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# Design and Analysis of Heat Sink and Heat Pipe Use for Mother Board

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## Abstract

***The heat pipe is widely used because of its amazing heat transfer rate. Since last decade heat pipes became more popular because of its wide applications in cooling systems. Earlier heat pipes were mostly used for temperature equalization in spacecrafts and satellites. Nowadays, we commonly find heat pipes in notebook computers, game consoles, and even integrated into normal PC CPU coolers. One reason for the rise in popularity is the fact that prices have dropped dramatically, since high-volume cooling product manufacturers like Asia Vital Components now have their own heat pipe manufacturing facilities, and heat pipe manufacturing is no longer reserved to a few specialized companies. The project aims at thermal analysis of a heat-pipe and heat sink of Computer Processing Unit (CPU) which is particularly useful in energy-conservation equipment where it is desired to recover heat from hot gases for air-pre heater or supplemental heating applications. In some cases the heat-pipe can take the place of more costly combinations of pumps, piping and dual heat-exchange configurations, further in this regard, design and theory is vital. Design of different heat pipes, heat sinks and heat transmitting systems are important based on the geometry and profile. It has to be designed optionally. In this CATIA V5 software is used for designing various heat-pipes and heat sink systems which are used in heavy machinery. Secondly, thermal analysis is made by using ANSYS 14.0 software which calculates the temperature distribution and related thermal quantities in a system or component. Typical thermal quantities of interest are the temperature distributions; the amount of heat lost or gained thermal gradients, thermal fluxes.***

*Keywords:* ***heat pipe, temperature, cooling rate, heat transfer.***

## 1.1 Introduction

Prior to the advent of the microprocessor, a computer was usually built in a card-cage case or mainframe with components connected by a backplane consisting of a set of slots themselves connected with wires; in very old designs the wires were discrete connections between card connector pins, but printed-circuit boards soon became the standard practice. The central processing unit, memory and peripherals were housed on individual printed circuit boards which plugged into the backplane.

During the late 1980s and 1990s, it became economical to move an increasing number of peripheral functions onto the motherboard .In the late 1980s, motherboards began to include single ICs (called Super I/O chips) capable of supporting a set of low-speed peripherals: keyboard, mouse, floppy disk drive, serial ports, and parallel ports. As of the late 1990s, many personal computer motherboards support a full range of audio, video, storage, and networking functions without the need for any expansion cards at all; higher-end systems for 3D gaming and computer graphics typically retain only the graphics card as a separate component.

The early pioneers of motherboard manufacturing were Micronics, Mylex, AMI, DTK, Hauppauge, Orchid Technology, Elite group, DFI and a number of Taiwan-based manufacturers. Popular personal computers such as the Apple II and IBM PC had published schematic diagrams and other documentation which permitted rapid reverse-engineering and third-party replacement motherboards. Usually intended for building new computers compatible with the exemplars, many motherboards offered additional performance or other features and were used to upgrade the manufacturer's original equipment.

### 1.2. Introduction to Heat Pipe

S. Gurgler of the general motors' corporation, USA, first put the heat pipe concept forward on dated December 21st, 1942. The heat pipe is described as applied to a refrigeration system. One form of refrigeration unit suggested by Gaugler is shown in figure no.1.1.

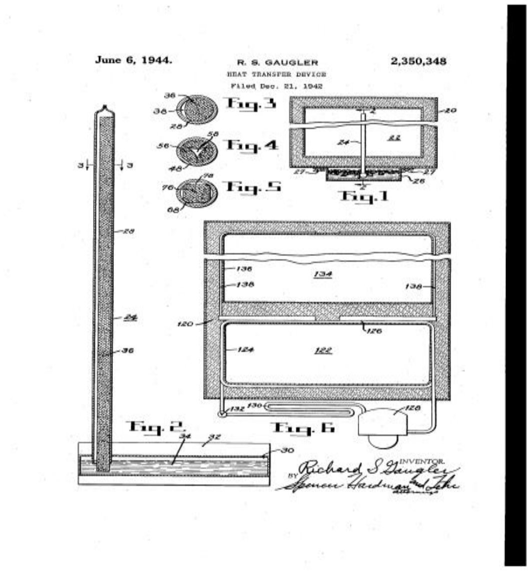

Fig.1.1 Refrigeration unit suggested by GAUGLER

The heat pipe is employed to transfer heat from the interior compartment of refrigerator to a pan below the compartment containing crushed ice. In order to improve heat transfer from the heat pipe into the ice, a tabular vapor chamber with external fins is provided, into which the heat pipe is fitted. This also acts as a reservoir for the heat pipe working fluid.

As proposed by Gaugler the heat pipe was not developed beyond this stage. In 1963, the Atomic Energy Commission and Natural Aeronautics and Space Administration by G.M.Grover revived the idea again. Grover however includes a limited theoretical analysis and presents results of experiments carried out on stainless steel heat pipe incorporating a wire mesh wick and sodium as the working fluid.

Most of their early support came from US Government contracts; during the two year period mid-1964 to mid 1966 they made heat pipes using glass, copper, nickel, stainless steel, molybdenum. Working fluids included water, cesium, sodium, lithium, and bismuth. Maximum operating temperature of 1650degree centigrade had been achieved.

Deverall and Kemme developed a heat pipe for satellite use incorporating water as the working fluid, and the first proposals for a variable conductance heat pipe were made again for a satellite. In 1969, NASA developed a new type of heat pipe, in which the wick is omitted. The application of heat pipes to electronics cooling in areas other than satellites was beginning to receive attention. By 1970 a wide variety of heat pipes were commercially available from a number of companies in United States.

### 1.3. Theory of Heat Pipe

### 1.3.1 Definition

The term 'heat pipe' as the name implies, is a simple device having high thermal conductivity to transfer heat very quickly from heat source to heat sink by means of evaporation and condensation of a fluid in a sealed system. Basically heat pipe can be considered as a super thermal conductor that transmits heat by the evaporation and condensation of a working fluid.

What is more amazing is that heat pipe has,

- no moving parts
- requires no external energy(other than the heat it transmits)
- it is reversible in operation

- completely silent

### 1.3.2 Working of Heat Pipe

The heat pipe operating principle is that a liquid is heated to its boiling point, vaporizes and gives of useful heat, condenses and returns to the heat source. The heat pipe is a closed and operates in vacuum. The boiling point of a liquid is a function of the pressure surrounding it .Because of the strong vacuum (about $10^{-3}$ microns of Hg), the working fluid is virtually in a state of liquid – vapor equilibrium. Consequently, a slight increase in temperature will cause it to boil and vaporize.

Inside the container is a liquid under its own pressure, which enters the pores of the capillary material wetting all internal surfaces. Applying heat at any point along the surface of the heat pipe causes the liquid at that point to boil and enter a vapor state. When that happens, the liquid picks up the latent heat of vaporization. The gas which then has a higher pressure, moves inside the sealed container to a colder location where it condenses. Thus, the gas gives up the latent heat of vaporization and moves heat from the input to the output end of the heat pipe.

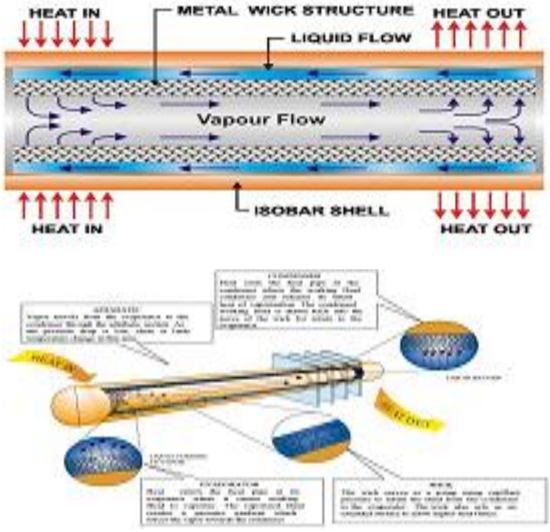

Fig.1.2. Heat Pipe Operation

The performance of heat pipe is affected by gravity. Optimum performance is achieved when the pipe is vertical with the condenser section directly above the evaporator. In this position gravity aids the pumping action in the wick. However, heat pipes can operate in any position and are bi-directional. If a heat pipe doesn’t take advantage of the gravitational forces, a high power rating is required. The heat pipe operation is as shown in figure no. 1.2.

### 1.4 Basic Components of Heat Pipe

The three basic components of heat pipe are as follows:

1. A hollow container.
2. A capillary wick structure.
3. A working fluid.

### 1.4.1 Container

It is generally a metal tube made of stainless steel, copper, aluminum or ceramic materials. The function of the container is to isolate the working fluid from the outside environment. It has to therefore be leak proof, maintain the pressure differential across its walls, and enable transfer of heat to take place from and into the working fluid. The physical sizes of heat pipes that have been operated successfully range from 6mm to 150mm in diameter and up to 5m long.

Selection of the container material depends on the following factors:

- Compatibility (both with working fluid and external environment)
- Strength to weight ratio
- Thermal conductivity
- Ease of fabrication, including welding, machinability and ductility.
- Porosity
- Wettability

### 1.4.2 A Capillary Wick Structure

The main purpose of the wick structure is to generate capillary pressure to transport the working fluid from the condenser to the evaporator section. These functions require wicks of different form, particularly, if the liquid is to be returned over a larger distance. As seen in figures 1.3, wick structures are placed against the inner wall of the heat pipes. They serve as both liquid and heat transporters and can be wire-mash or sintered powder type.

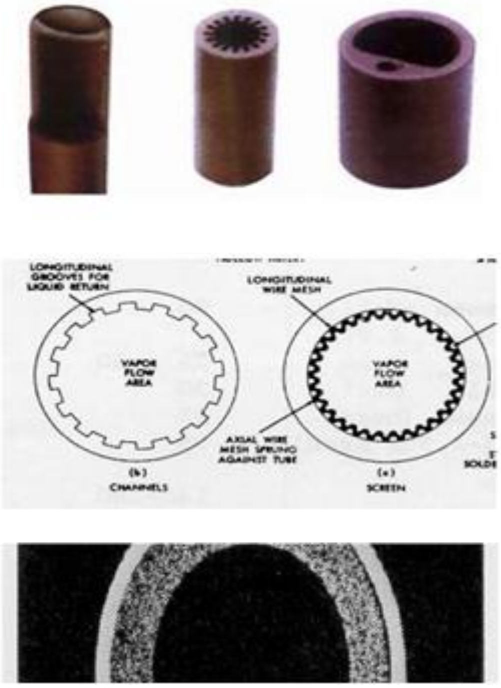

Fig. 1.3. Different types of wick structure

### 1.4.3 Working Fluid

A first consideration in the identification of a suitable working fluid is the operating vapor temperature range. Within the approximate temperature band, several possible working fluids may exist, and a variety of characteristics must be examined in order to determine the most acceptable of these fluids for the application considered.

The prime requirements are:

- Compatibility with wick and wall materials
- Good thermal stability
- Wettability of wick and wall materials
- Vapor pressure not too high or low over the operating temperature range
- High latent heat
- High thermal conductivity
- Low liquid and vapor viscosities
- High surface tension
- Acceptable freezing or pour point

| Fluids | Temperature Range °c | | |
|---|---|---|---|
| Helium | -271 | ---- | -269 |
| Nitrogen | -203 | ---- | -160 |
| Ammonia | -78 | ---- | 100 |
| Acetone | 0 | ---- | 120 |
| Methanol | 10 | ---- | 130 |
| Water | 30 | ---- | 200 |
| Mercury | 250 | ---- | 650 |
| Sodium | 600 | ---- | 1200 |
| Silver | 1800 | ---- | 2300 |

Table 1.1 shows the range of working temperature for some working fluids

The selection of the working fluid must also be based on thermodynamic considerations which are concerned with the various limitations to heat flow occurring within the heat pipe like, viscous, sonic, capillary, entrainment and nucleate boiling levels. In heat pipe design, a high value of surface tension is desirable in order to enable the heat pipe to operate against gravity and to generate a high capillary driving force. In addition to high surface tension, it is necessary for the working fluid to wet the wick and the container material i.e. contact angle should be zero or very small. The vapor pressure over the operating temperature range must be sufficiently great to avoid high vapor velocities, which tend to setup large temperature gradient and cause flow instabilities. A high latent heat of vaporization is desirable in order to transfer large amounts of heat with minimum fluid flow, and hence to maintain low pressure drops within the heat pipe. The thermal conductivity of the working fluid should preferably be high in order to minimize the radial temperature gradient and to reduce the possibility of nucleate boiling at the wick or wall surface. The resistance to fluid flow will be minimized by choosing fluids with low values of vapor and liquid viscosities.

### 1.5. Applications of Heat Pipe

#### a) Application in electrical and electronics systems

Heat pipe can reduce size of most magnetic components by 30% and more. Transformers are big in size because they need a lot of surface area to dissipate the heat generated. Heat pipes can be inserted into transformer core to dissipate more heat and reduce transformer size substantially. They can be used to remove heat from high voltage TV circuits, motor stator and armatures. When the components of electronic equipment are at high voltage potential, it becomes necessary to use an electrically insulating heat pipe and for this, container, wick and working fluid must be non-conducting. Fig4.1. Shows one form of such unit and the material used are glass for container, ceramic fiber for wick and FLUTEC as working fluid.

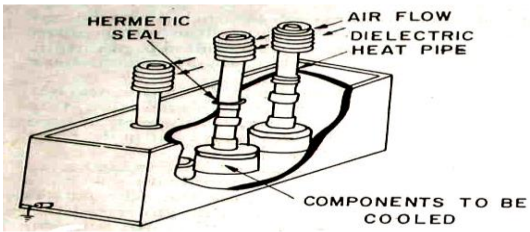

Fig: 1.9. Cooling Of High Voltage Components Using Electrically Insulated Heat Pipes

### Necessity of heat pipes in electronics coolin

The days where heat pipes were mostly used for temperature equalization in spacecrafts and satellites are over. Nowadays, we commonly find heat pipes in notebook computers, game consoles, and even integrated into normal PC CPU coolers. All electronic components from microprocessors to high-end power converters (electric motors, generators, transformers, transistors, capacitors, CPU, laptops etc.,) generate heat and rejection of this heat is necessary for their optimum and reliable operation. As electronic design allows higher through put in smaller packages, dissipating the heat load becomes a critical design factor. The heat pipe is meeting this need and is rapidly becoming a mainstream thermal management tool.

One reason for the rise in popularity is the fact that prices have dropped dramatically, since high-volume cooling product manufacturers like Asia Vital Components now have their own heat pipe manufacturing facilities, and heat pipe manufacturing is no longer reserved to a few specialized companies.

Another reason is that as a thumb rule, heat pipe can reduce the size of most magnetic components by 30%. Transformers are large in size because they need a lot of surface area to dissipate the generated. Heat pipes can be inserted in the transformer core to dissipate that heat and reduce transformer size substantially.

When it comes to PC cooling, "heat pipe" has become a buzzword; but still, few people understand how heat pipes work, and what factors must be considered when using a heat pipe-based cooling system.

### b) Applications to air conditioning systems

Exhaust air leaving room can be used to preheat or pre cool incoming air by heat pipe as shown in below fig . Air conditioning systems require fresh make up air. In winter outside makeup air entreat –18°C and heated to 22°C.Heat pipes installed in the exhaust air duct could preheat the incoming air to about 12°C.Then instead of air

Through 40°C, the furnace would only have heat by 10°C.In summer; the heat pipes would transfer heat from incoming hot make up air to cool exhaust air. Pre cooling air obviously reduces load on the system and cost of operation.

### c) Applications for IC engines and Gas turbines

Heat pipes can be used to vaporize gasoline by exhaust gases before it enters the engine via carburetor. The Vaporized fuel makes a homogenous mixture of fuel and air and improves combustion. In a gas turbine, the exhaust is used to preheat compressed air by heat pipes before it enters combustion chamber.

### d) Applications for production process (or) manufacturing systems

The use of heat pipe in production process helps to improve quality and increase life of machinery. In the text rising of manmade fibers are drawn across a hot surface. The quality of the fibers depends on the temperature uniformly. In extrusion of plastic materials the temperature gradient is leveled by the use of heat pipe. Heat pipes are also used for manufacture of glass bottles

### e) Use of heat pipe as a temperature control device

A modified heat pipe used for controlling the temperature is shown in below fig reservoir containing non-condensate gas is connected to the condenser side shown.

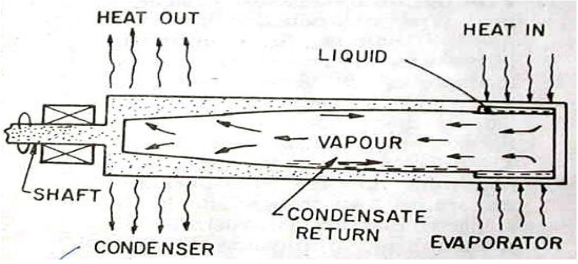

Fig: 1.10 Heat Pipe Used To Control Temperature.

This gas forms an interface with the vapor and chock off part of the condensation to the Wick. With an increased addition of heat to evaporator with an increased addition of heat. To evaporator, more vapor is generated with an increase in vapor pressure and non condensable gas is forced back into the reservoir. Thereby opening an additional area of condenser to remove the additional heat. The reverse operation takes place for reduction in heat added to evaporator.

### f) Spacecraft temperature equalization

Temperature equalization in space craft where by thermal gradients in the structure can be minimized to reduce effects of external heating, such as solar radiation and internal heat generation by electronic components or nuclear power supplies has been discussed by savage in a paper reviewing seven potential applications of the basic heat pipe. The use of a heat pipe connecting two vapor chambers on opposite faces of a satellite is analyzed with proposals for reducing temperature between a solar cell array facing the sun and the cold satellite face. If the solar cell array was two sided savage proposed to mount the cells on a vapor chamber using one side for radiation cooling, in addition to connecting the cell vapor chamber to extra radiators via heat pipes.

### g) Component cooling, temperature control and radiator design

The widest applications of variable conductance heat pipes and a major use of basic heat pipe units in the removal of heat from the electronic components and other heat generating devices on satellites. The variable conductance heat pipe offers temperature control within narrow limits, in addition to the simple heat transport function performed by basic heat pipes.

### h) Heat recoveries and space heating

With rising energy costs, the economics of waste heat recovery are being studied in industrial, commercial and domestic situations where the price of fuel for heating is becoming prohibitive or where waste heat currently rejected to the atmosphere, rivers etc, could be more usefully employed.

There are several ways in which waste heat can be reclaimed for space heating, recycling etc, including heat pumps, thermal wheels and generators. However the heat pipe is also receiving attention in this area and at least two manufacturers in United States market heat recovery units utilizing heat pipes and in addition units are being developed to heavy water and air from domestic use, replacing conventional boiler systems.

### i) Heat pipe used extracting solar energy

Heat pipe can also captured heat from the hot sun. The arrangement is shown in below figure. In this arrangement; the solar radiation is focused on the surface of the pipe by a parabolic reflector. About 0.8kw/m$^2$ of projected area of reflector are available and at an operating temperature of 300°C. Heat pipes leading from the reflectors could be coupled to steam raising boilers, which could be ganged-up to feed a turbine. Alternatively; the end of a heat pipe may be used directly as a cooking plate. This solar kitchen may find extensive use in countries where fuel is scare but sunshine is plentiful.

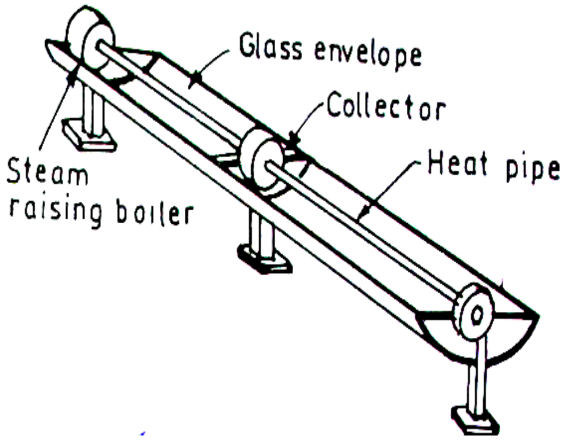

Fig: 1.11 Solar energy collector using heat pipe

A recent use of heat pipe in kitchen is a cooking pin. This is simply a heat pipe which, when inserted into a joint of meat cooking in an oven, speeds up the rate of heat flow into the meat thus saving time and fuel and yielding a more uniform roast. The finned end transfers heat from oven to cook meat. If the pin is inserted only halfway into the roast, one half will be welded and the other half rare.

### j) Thermo ionic power generation

The thermo ionic generation method has received a considerable amount of attention as a possible way of converting nuclear fission heat directly to electricity. It has particularly advantages in the latter arrangement but the extraction of the nuclear generated at a temperature of around 1600°C present a serious problem which it has been suggested might be solved by the use of heat pipes. Electronics are emitted from the emitter and cross the inter electrode space to be collected at the colder collector surface, the electrons return to the emitter through the external electrical load resistance. The device is a heat engine, which converts some of the energy and rejects the remainder at a lower temperature at the collector.

### k) Space technology

The use of heat pipes had been mainly limited to this field of science until recently due to cost effective and complex wick construction of heat pipes. There are several applications of heat pipes in this field.

- Space craft temperature equalization
- Component cooling, temperature control and radiator design in satellites
- Other applications include moderator cooling, removal of heat from the reactor at emitter temperature and elimination of troublesome thermal gradients along the emitter and collector in spacecrafts.

### l) Laptop heat pipe solution

Heat pipe technology original used for space applications has been applied it to laptop computer cooling. It is an ideal, cost effective solution. It is of light weight (generally less than 40 Gms), small compact, profile and its passive operation; allow it to meet the demand requirements of laptop.

One end of the heat pipes is attached to the processor with a pin, clip- on mounting plate. The other is attached to the heat sink, in this case, a specially designed keyboard RF shield. This approach uses existing parts to minimize weight and complexity. Then heat pipes also are attached to other physical components suitable as a heat sink to dissipate heat.

### m) Residential buildings

There are about 50 million existing homes in this country. Heating, air conditioning and hot water supply of these homes use about 15% of total annual energy consumption every year in the United States used about $2.1\times10^{11}$ J per heating season. Hence, there is great incentive for home energy conservation several devices using heat pipes have been developed, example heat recovery from finance flue gas, waste hot water and fireplace. It will be seen below that heat pipes are well suited for these applications.

Temperature of the flue gases at domestic furnace for space heating is about $533^0$K, which is about 12% of the energy available from the fuel. In order to reclaim this based heat a device using a heat pipe has been developed. A heat pipe heater that attached to the flue pipe above the furnace water-copper heat pipe would be suitable for this application. The device reclaims heat from the flue gases. This heat can then be used to heat part or all of the recreation room, workshop, laundry room or a duct can be attached to the unit to carry the heat to otherwise chilly spaces inside the houses.

The principle can be used to be reclaiming the waste heat from flue gas in fireplace flue gas. Current fireplaces are built for decoration rather than heating effectiveness although an investment in a fireplace is known to homebuyers to be sizable along the heat pipe.

### 1.6. Advantages of Heat Pipes

1. Large quantity of heat can be moved with a small drop in temperature as the heat is carried away by evaporation and dissipated in the form of latent heat by condensation.
2. Heat pipes are capable of transporting heat over appreciable distances, thus permitting separation of heat source and heat sink. The price paid for this separation in terms of temperature loss is also minimal, usually only a few degrees. Heat source like flame and heat sink line air can be separated without difficulty.
3. It has high APR capacity, a few hundred times more than any other known transferring equipment.
4. The outstanding feature of heat pipe is the ability of the heat pipe to accept heat non uniformly.
5. The heat pipe is relatively light in weight, since the volume consists essentially of vapor.
6. It is mechanically simple and has no moving parts.
7. It requires no power source to accomplish its function.
8. The absence of gravity does not affect the operation of the heat pipe detrimentally. Liquid flow does not depend on gravity
9. It is an ideal device for removing heat from a concentrated heat source or from a low temperature heat source. This feature is very much useful for space applications.
10. The heat pipe transmits heat from heat source to the heat sink essentially isothermally.
11. The weight of the heat pipe is considerably small compared with any other heat transfer equipment.

### 1.7. Limitations of Heat Pipe

1. Heat pipes must be tuned to particular cooling conditions.
2. The choice of pipe material, size and coolant all have an effect on the optimal temperatures in which heat pipes work.
3. When heated above a certain temperature, all of the working fluid in the heat pipe will vaporize and the condensation process will cease to occur; in such conditions, the heat pipe's thermal conductivity is effectively reduced to the heat conduction properties of its solid metal casing alone.
4. In addition, below a certain temperature, the working fluid will not undergo phase change, and the thermal conductivity will be reduced to that of the solid metal casing.
5. Most manufacturers cannot make a traditional heat pipe smaller than 3mm in diameter due to material limitations (though 1.6mm thin sheets can be fabricated). Experiments have been conducted with micro heat pipes, which use piping with sharp edges, such as triangular or rhombus-like tubing. In these cases, the sharp edges transfer the fluid through capillary action, and no wick is necessary.
6. Undesired increase in the point to point temperature differential along the heat pipe can lead to damage to the evaporator section.
7. The heat pipe is normally rated in terms of the thermal power that can be transferred at the given temperature. If this is exceeded, an increase in the temperature difference along the heat pipe is exhibited. Its further effect occurs quite abruptly as the pumping capacity of the wick is exceeded which causes starvation of fluid flow in the extreme end of the evaporator and its temperature rises rapidly.
8. A heat pipe is also rated as the heat flux transported per unit area of evaporator surface and it should not exceed safe level. If the input density is

above critical at any point in the input area, thermal run away of the fluid can occur at that spot

9. The cost of a given size heat pipe will tend to reach a minimum in the $70^0$ C to $120^0$ C temperature range. Above and below this range, material cost and probable production volumes dictate an increasing cost. For small capacity heat pipes, the cost varies from Rs.10/- to Rs.100/- per unit of power transported.

## 2.1 Data Collection

### 2.1.1 Motherboard

A motherboard is the central or primary circuit board making up a complex electronic system, such as a modern computer. It is also known as a main board, baseboard, system board, planar board or, on Apple computers, a logic board, and is sometimes abbreviated as mobo.

Most motherboards produced today are designed for so-called IBM-compatible computers, which held over 96% of the global personal computer market in 2005. Motherboards for IBM-compatible computers are specifically covered in the PC motherboard article.

Fig.2.1 the ASUS CUSL2-C motherboard

A motherboard, like a backplane, provides the electrical connections by which the other components of the system communicate, but unlike a backplane also contains the central processing unit and other subsystems such as real time clock, and some peripheral interfaces. A typical desktop computer is built with the microprocessor, main memory, and other essential components on the motherboard. Other components such as external storage, controllers for video display and sound, and peripheral devices are typically attached to the motherboard via edge connectors and cables, although in modern computers it is increasingly common to integrate these "peripherals" into the motherboard.

### 2.1.2 Heat Sink

A heat sink is an environment or object that absorbs and dissipates heat from another object using thermal contact (either direct or radiant). Heat sinks are used in a wide range of applications wherever efficient heat dissipation is required; major examples include refrigeration, heat engines and cooling electronic devices.

Heat sinks function by efficiently transferring thermal energy ("heat") from an object at high temperature to a second object at a lower temperature with a much greater heat capacity. This rapid transfer of thermal energy quickly brings the first object into thermal equilibrium with the second, lowering the temperature of the first object, fulfilling the heat sink's role as a cooling device. Efficient function of a heat sink relies on rapid transfer of thermal energy from the first object to the heat sink, and the heat sink to the second object.

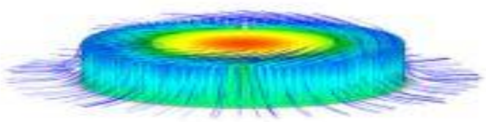

Fig2.2. Radial Heat Sink with Thermal Profile and Swirling Forced Convection Flow Trajectories

The most common design of a heat sink is a metal device with many fins. The high thermal conductivity of the metal combined with its large surface area result in the rapid transfer of thermal energy to the surrounding, cooler, air. This cools the heat sink and whatever it is in direct thermal contact with. Use of fluids (for example coolants in refrigeration) and thermal interface material (in cooling electronic devices) ensures good transfer of thermal energy to the heat sink. Similarly a fan may improve the transfer of thermal energy from the heat sink to the air.

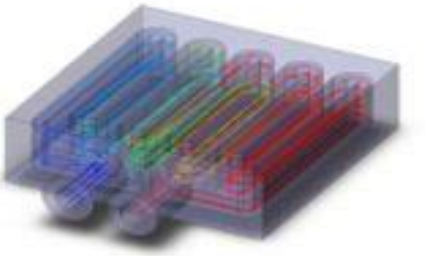

Fig.2.3 Liquid Cooled Heat Sink with Forced Convection Flow Trajectories

### 2.1.3 Performance

Heat sink performance (including free convection, forced convection, liquid cooled, and any combination thereof) is a function of material, geometry, and overall surface heat transfer coefficient. Generally, forced convection heat sink thermal performance is improved by increasing the thermal conductivity of the heat sink materials, increasing the surface area (usually by adding extended surfaces, such as fins or foam metal) and by increasing the overall area heat transfer coefficient (usually by increase fluid velocity, such as adding fans, pumps, etc.).

Online heat sink calculators from companies such as Novel Concepts, Inc., can accurately estimate forced convection heat sink performance. For more complex heat sink geometries, and/or heat sinks with multiple materials, and/or heat sinks with multiple fluids, computation fluid dynamics (CFD) analysis is recommended (see graphics on this page).

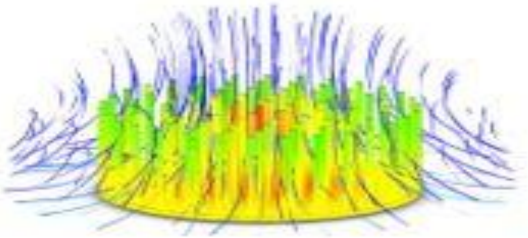

Fig2.4 Pin Fin Heat Sink with Thermal Profile and Dionne Convection Flow Trajectories

### 2.1.4 Use in Electronics

In common use, it is a metal object brought into contact with an electronic component's hot surface — though in most cases, a thin thermal interface material mediates between the two surfaces. Microprocessors and power handling semiconductors are examples of electronics that need a heat sink to reduce their temperature through increased thermal mass and heat dissipation (primarily by conduction and convection and to a lesser extent by radiation). Heat sinks are widely used in electronics, and have become almost essential to modern integrated circuits like microprocessors, DSPs, GPUs, and more.

### Construction and materials:

A heat sink usually consists of a base with one or more flat surfaces and an array of comb or fin-like protrusions to increase the heat sink's surface area contacting the air, and thus increasing the heat dissipation rate. While a heat sink is a static object, a fan often aids a heat sink by providing increased airflow over the heat sink — thus maintaining a larger temperature gradient by replacing the warmed air more quickly than passive convection achieves alone — this is known as a forced air system.

Heat sinks are made from a good thermal conductor such as copper or aluminum alloy. Copper (401 W/(m·K) at 300 K) is significantly more expensive than aluminum (237 W/(m·K) at 300 K) but is also roughly twice as efficient as a thermal conductor.

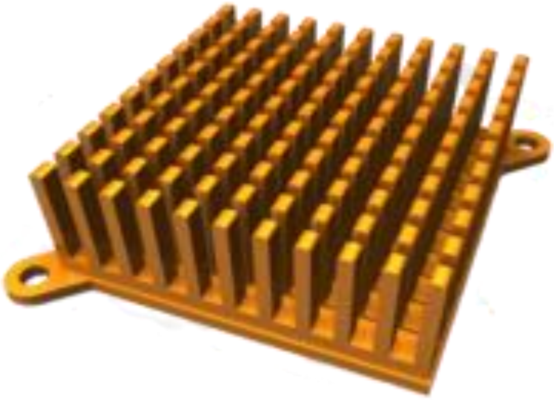

Fig.2.5 A motherboard heat sink

Aluminum has the significant advantage that it can be easily formed by extrusion, thus making complex cross-sections possible. The heat sink's contact surface (the base) must be flat and smooth to ensure the best thermal contact with the object needing cooling. Frequently a thermal conductive grease is used to ensure optimal thermal contact; such compounds often contain colloidal silver. Further, a clamping mechanism, screws, or thermal adhesive hold the heat sink tightly onto the component, but specifically without pressure that would crush the component.

Due to recent technological developments and public interest, the retail heat sink market has reached an all time high. In the early 2000s, CPUs were produced that emitted more heat than ever before, escalating requirements for quality cooling systems.

Over clocking has always meant greater cooling needs, and the inherently hotter chips meant more concerns for the enthusiast. Efficient heat sinks are vital to over clocked computer systems because the higher a microprocessor's cooling rate, the faster the computer can operate without instability; generally, faster operation leads to higher performance.

### 2.1.5 In Soldering

Temporary heat sinks were sometimes used while soldering circuit boards, preventing excessive heat from damaging sensitive nearby electronics. In the simplest case, this means partially gripping a component using a heavy metal crocodile clip or similar clamp.

Modern semiconductor devices, which are designed to be assembled by reflow soldering, can usually tolerate soldering temperatures without damage. On the other hand, electrical components such as magnetic reed switches can malfunction if exposed to higher powered soldering irons, so this practice is still very much in use.

### 2.2 Data Considered For the Analysis of Heat Sink

| |
|---|
| The fins are made up of Aluminum. |
| Thermal conductivity of the aluminum is 160W/mK |
| Specific Heat of Aluminum is 963J/KgK. |
| Density of the Aluminum is 2770Kg/$m^{3.}$ |
| The film Co-efficient is 20W/$m^2$K |
| Heat sink is assumed to be a thermal mass solid of Brick 8Node 70 |
| Heat lost from the base is 5.44W |
| Heat flux is 1133.33W/$m^2$ |
| The base of the heat sink is rectangular in section and base dimensions are 60mm x 80mm x 35mm. |

### 2.3 Data Considered For the Analysis of Heat Pipe

| |
|---|
| The fins are made up of Copper. |
| Thermal conductivity of the copper is 393W/mK |
| Specific Heat of copper is 385.2J/KgK. |
| Density of the copper is 8900Kg/$m^{3.}$ |
| The inside film Co-efficient is 5000W/$m^2$K |
| the outside film co-efficient is 10 W/$m^2$K |
| Heat pipe is assumed to be a thermal mass solid of Brick 8Node 70 |
| Heat lost from the base is 5.44W |
| Heat flux is 1133.3W/$m^2$ |
| The base of the heat pipe is circular and dimensions are $\Phi$ 75mm x105mm long |

### 3.0 Thermal Design of Heat Pipe

Different sections of heat pipe are shown in the following fig .3.1

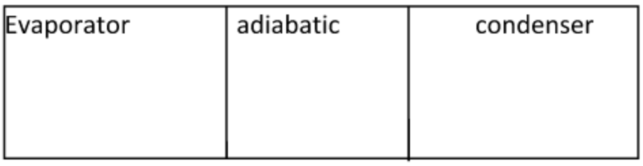

Fig: 3.1 sections of heat pipe

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For this experimental set up we required heat pipe which operated temperature range 40°C to 100°C and transmitted 100w power. For that we design heat pipe.

### Design of Heat Pipe

| | |
|---|---|
| Height of the pipe | 105 mm |
| External diameter of the vertical pipe | 19 mm |
| Internal diameter of the vertical pipe | 17 mm |
| Thickness of the base plate | 2 mm |
| Diameter of the base plate | 75 mm |

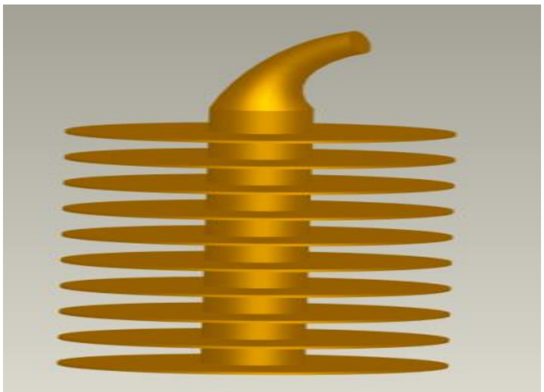

Fig.3.2 Design of a Heat pipe

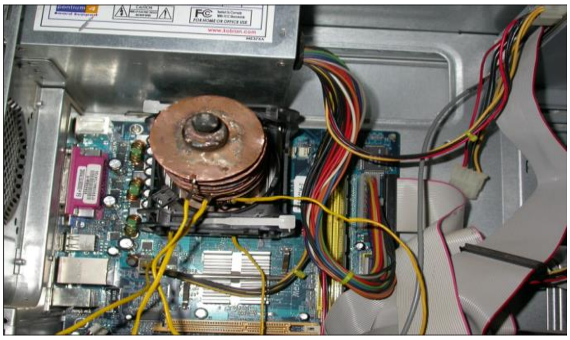

Fig 3.3 experimental setup

| FLUID | h (W/m²K) |
|---|---|
| Flowing gases | 10 --- 280 |
| Flowing liquids | 170 --- 5700 |
| Flowing liquid metals | 570-- 284000 |
| Gases(free convection) | 5 ---- 28 |
| Boiling liquids | 1000-- 284000 |
| Condensing vapors | 2840--- 28400 |

Table3.1: order of magnitude of heat transfer coefficient, h

### 3.1.1 Internal Heat Pipe Stress

The operating pressure inside the heat pipe gives rise to hoop stress in the heat pipe walls. This stress can be calculated using the following hoop stress equation:

$$\sigma_{hoop} = \frac{p.r_o.n}{2t_w} \text{-----------------(1)}$$

Where:

$\sigma_{Hoop}$= hoop stress = 280 – 460 MPa for copper
$r_o$=outer radius of the heat pipe
n= factor of safety
$t_w$= heat pipe wall thickness

The hoop stress in equation 1 is set to be one third of the ultimate tensile stress value for copper. To ensure pipe rigidity and reliability a safety factor of 5 is included. Rearranging and solving for $t_w$, the following heat pipe wall thickness value is obtained:

$$t_w = \frac{87755.0.0095.5}{300.10^6} = 1.39\text{x}10^{-5} \text{ m} = 1.35\text{x}10^{-2} \text{ m}$$

=0.00675 mm

Evidently, this is much less than can be reasonably manufacturing. Therefore a more common size of 2mm is assigned for the heat pipe wall thickness.

### The following are specifications of heat pipe:

| | | |
|---|---|---|
| Material of heat pipe | | Copper |
| Working fluid used | | Water |
| Total length of the heat pipe, L | | 105mm |
| Adiabatic length | $L_a$ | 35mm |
| Evaporator length | $L_e$ | 35mm |
| Condenser Length | $L_c$ | 35mm |
| Evaporator temperature | $T_e$ | 55°C |
| Processor temperature | $T_p$ | 64°C |
| Condenser temperature, | $T_a$ | 38°C |
| Outside diameter of pipe | $d_o$ | 19mm |
| Inside diameter of pipe | $d_i$ | 17mm |

A simple model for calculating the thermal performance of heat pipe is as follows:

### 3.1.2 Inside Thermal Resistance ( Ri):

Approximately, the thermal resistance of inside working fluid of heat pipe can be calculated using the equation,

$$R_i = \frac{1}{h_e A_e} + \frac{1}{h_i A_i} \qquad \text{-------- (2)}$$

From the data book [13]:

From table 3.1,For boiling liquids and condensation of vapors, Heat transfer coefficient lies between 1000 and 284000 W/m$^2$ $^o$k and 2840 and 28400 W/m$^2$ $^o$k respectively.

Where, $A_c$ = internal surface area of the condenser (m$^2$)

$A_e$ = internal surface area of the evaporator (m$^2$)

$h_c$ = condensation heat transfer coefficient (W/m$^2$ $^o$k)

$h_e$ = evaporator heat transfer coefficient (W/m$^2$ $^o$k)

$R_{hp}$ = thermal resistance of heat pipe ($^o$C/W)

The evaporating heat transfer coefficient $h_e$ and condensation heat transfer coefficient $h_c$ are assumed to be about 5000W/m$^2$ $^o$k.

From(2),

$$R_i = \frac{1}{5000X(\pi/_4 0.017^2)} + \frac{1}{5000X(\pi/_4 0.017^2)_i} \qquad R_i$$

= 1.762 $^o$C/W

### 3.1.3 Thermal Resistance Of Pipe Material ( Rp):

The pipe is a hollow and there is radial heat transfer, therefore the thermal resistance of is given by

$$R_p = \frac{\ln(r_o/r_i)}{2\pi KL} \qquad \text{---------------(3)}$$

Where $r_o$ and $r_i$ - outer and inner radii of heat pipe respectively (9.5mm, 8.5mm)

K – thermal conductivity of pipe material (393 W/m K)

From(3) $R_i = \frac{\ln(9.5/8.5)}{2\pi.393.0.105}$ =4.29x10$^{-4}$ $^o$C/W

### 3.1.4 Thermal Resistance Of Fins Rf :

There are 9 circumferential fins, they also offer some resistance and can be determined by the following equation

$$R_f = \frac{1}{n\eta_f A_s h_f} \text{-----------(4)}$$

Where, n = 9; $\eta_f$ = 0.9; $h_f$ = 10W/m$^2$K (from table 5.1) ; $A_s = 2\pi (R^2 - r_o^2) = 8.268 \times 10^{-3}$ m$^2$

From(4), $R_f = \frac{1}{9X0.9X10X8.268X10^{-3}}$

= 1.5$^o$C/W

### 3.1.5 Total Thermal Resistance Of Heat Pipe (Rhp):

$R_{hp} = R_f + R_p + R_i$ --------(5)

= 1.5 + 4.29x10$^{-4}$ + 1.762

= 3.2563 $^o$C/W

The rate of heat transfer from the processor to the atmosphere is given by:

$$Q_{hp} = \frac{\Delta T}{R_{hp}} \qquad \text{--------- (6)}$$

Where Q = rate of heat transfer (W)

ΔT = Temperature difference between the processor surface temperature and condenser temperature.

Heat transfer rate (Q):

From (6) $Q_{hp}$ =(64-38)/3.2563 = 8 W

Actually the heat pipe is designed for 8 W but the necessity is only 5.44W.this is due to the pipe has to transfer the heat in all conditions.

### 3.2 Thermal Design of Heat Sink

A heat sink is an object that transfers thermal energy from a higher temperature to a lower temperature fluid medium. The fluid medium is frequently air, sometimes water. The heat sink base receives heat from processor and the same is flowing through the fins. From the fins, high velocity air which flows over the surfaces of the fins takes away the heat. High velocity air is supplied by a blower which is placed on heat sink as shown in figure 3.2

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Consider a heat sink in a duct, where air flows through the duct, as shown in Figure It is assumed that the heat sink base is higher in temperature than the air. The following figures show different parameters of heat sink and how the air flows across the fins.

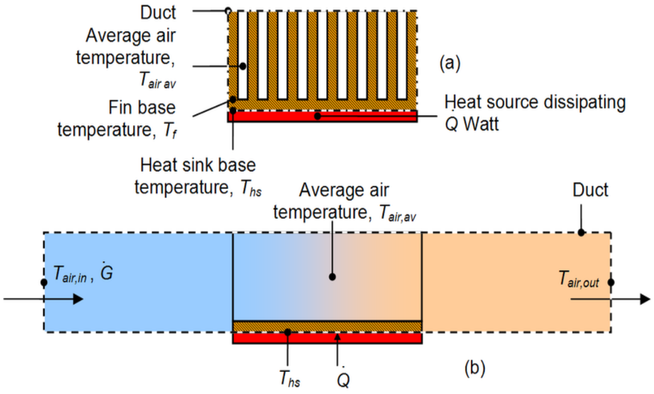


Fig: 3.2 working and variables of heat sink

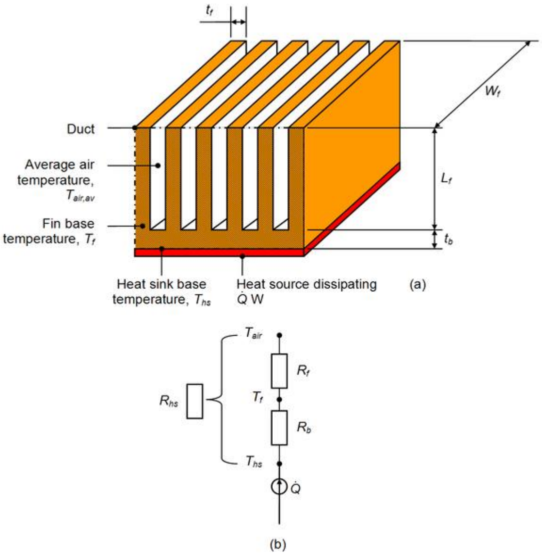


Fig: 3.3 parameters and thermal resistance of heat sink

### Data considered for design of heat sink:

Material used for heat sink:Aluminum

(K = 160 W/mK)

Base dimensions of heat sink : 60mmx 80mm

| | | |
|---|---|---|
| Thickness of base | $t_b$ | : 10mm |
| Width of fin | $W_f$ | : 80mm |
| Thickness of fin $t_f$ | | : 2mm |

### 3.2.1 Thermal Resistance of Base (Rb):

Thermal resistance of base of heat sink is given by

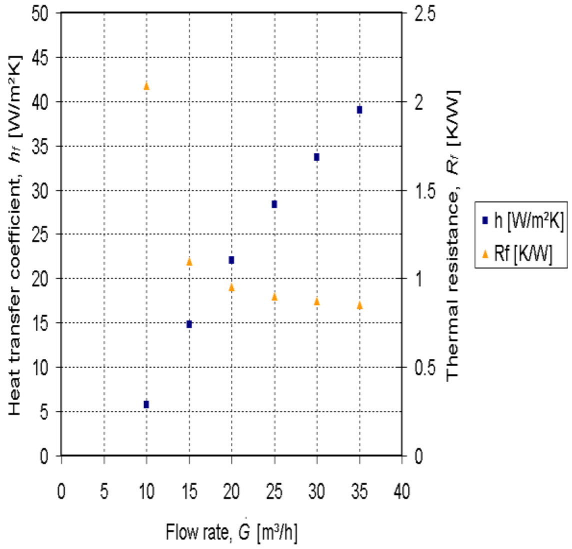
$$R_b = \frac{t_b}{K\,A_b} \text{-------- (7)}$$

Where, $A_b$ - base area of heat sink = 60x80mm$^2$ = 4.8x10$^{-3}$ m$^2$

$$R_b = \frac{10X10^{-3}}{160X\,4.8X10^{-3}} = 0.013\ ^{o}C/W$$

### 3.2.2 The Thermal Resistance of Fins ( Rf):

Thermal resistance of fins should be less than 1$^o$C/W i.e 0.8 $^o$C/W is chosen and heat transfer co-efficient is around 20W/m$^2$K for 20m$^3$/h flow rate from the figure 3.1.



Graph 3.1: Thermal resistance and heat transfer coefficient plotted against flow rate for the specific heat sink design the data shows that for an increasing air flow rate, the thermal resistance of the heat sink decreases.

Thermal resistance of fins is given by

$$R_f = \frac{1}{n\,h_f\,W_f\,(t_f + 2\eta_f L_f)} \text{----------- (8)}$$

Where $R_f$ = 0.8 $^o$C/W; n- no of fins=12;

$\eta_f$ = 0.9; $L_f$ = length of fin to be determined

Rearranging the equation (8),

$$L_f = \frac{1}{2\eta_f}\left(\frac{1}{n h_f W_f R_f} - t_f\right)$$

=>

$$L_f = \frac{1}{2X0.9}\left(\frac{1}{12X20X0.08X0.8} - 0.002\right)$$

$L_f = 35\text{mm}$

### 3.2.3 Thermal Resistance of Heat Sink Rhs

Thermal resistance of heat sink is the sum of that of base and fins

$R_{hs} = R_b + R_f$-------------- (9)

$= 0.0133 + 0.8 = 0.8133\ ^{o}\text{C/W}$

The heat transfer rate of heat sink is also given by

$$Q_{hs} = \frac{\Delta T}{R_{hp}} = \frac{56-38}{0.8133} = 22.13W$$

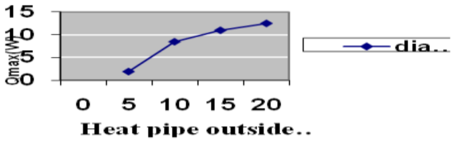
The heat transfer by heat sink is 22.13W but it is required transfer 5.44W only. This is due to the fact that after usage of some period of time, heat sink is covered by a layer of dust particles as air flows over fin continuously unless it is not cleaned, which increases thermal resistance there by reducing heat transfer rate. In those situations also, the heat sink may transfer at least 5.44W to surroundings. This is for safety only.

### Results and discussions:

### 4.1.1 Maximum Heat Transfer Vs Heat Pipe Diameter

Theoretically the performance of heat pipe increases as the length of the heat pipe decreases and its performance increases when the diameter of heat pipe increases. Typical heat transfer capabilities of heat pipes for various diameters as shown in the following graph 4.1.

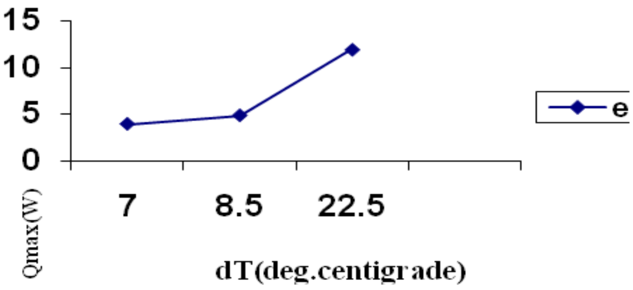
Graph 4.1 Qmax Vs Diameter



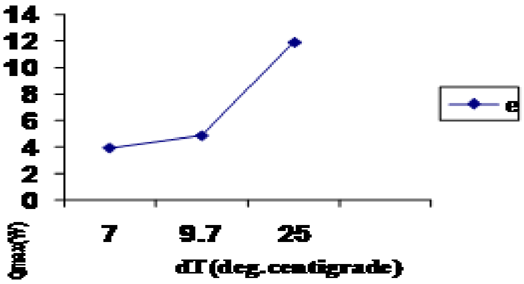
### 4.1.2 Working Temperature Vs Maximum Heat Transfer Rate

The Graph No. 4.2 shows the fundamental performance of a heat pipe. Experiments were conducted with a processor heat on to the evaporator section at one end over heat conducting element. While other end (the condenser section) was fan cooled to keep the intermediate (the adiabatic section) at constant temperature. In these tests, since the temperature of adiabatic section equals that of the vapor in the heat pipe, it taken as the working temperature (Tw) of the heat pipe. The maximum heat transfer rate Qmax was defined as a rate immediately before the thermocouple at the extreme tip of the evaporator section. At working temperatures of 40-60ºC.the maximum heat transfer rate tended to increase in linear position to the working temperature for the diameter of heat pipe. From this it can be seen that when the heating value exceeds 14watts the diameter of the heat pipe more than 20mm would be more effective.

Graph4.2:Temperature Vs Heat Transfer rate



Graph 4.3: Temperature Vs Heat Transfer rate



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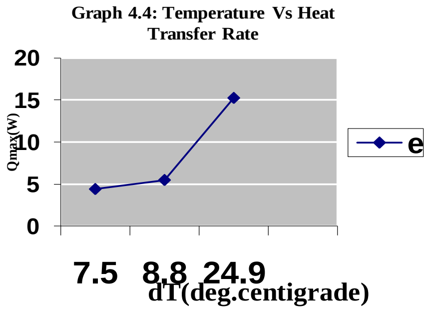
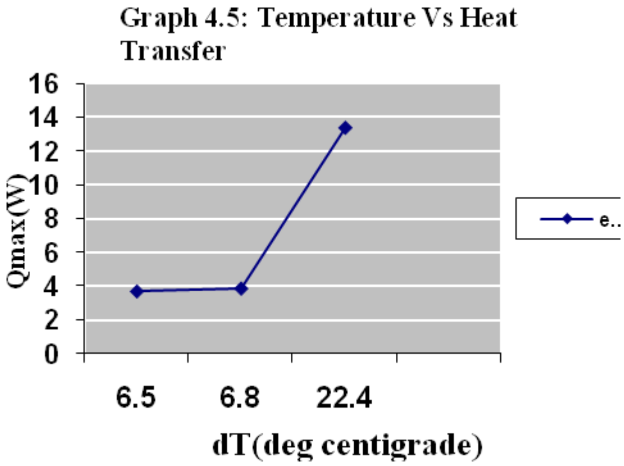
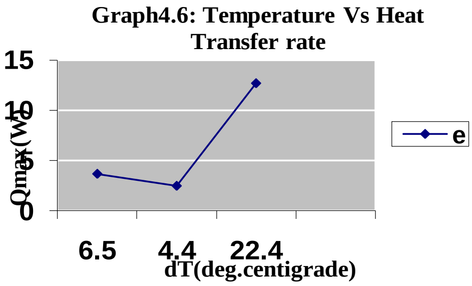
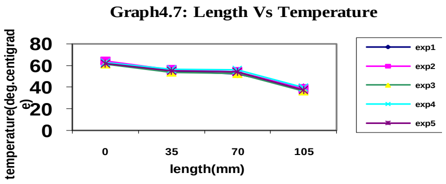

Graph 4.4: Temperature Vs Heat Transfer Rate


Graph 4.5: Temperature Vs Heat Transfer


Graph4.6: Temperature Vs Heat Transfer rate

## 4.1.3 Temperature Distribution along the Length of the Heat Pipe

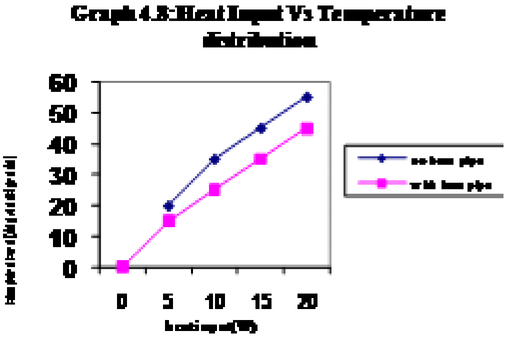
This graph present some representative testing results for the heat pipe in terms of temperature distribution along the length of the heat pipe. The evaporator and condenser lengths were respectively, 0-35mm and 70-105mm.


Graph4.7: Length Vs Temperature

The experiments were undertaking for different temperatures through the adjustment of coolant bath temperature. At each temperature the power input to the heat pipe was gradually increased from a lower level to a higher level until the temperature drop across the heat pipe length reached about 30-35ºC. It should point out that the heat pipe was still able to work steadily at this range of temperature drops.

## 4.1.4 Heat Input Vs Temperature Distribution.

This Graph 4.8 shows the test results. The y-axis of the graph represents the temperature difference (ºC) between an atmosphere and the processor temperature and the heat input (W) is represented along x-axis. The variations in the difference in temperatures with heat pipe and without heat pipe are represented in the graph. It should be pointed out that the temperature drop is very less when heat pipe is in use and the temperature drop is more for the system without heat pipe.


Graph 4.8:Heat Input Vs Temperature distribution

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## 4.2 Analysis of Heat Sink and Heat Pipe

**Fig 4.1 Heat sink used for the analysis of the temperature distribution**

Fig. 2. Heat sinks with three different pin configurations for: low air speed (top), moderate air speed (middle) and high air speed (bottom).

**Fig:4.2 heat sink used for motherboard of CPU**

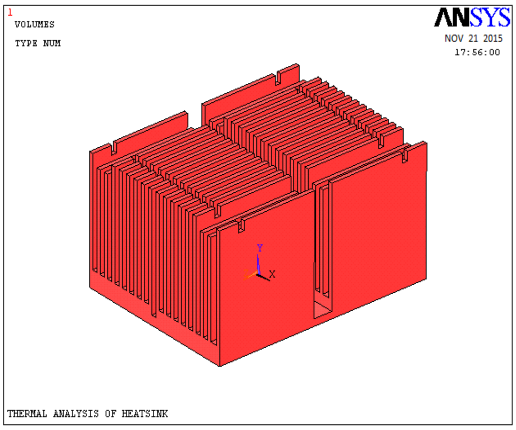

**Fig: 4.3 Heat sink used in CPU is designed for the analysis**

The above figure shows the design of a heat sink which used for the analysis.

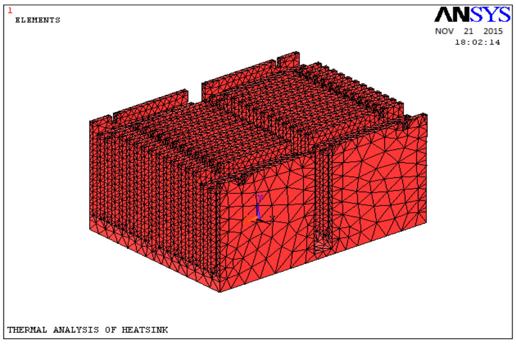

**Fig :4.4 Heat sink is meshed for the analysis**

The above figure shows the meshing of a heat sink with mesh size as 4, which used for the analysis.

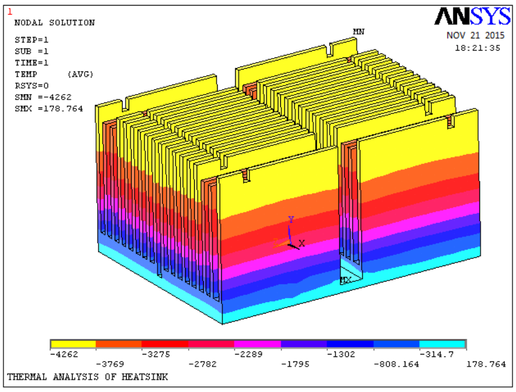

**Fig:4.5 Temperature distribution of the heat sink at 62 0C**

The fig.4.5 shows temperature distribution along the heat sink with max stress value of 178.764 at 62$^0$C.

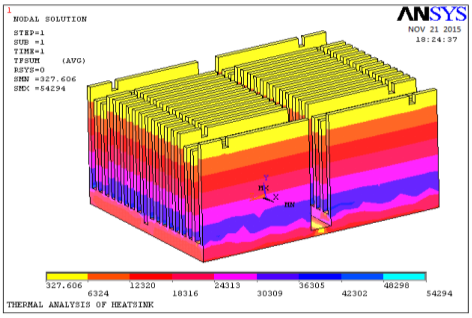

**Fig: 4.6 Thermal Flux of the heat sink at 62 0C**

The above figure shows thermal flux along the heat sink with min stress value of 327.606 and maximum value of 54294 at 62$^0$C.

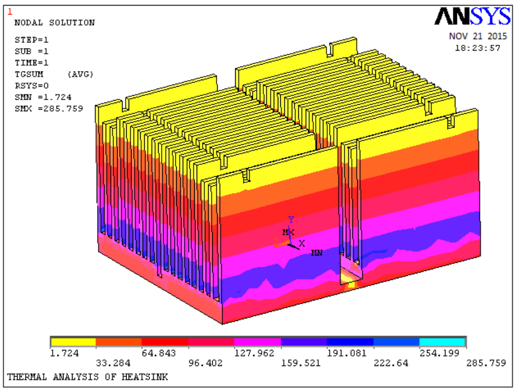

**Fig:4.7 Thermal Gradient of the heat sink at 62 0C**

The above figure shows thermal gradient along the heat sink with min stress value of 1.724 and maximum value of 285.759 at 62$^0$C.

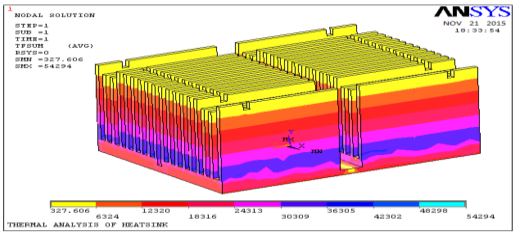

**Fig: 4.8 Temperature distribution of the heat sink at 64 0C**

The above figure shows temperature distribution along the heat sink with minimum value of 327.606 and max stress value of 54294 at 64$^0$C.

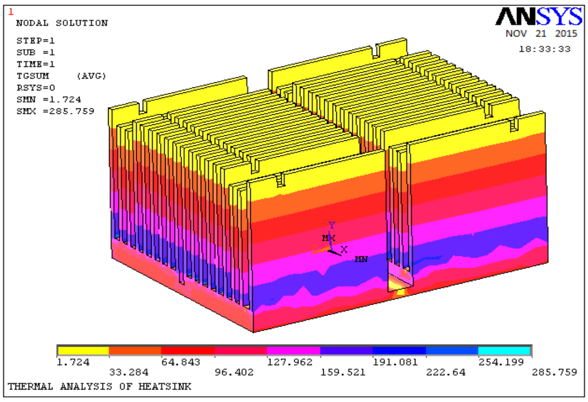

**Fig: 4.9 Thermal Flux of the heat sink at 64 0C**

The above figure shows thermal flux along the heat sink with min value of 1.724 and max stress value of 285.759 at 64$^0$C.

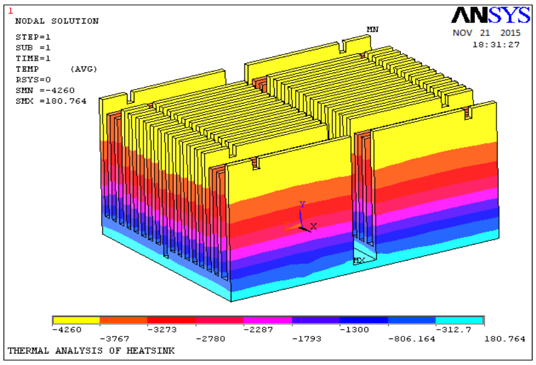

**Fig: 4.10 Thermal Gradient of the heat sink at 64 0C**

The above figure shows thermal gradient along the heat sink with min stress value of -80.764 and maximum value of 4260 at 64$^0$C.

**Fig: 4.11 Photo of the Heat Pipe used for the Experiment Base plate, circular fin, Pipe (copper) & Lid**

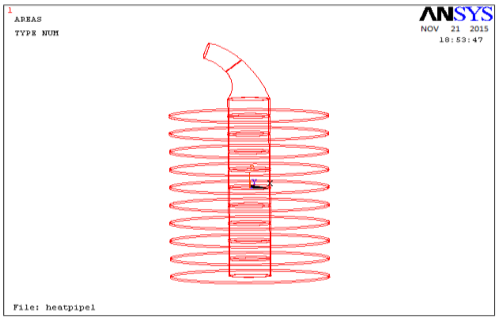

**Fig: 4.12 Heat sink used in CPU is designed for the analysis.**

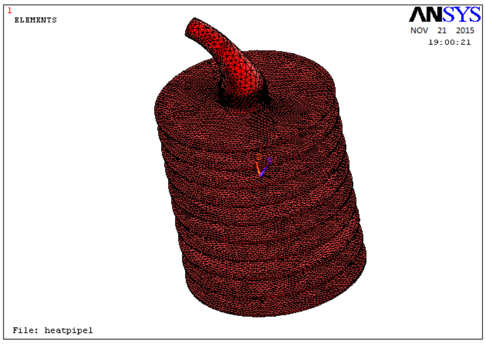

**Fig: 4.13 Heat pipe is meshed for the analysis**

The above figure shows the meshing of a heat pipe with mesh size as 4, which used for the analysis.

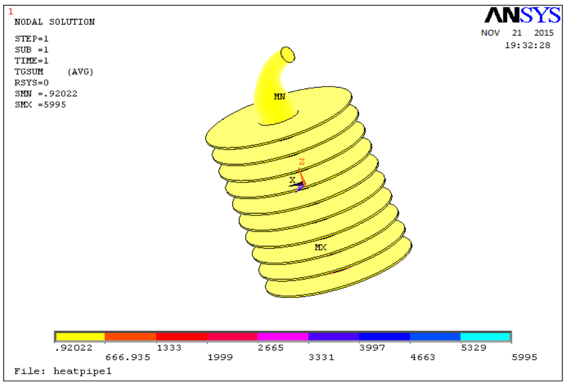

**Fig: 4.14 Temperature distribution of the heat pipe at 62 0C**

The above figure shows temperature distribution along the heat pipe with max stress value of 5995 at $62^0$C

.

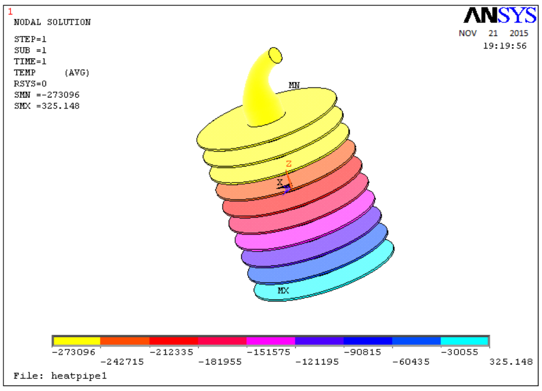

**Fig: 4.15 Thermal Flux of the heat pipe at 62 0C**

The above figure shows thermal flux along the heat pipe with maximum value of 325.148 at $62^0$C.

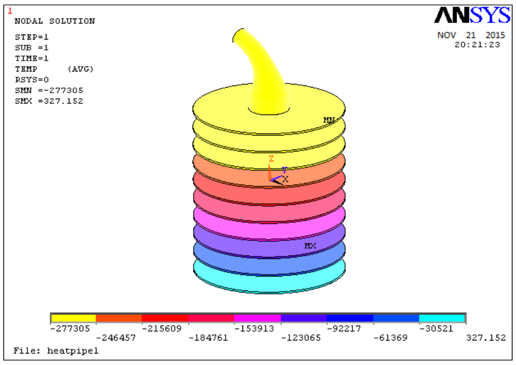

**Fig: 4.16 Temperature distribution of the heat pipe at 64 0C**

The above figure shows temperature distribution along the heat pipe with max stress value of 327.152 at $64^0$C.

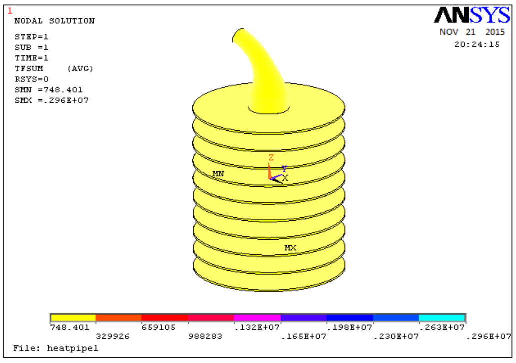

**Fig: 4.17 Thermal Flux of the heat pipe at 64 0C**

The above figure shows thermal flux along the heat pipe with maximum value of 743.401 at $64^0$C

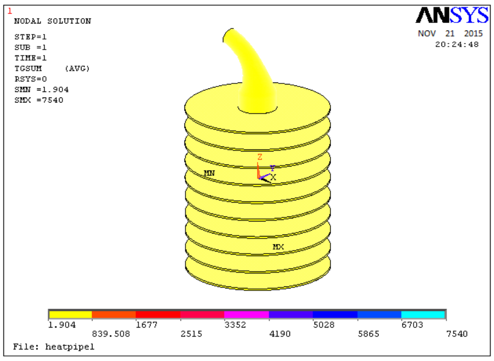

**Fig: 4.18 Thermal Gradient of the heat pipe at 64 0C**

The above figure shows thermal gradient along the heat pipe with maximum value of 7540 at 64$^0$C.

## Conclusions:

The fabrication of heat pipe has been carried out and experiments were done comparing with heat pipe and heat sink of the computer processing unit (CPU). The temperature without using heat pipe is reduced from 64ºC to 46ºC and by introducing heat it is reduced further to 36ºC. The obtained values are tabulated in the tables. As a result, overall heat transfer rate was calculated. Experimental calculations are also done and results are represented in graphs. As a result of the tests, maximum heat transfer rate and reliability of the heat pipe developed were obtained and it was indicated that the heat pipe can be applied to electronic equipment cooling.

When used properly, heat pipes can do wonders. However, they are certainly not the ultimate solution to all cooling related problems. Due to the number of factors to consider when applying heat pipes, our advice is: Use ready-made heat pipe-based coolers only if you are absolutely sure that they are suitable for your particular cooling problem. Do not try to build your own heat pipe-based cooling system, unless you really know what you are doing.

## Scope for Future Work

More recently, synthetic diamond cooling sinks are being researched to provide better cooling. Also, some heat sinks are constructed of multiple materials with desirable characteristics, such as phase change materials, which can store a great deal of energy due to their heat of fusion.

The experiment was done using water as a working fluid and copper as a shell material at single power input. This can be done at different inputs by changing the working fluid and shell material and also can be carried out by using wick structure. So, those accurate results may be obtained. This was conducted with limited sources.

The experiment can be conducted keeping the heat pipe at the different inclinations, at different positions and at different operating conditions to obtain the best possible results. Now a-days the heat pipes are widely used in different fields such as in electronic cooling system, in space craft technology, in laptops, in the isothermal furnaces etc., This will be more advantageous in IC engines and in air-crafts.

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