel.

b) Staggered pin fin array – in these, pin fins are not in straight line they are randomly oriented in rectangular channel.

c) Radial pin fin array- in these, pin fins are along radial direction in circular channel.



a) inline pin array

b) staggered pin fin array

c) radial pin array

Fig 5.1 Types of PIN FIN array

Heat transfer performance of the staggered arrangement is better than inline arrangement because in staggered arrangement of pin-fins increases turbulence around the pins, which increases the cooling rate significantly.

5.2.2 GEOMETRY OF FINS (CROSS SECTION OF THE FINS)

There are various geometries of the fins such as circular, Elliptical, square, NACA, Dropform, Lancet etc.

The heat transfer performance is better in circular array in inline arrangement but there is large pressure drop & in staggered arrangement elliptical fin has better performance.

The elliptical fin has heat transfer rate 20% more than circular pin fins but it has reduction in pressure 100%. The pressure drop is maximum in circular in inline arrangement while square in staggered arrangement.

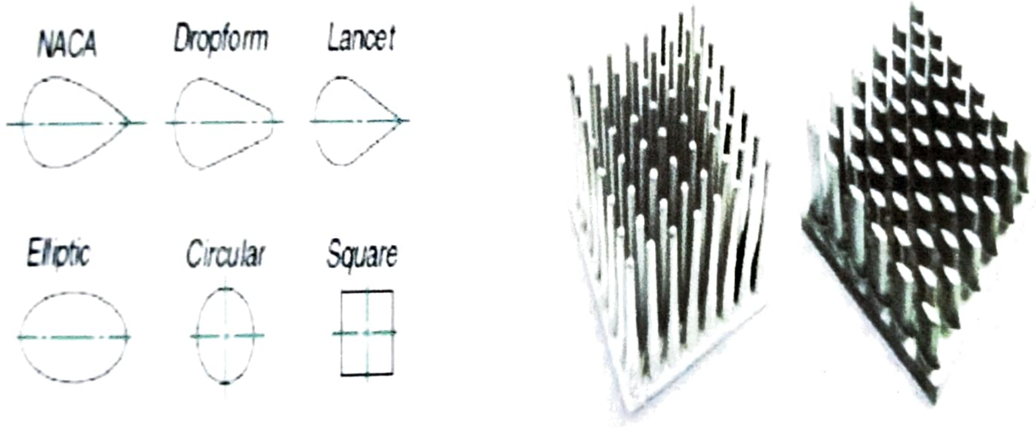


Fig 5.2 Shape of PIN FINS

5.2.3 GEOMETRIC PARAMETERS (Diameter, Length, Aspect ratio, Void fraction)

The change in diameter does not large effect on heat transfer performance change in diameter by 25 % has only 6% change in thermal performance but change in length has significant effect on the heat transfer performance.

Aspect ratio- it's ratio of the height of the fin to the length of the fin. Longer fins i.e. Aspect ratio more than 4 has better heat transfer performance. Fins that are too short cannot be modeled with an adiabatic tip which may lead to poor performance and overheating of the sink surface. Fins that are too long will have Compromised fin efficiency since fin efficiency is a strong function of fin height. Therefore, the variation in aspect ratio was done by varying the height of the pin fin with fin efficiency close to 90%.Generally as void fraction & hydraulic diameter increases heat transfer performance increases.

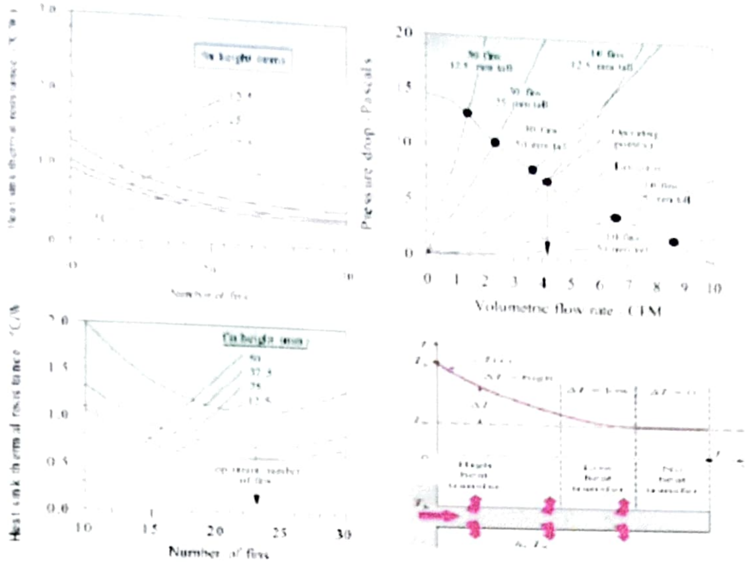


Fig 5.3 Effects of the geometrical parameters on the pin fin.

5.2.4 PITCH BETWEEN ADJACENT FINS (Transverse & Longitudinal)

Generally heat transfer increase with decrease in stream wise pitch (XL) & Span wise pitch (XT). Streamwise spacing (XL) had a larger effect than spanwise spacing (XT) on array heat transfer. Span wise spacing (XT) had a larger effect than Stream wise spacing (XL) on array pressure drop. The heat transfer can be maximized & pressure drop can be minimized by reducing stream wise spacing (XL) & increasing span wise spacing (XT) between pin fins. The results of stream wise pitch (XL) & span wise pitch (XT) for pressure drop of array are controversial than heat transfer results.

The variations of axial pitch between structures do not have much effect on thermal resistance & pressure drop for square heat sink but for circular heatsink thermal resistance decreases & pressure drop increases as axial pitch decreases. For square & circular heat sink as transverse pitch decreases thermal resistance decreases & pressure drop increases.

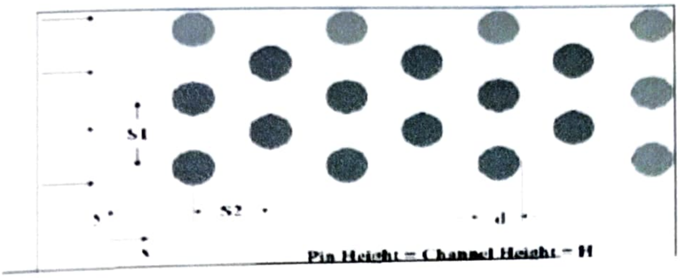


Fig 5.4 Effects of stream wise & span wise spacing

5.2.5 NUMBER OF PIN FINS

Generally increasing no of fins on array (fin density) increases heat performance reaches maximum & again decreases due to increase in conduction resistance over convection resistance so we have to choose optimum no of fins on pin fin array. So we have to select optimum no of fins so that thermal performance of fins will increase.

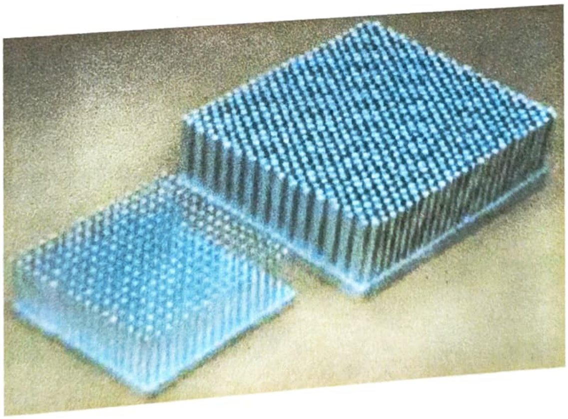
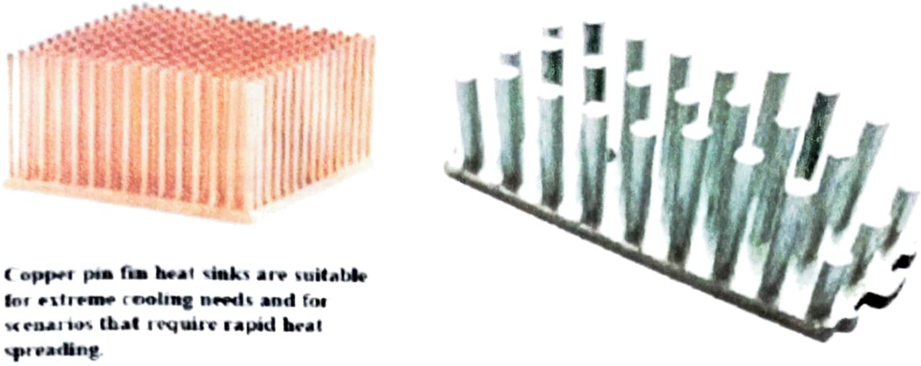


Fig 5.5 Effects of fin density on pin fin array

5.2.6 MATERIAL USED FOR PIN FIN

Generally material which are good conductor of heat are used for pin fin heat sink such as copper (k= 398 w/mk) but sometimes aluminum (k= 238 w/mk) is preferred due to it's low cost &weight. Thermal performance is better in case of copper but it has high cost compared with aluminum so copper is used when temp is reduced in large amount otherwise aluminum fins are used.



Copper pin fin heat sinks are suitable for extreme cooling needs and for scenarios that require rapid heat spreading.

Fig 5.6 Material used for pin fin (copper & aluminum).

5.2.7 SHROUD CLEARANCE (Bypass factor)

It's found that performance is maximum when the ratio of height of fin to the height of channel (h/H) is 0.5.

5.2.8 NATURE OF FLUID FLOW (Natural or Forced)

Generally force convection has better performance than natural convection. In natural convection the buoyancy effect forces hot air to flow to the top and cold air to come to the bottom. The typical velocity is 0.2 m/sec & in forced convection. Air is forced over the components with a fan or blower. The velocity of air depends on the fan and the local conditions.

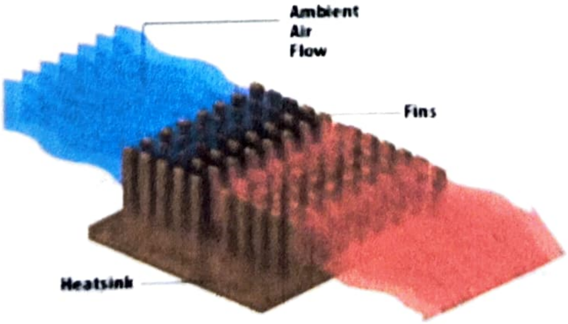


Fig 5.7 Nature of the fluid flow

5.2.9 LOCATION OF FAN /BLOWER IN CASE OF FORCED CONVECTION i.e. velocity of flowing fluid

Location of the fan from the fin array & velocity of fluid plays very important roll increase in velocity performance increases riches to the peak & further increases in velocity performance reduces .The location of fan affects the performance of heat sinks. The angles of intake and exit of flow of air decides which type of fan/blower is to be selected. Location of fan/blower is selected in such a way that flow of air will be free from obstructions or will have minimum obstructions. Design of electronic equipment is done with considering the effects of location of fan.

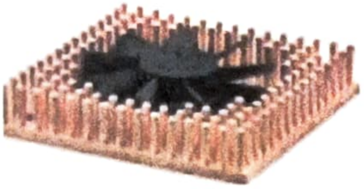


Fig 5.8 Location of the fan &velocity of fluid.

5.2.10 TYPE OF FLOWING FLUID

The type of the fluid used (e.g. air, gas etc.) effects the performance of the array. Generally air is used as fluid due to its available at free of cost but sometimes special heat absorbing gases are used to improve performance of heat sink.

5.2.11 SURFACE FINISH OF FINS

Surface finish of the fins also effects thermal performance of the pin fin. Generally smooth surface finish has less heat transfer performance. Because the friction between air & smooth fin is less as compared with friction between air & rough fins.

5.2.12 INCLINATION OF PIN FINS

Splayed pin fins has inclined fins inclination of the fins also affects the performance of the pin fin. Due to inclined fins flow of air disturb and air comes in contact with fin for more time so inclination of fins affects thermal performance of fin.

Fig 5.9 Splayed fins

5.3 TYPES OF FINS

A pin fin heat sink is a heat sink that has pins that extend from its base. There are four different types of fins. They are

1. Straight fin
2. Parabolic fin
3. Annular fin
4. Pin fin

5.3.1 STRAIGHT FIN

Fins are used in a large number of applications to increase the heat transfer from surfaces. Typically, the fin material has a high thermal conductivity. The fin is exposed to a flowing fluid, which cools or heats it, with the high thermal conductivity allowing increased heat being conducted from the wall through the fin. The design of cooling fins is encountered in many situations and we thus examine heat transfer in a fin as a way of defining some criteria for design.

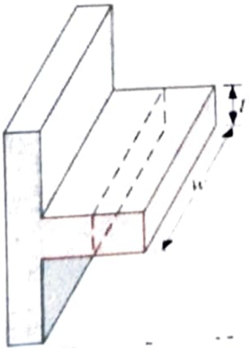


Fig 5.10 Rectangular fin of uniform cross-**section**

5.3.2 PARABOLIC FINS

It is obvious that the heat dissipated by every segment of a fin of uniform cross sectional area is not the same. In fact, the part of the fin away from the base or root is much less effective than cross-section at the base. The fin material near the tip is not properly utilized. A fin of parabolic profile is very effective in the sense that it dissipates the maximum amount of heat at minimum material cost.

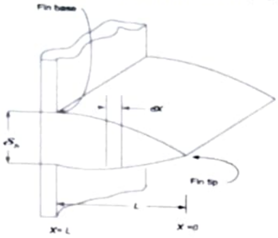


Fig 5.11 Parabolic fin

5.3.3 ANNULAR FIN

Annular fin is a specific type of fin used in heat transfer that varies, radially, in cross-sectional area. Adding an annular fin to an object increases the amount of surface area in contact with the surrounding fluid, which increases the convective heat transfer between the object and surrounding fluid. Because surface area increases as length from the object increases, an annular fin transfers more heat than a similar pin fin at any given length. Annular fins are often used to increase the heat exchange in liquid–gas heat exchanger systems.

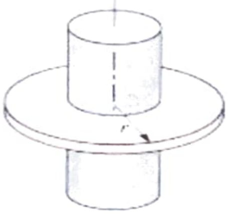


Fig 5.12 Annular fin

5.3.4 PIN FIN

A Pin Fin heat sink is a normal heat sink, but it differs from other heat sinks as it consists of pins that are extended from its base. These pins are in various shapes including elliptical, cylindrical and square shapes.

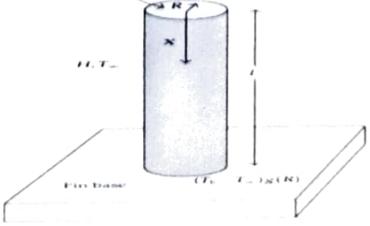


Fig 5.13 Cylindrical pin fin

CHAPTER 6
EXPERIMENTAL SETUP

CHAPTER 6
EXPERIMENTAL SETUP

6.1 Introduction

The main objective of our experimental investigation is to compare the performance of Pin Fins for cooling of electronics. In the present work Straight and Splayed pin fins are used and compared their performances. The surface temperature of the heated aluminium block is used to calculate the heat transfer.

The Experimental Setup consists of:

1. Pin Fin heat sink.
2. An aluminium heated block, to simulate heat generation of electronic component.
3. Fan for cooling the Fins.
4. K-type thermocouples.
5. Thermal Interface Material (TIM).
6. High density Cartridge heater.
7. Dimmerstart.
8. Voltmeter, Ammeter, Wattmeter.
9. Glass Wool.

6.2 PIN FIN HEAT SINK

A pin fin heat sink is a heat sink that has pins that extend from its base. The pins can be cylindrical, elliptical or square. A pin is one of the more common heat sink types available on the market. A second type of heat sink fin arrangement is the straight fin. These run the entire length of the heat sink. A variation on the straight fin heat sink is a cross cut heat sink. A straight fin heat sink is cut at regular intervals.

Another configuration is the flared fin heat sink; its fins are not parallel to each other, as shown in figure 6.1. Flaring the fins decreases flow resistance and makes more air go through the heat sink fin channel; otherwise, more air would bypass the fins. Slanting them keeps the overall dimensions the same, but offers longer fins. Forghan Et Al. have published data on tests conducted on pin fin, straight fin and flared fin heat sinks. They found that for low approach air velocity, typically around 1 m/s, the thermal performance is at least 20% better than straight fin heat sinks.

Fig 6.1 Straight pin, flared fin

6.3 HEAT SINK DESIGN

Primarily a copper and aluminium heat sink plate of 40*40*2 mm is cut properly. The pin fins are 2mm in diameter and number of pins arranged in a row are 4. The length of these pins are 30mm and number of fins attached to square heat sink are 16. The heat sinks are attached to the aluminium block such that the heat flows through the pins and air flow is made to pass over the pins and pins are cooled.

One K-type thermocouple is inserted to the block to note the base temperatures of the pin fin.

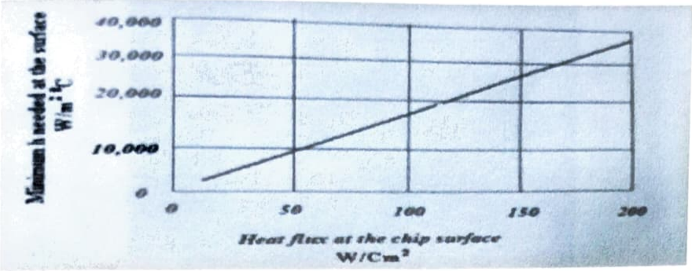


Fig 6.2 Variation of heat transfer coefficient

6.4 HEATED ALUMINIUM BLOCK

A solid aluminium block of overall dimensions 40*40*90 mm is used as heated block to simulate any electronic device. A hole was precisely machined in the heated aluminum block at the bottom surface to insert the high density catridge 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 40mm 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. Details of heated aluminium block are shown in Fig 6.3 & Fig 6.4

Fig 6.3 Bottom surface of the heated aluminium block

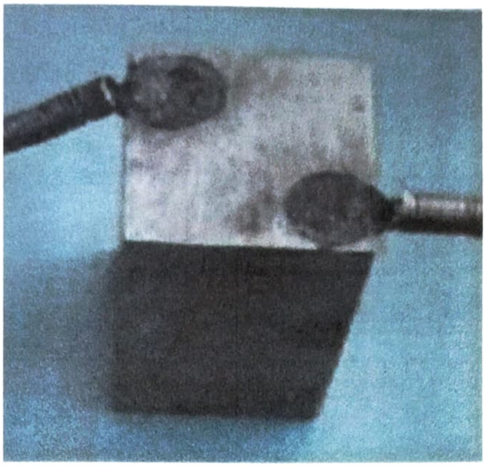


Fig 6.4 Heated aluminium block with thermocouples

6.5 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.

6.5.1 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 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 related 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 considerable between samples. One of the constituent metals, nickel, is magnetic; a characteristic of thermocouple 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 K type thermocouples).

K- type thermocouples and temperature indicator are shown in Fig. 6.5 & Fig 6.6

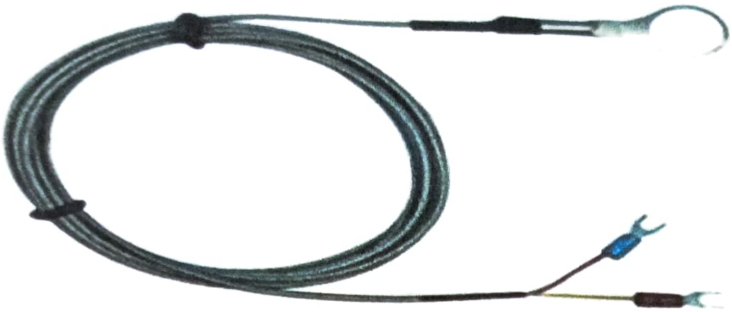


Fig 6.5 K-Type Thermocouple

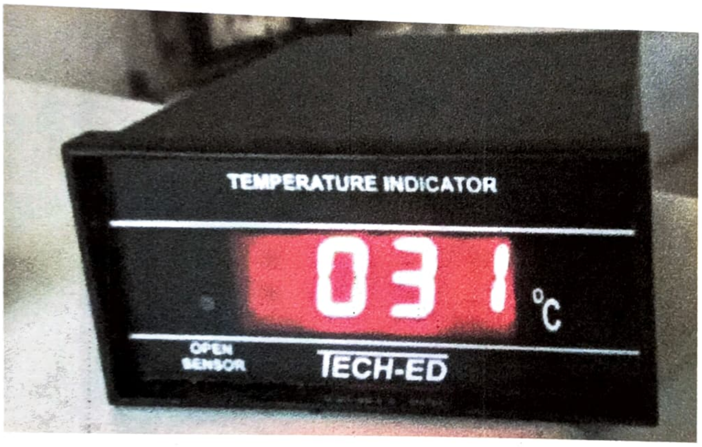


Fig 6.6 Temperature Indicator

6.6 THERMAL INTERFACE MATERIAL

A thermal interface material is used to fill the gaps between thermal interface 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 Fig. 6.7. The heated aluminium block and the heat sink after application of thermal interface material are shown in fig 6.8 and 6.9 respectively.

6.6.3 MECHANICAL PROPERTIES

- Thermal expansion
- Moisture diffusion
- 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 Elastomeric pads, Thermal adhesives, gels and solders, greases, phase changing materials.

6.7 HIGH DENSITY CARTRIDGE HEATER

A high density cartridge heater of 150W 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 10mm and 40mm respectively. A dimmerstat 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 Fig.6.10

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

$$(\text{Operated Voltage}/\text{Rated Voltage})^2 \times \text{Wattage at rated voltage} = \text{Derated Wattage}$$

The tightly compacted refractory insulation provides excellent heat transfer to the heavy wall stainless stell 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.

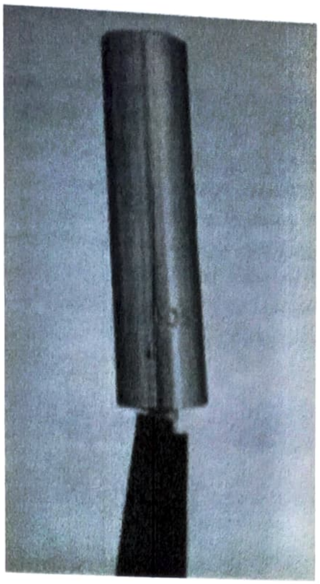


Fig 6.10 High Density Cartridge Heater

6.7.1 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 calculations would be as follows:

Watt Density = W / (πn x D x HL)

Where W=wattage

D= diameter

HL=heater length

6.8 EXPERIMENTAL SETUP

The general layout of experimental setup is shown in Fig 6.11. The major components are heated aluminium block, heat sink made with copper plate and copper tubes, high density cartridge heater and air cooled cross flow heat exchanger. An aluminium block of size 38x38x70mm 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 150W. Any air gap between the heater and hole would damage the heater, so heater is fitted into the hole carefully such that there is no air gap between the two.

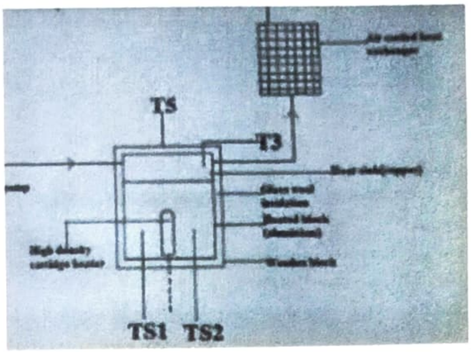


Fig 6.11 Line diagram of experimental setup

For heat sink copper and aluminium pins are brazed to the base plate of same material. The number of pins are 16. The length of each pin is 30 mm having a diameter of 2 mm. the overall dimensions of pin fin is 40*40*2 mm. The top surface of aluminium block and bottom surface of the pin fin heat sinks are polished to minimise the gaps. Heat sinks are 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 6.12. To improve the thermal conductance between the heat sink and heated aluminium block, thermal interface material (TIM) is applied.

Fig 6.12 Assembly of heat sink on aluminium block

Two 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 minimise 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*50 mm as shown in fig 6.13.

CONCLUSIONS

Experiments are carried out for straight and splayed pin fins for both aluminium and copper pin fin heat sinks at an average velocity of 7.07m/s. The major conclusions are:

1. The performance of pin fin heat sinks is greatly enhanced with application of thermal compounds.
2. The surface temperature of the heated aluminium block is 153^0C for aluminium pins with straight geometry and heat transfer rate is 97.82 W.
3. The surface temperature of the heated aluminium block is 132^0C heat for aluminium splayed pin fins and heat transfer rate is 106.2 W.
4. The surface temperature of the heated aluminium block is 139^0C heat for Copper straight pin fins and heat transfer rate is 105.8 W.
5. The surface temperature of the heated aluminium block is 119^0C heat for Copper Splayed pin fins and heat transfer rate is 115.7 W.
6. The percentage of heat removal from aluminium straight and splayed pin fins is 81.52 and 88.5% respectively.
7. The percentage of heat removal from copper straight and splayed pin fins is 88.16 and 96% respectively.
8. From the above experiment, the copper pin fins have better heat dissipation rate compared to aluminium pin fins.
9. Splayed fin arrangement is better than Straight fin arrangement for better dissipation.

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