Northern Arizona University

“*Designing and Building a heat pipe demonstration unit for a mechanical engineering laboratory class at NAU*”

Prepared By:

Kaled Aleweehan

Abdullah Almutairi

Waleed Almutairi

Abdullah ben Gheyam

Omar Alotaibi

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Background & Preliminary Report

Project Sponsor: Dr. David Trevas

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1. BACKGROUND

1.1 Introduction:

Demonstration units are used in laboratory classes in the Mechanical Engineering Department at Northern Arizona University (NAU) to teach students engineering principals. Our project is to build a heat pipe demonstration unit, which will help students understand the basic principles of heat transfer and thermodynamics. A heat pipe is pipe filled with a liquid and a wicking material that transfers heat much faster than a stand-alone pipe because it uses conduction and convection as opposed to conduction alone.
A heat pipe is a heat-transfer gadget that joins the standards of both warm conductivity and stage change to viably transfer heat between two strong interfaces. At the hot interface of a heat pipe a fluid in contact with a thermally conductive strong surface transforms into a vapor by retaining heat from that surface. The vapor at that point goes along the heat pipe to the chilly interface and gathers once more into a fluid – discharging the inactive heat. The fluid at that point comes back to the hot interface through either fine activity, diffusive power, or gravity, and the cycle rehashes. Because of the simple high heat transfer coefficients for bubbling and buildup, heat pipes are very viable warm conductors. The successful warm conductivity changes with heat pipe length and can approach 100 kW/(m·K) for long heat pipes, in correlation with roughly 0.4 kW/(m·K) for copper. Heat pipes are commonly used in electronics and space applications, where rapid heat transfer to remove heat from the system is necessary.

The sponsor for this project is our instructor, Dr. David Trevas. The stakeholders include mechanical engineering students and faculties at NAU.

1.2 Project Description:

Our team has been tasked with designing and building a heat pipe demonstration unit for a mechanical engineering laboratory class at NAU. We will use various different fluids, wicking materials, and pressures to test the efficiency of the heat pipe and create a laboratory experiment to compare and analyze these parameters.

Overview of the heat pipe:

A heat pipe is a passive heat transfer equipment which has the ability to transfer heat with very small temperature gradient if compared to high thermal conductivity metals such as copper. Generally speaking heat pipes is consisting of shell or (wall), a wick and a little amount of the working fluid or (coolant).Three sections can characterized in a heat pipe, the evaporator, the condenser, and the adiabatic section. Evaporator part sinks the heat from the high temperature side and convert the coolant or the working fluid to vapor inside. The vapor start flowing through the diabetic part and then condensate at the consider side, the latent heat of condensation will be released to a low temperature source. The condensate liquid then returns back the evaporator side through the wick by the virtue of capillary driving force. The wickless heat pipe, heat pipe without wick, that depends on gravity to return the condensate liquid to the evaporator side is called thermosiphon.

Main idea of the project:

The main objective of this capstone design project titled "***Designing and building a heat pipe demonstration unit for a mechanical engineering laboratory class at NAU***" is to study the main characteristics and specifications of heat pipe, such as the thermal response-time for heat pipe and compare it to a regular copper rod, Measure and report the response-time and temperature profile along the heat pipe, and finally calculate the effective thermal conductivity for the heat pipe and compare it to with high thermal conductivity alternatives. And finally compare different scenarios for the wick materials.

In this project, firstly a qualitative analysis will be made to assess the thermal response time of a copper-water heat pipe, at the moment it is put in a hot and cold water in row and compare that to the copper rod with same size and the same length. After the qualitative observation, a horizontally heat pipe made of a copper as manufacturing material, a copper wick, and water will be the working fluid will be tested and thermal characteristics will be concluded, during this part variation of parameters will be there to see how the thermal characteristics will be changed.

To simulate the hot side a flexible heater will be wrapped on one side of the heat pipe and will be secured using clips. The other side is the uncovered portion of the heat pipe will be exposed to the surroundings (ambient temperature) and works as the condenser section that is cooled down by natural convection. Then a k-type thermocouples will be installed at the condenser side. Those thermocouples will be connected to a data acquisition system to record and monitor the temperature readings recorded by thermocouples. The input power given to the electric heater will play an important role when studying the effect of the hot side in the whole heat transfer process, simply the input power to the heater can be calculated by multiplying the input rated current by the input rated voltage of the heater.

2 REQUIREMENTS

. In this section, it contains the requirements that team need to design a heat pipe in mechanical engineering laboratory, including the customer needs, engineering requirements, and house of quality (HoQ). The customer and engineering requirements for this capstone project arise from the demand of electronics industry stakeholder and space applications. These requirements need to be met during the different stages of the project. House of Quality (HoQ) is a tool which hence convert a customer requests into engineering characteristics so as to make it easy for the engineers to understand the engineering requirements. It takes into consideration the 7 management and planning tools including the affinity diagram, relation diagrams, tree diagram, matrix diagram, arrow diagram, PDPC and Matrix data analysis. With the help of this there is a smooth transition between the customer's request to creating engineering requirements.

2.1 Customer Requirements (CRs)

Customer requirements (CRs) were generated by meeting with our client and discussing what is most important for this project. Additional CRs were taken by looking at existing designs for heat pipes and what their advantages are disadvantages. The CRs for this project are given in in Table 1.

Table 1: Customer Requirements

Customer Requirement	Description	Weight
Durability	How long it is withstanding	0.16
Reliability	How accurate it will work	0.16
Manufacturalble	Rate which it could be mass produced	0.11
Safety	How safe the heat pipe setup is for the end user	0.13
Ease of Assembly	Able to install the parts	0.14
Variability	Capable of varying with the situation	0.17
Easy to Measure	Measuring of the temperature is easy	0.13

The above customer requirements are the main factors customer will require when purchase the heat pipe. The team weighted CRs based on their importance. The highest weights of 0.17 were given to variability. This is given the higher weight because they are fundamental to everyday usage. Following these high weights comes durability and reliability at 0.16. This is because the heat pipe must be durable with stand the thermal load for long time and can be rely on when we use to sink the heat from the heat source. The next weight comes in at 0.14 for ease of assembly. This was assigned the weight of 0.14 because they are important for the product to be installed easily and be user friendly. The next lowest weight comes from safety at 0.13. This is because safety of the human being is very important especially in mechanical engineering laboratory. The lowest weighted requirement is to be manufacturable and operate in various conditions, with a weight of 0.11. This is because while cost is important, the team will design the heat pipe in excellent way to satisfy this factor.

2.2 Engineering Requirements (ERs)

Engineering requirements (ERs) were generated from CRs. Table 2 is a summary list of engineering requirements created by meeting with our client to fit the CRs and meet the engineering design principles. The team set up targets for each ERs. These are targets that should be accomplished, if the team need to override them that will be completed. For instance the setup time is 1 min. When the team finished the design, and had some changes, the targets will be moved forward to achieve optimum performance.

Table 2: Engineering Requirements

ERs	Description	Targets
Material Melting Temperatures	The materials must be able to withstand the maximum operating temperatures, but for safety, all temperatures will be kept below 200℃.	> 200℃
Reliability	Being able to switch fluids, pressure and wicking materials.	> 5 years
Set-up time		1 min
size	Volume, size of the set up to be useable for lap demo.	12 cubic feet
Light Weight	Must be light weight to utilize it in better way	> 5 Kg

2.3 House of Quality (HoQ):

House of quality is a matrix which relates the customer requirements with the engineering requirements, as the customer requirements are the one which have given by the client and engineering requirements are those which have developed from the customer requirements. Therefore, it is important to relate engineering requirements with the CR's and see which engineering requirement is most important from the list. HoQ do the same thing and it gives the Relative Technical Importance and Absolute Technical Importance. From the RTI, we got the priority order list of engineering requirement. Highest percentage of RTI is most important and lowest percentage of RTI is least important engineering requirement.

Table 3: HoQ

Engineering Requirements / **Customer Requirements**	**Importance**	Material Metling Temperatures	Reliability	Setup Time	Size	Light Weight			
Durability	9	9	3	1	1	1			
Reliability	3	3	9	3	9	3			
Manufacturable	3				3				
Safety	9	3	3	3	9	1			
Easy to Assembly	9	1	1	3		3			
Variability	1		1	3	1	1			
Easy to Measure	3	1	9	9	3	3			
Technical Importance: Raw Score		129	118	102	136	64			
Technical Importance: Relative Weight		**23.5%**	**21.5%**	**18.6%**	**24.8%**	**11.7%**			
Techanical Target Value		200	5	1	12	5			
Upper Target Limit									
Lower Target Limit									
Units		C	Years	Min	ft^3	Kg			

In the above Table 3, it has found that size is the most important factor to consider and it will affect the design of project maximum and on number second in importance list is material melting temperature setting, third is reliability, fourth in the list of important factors is Setup time and the least important factor is light weight. So, the weight isn't affecting much to the project, but size of the product will effect maximum to the project.

3 EXISTING DESIGNS

This part includes the research that the team has processed into what subsystems are subsist for the heat pipe. Researching these systems was mainly done by searching for previously done thoroughly for the heat pipe.

3.1 Design Research

Design research for heat pipe design was done mainly by parts of the team continuous research. The group took broad pictures of different plans and noticed how each outline performed, and additionally any issues the plan kept running into. The gathering utilized a lot of what was found from this examination when settling on choices for which designs to choose. Design research is basically an important part of designing and it plays vital role in the design project. Design research provide the information about project, it provides the information about existing work done on the project, and it also provide great help in doing the project. Design ideas can obtain from design research. Existing designs can find using design research to take help from them. With all these possible advantages design research is an important aspect for the design projects.

The general trend in the electronics industry sector of compacting extra power in small spaces has urged increasing thermal management obstacles. Many of the cutting-edge electronics' devices inquire cooling over the limit of standard of metal heat sinks. In many occasions, heat pipes have make better heat sink performance and have become a vital thermal management tool. As an example, Pentium-processors in desktop and laptop computers. Due to the compact space and power available in laptop computers, heat pipes are ideally suited for cooling the high-temperature power chips, another application is Heat Pipe Heat Exchangers (HPHE), And finally as heat sink for power electronics, (H.S.).

On the other hand, heat pipe is used effectively in space applications such as in satellites used for communications, global positioning systems, and defense purposes, a heat pipe is the device used to regulate temperature and keep the overall systems operating reliably

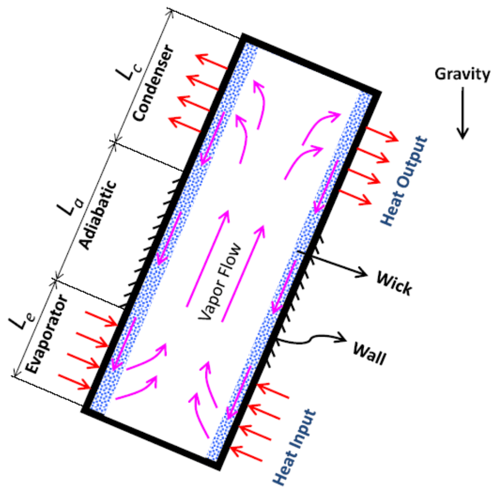

Figure 1: Schematic view of Heat Pipe

Heat Pipe Operation:

A heat pipe is mainly composed of a vacuum envelope, a wick structure and a working fluid (Figure 2). The heat pipe is totally evacuated and then filled again with a little quantity of working fluid (coolant), an amount just to fill the wick. Because the coolant is the vital member in the heat pipe, the pressure inside the pipe is the same as the saturation pressure accompanied with the heat pipe temperature. When the heat enters at the evaporator, equilibrium is disturbed, this will cause vapor to generate at a little higher pressure and temperature. The higher pressure leads vapor to travel to the condenser end where the slightly lower temperature leads the vapor to condensate and release its latent heat of vaporization. The condensed fluid after that is pumped towards the evaporator by the capillary forces initiated in the wick structure. This going on cycle can transfer large amounts of heat even with very small thermal gradients. A heat pipe's operation is passive, being leaded only by the heat that it transfers, which consequently will result in high reliability and long life. [1-3]

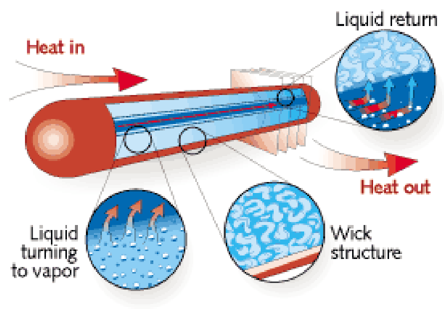

Figure 2: The Structure and functioning of a heat pipe

Limits to Heat Transport:

Heat pipes can be designed in certain way to transfer from a few watts to kilowatts, this will depend on the application. For a given thermal gradient, heat pipes is able to transfer comparably more heat than even the metal conductors. When loaded beyond its nominal capacity, however, the effective thermal conductivity of the heat pipe will be dramatically decrease. Therefore, it is very important to design the heat pipe to safely transport the required heat. Heat transfer capability of the heat pipe is depending on several limiting factors viscosity, capillary pumping, flooding and boiling.

3.2 System Level

The whole system for heat pipe would be the one entity. There is no exit for clear subsystems to the design, but we will categorize the wick material selection is our main sub-system for our whole system due to its importance. As a starting point for determining heat pipe design we need to have a look on the ***heat sink*** selection, *Equation (1)* can be used to estimate the required heat sink volume for a given application:

$$V = \frac{QR_v}{\Delta T} \quad \text{...} \quad (1)$$

Where: V= heat sink volume [cm^3], Q = heat to be dissipated [W], R_v = volumetric thermal resistance [cm^3–°C/W], ΔT = maximum allowable temperature difference [°C].

Table 4: provides guidance on the range of heat sink volumetric thermal resistances as a function of air flow conditions.

Table 4. Typical heat sink volumetric thermal resistance range as function of air flow conditions [6].

Air Flow (m/s)	Volumetric Thermal Resistance (cm^3-°C/W)
Natural Convection	500 – 800
1 m/s (gentle air flow)	150 - 250
2.5 m/s (moderate air flow)	80 - 150
5 m/s (high air flow)	50 - 80

Whether dealing with a heat exchange, for the heat pipe, that is local or remote to the heat source, the options for mating heat pipes to them are identical and include grooved base, grooved mounting block and direct contact methods.

It should go without saying that simply soldering a round pipe to a flat surface is far from optimal. Circular or semi-circular grooves should be extruded or machined into the heat sink. It's advisable to size the grooves about 0.1 mm larger than the diameter of the heat pipe in order to allow enough room for the solder.

3.2.1 Existing Design #1: uses both a local and remote heat sink:

The heat sink shown in Figure (5) uses both a local and remote heat sink. The extruded heat exchanger is designed to accommodate slightly flattened heat pipes, helping to maximize the contact between the copper mounting plate and the heat source. A remote stamped fin pack is used to further increase thermal performance. These types of heat exchanger are particularly useful because the pipes can run directly through the center of the stack, decreasing conduction loss across the fin length. Because no base plate is required with this fin type, weight and cost can be reduced.

Figure 4: Grooved base type Heat Pipe

3.2.2 Existing Design #2: Grooved Mounted Block type:

The second existing design is shown in figure (6), A gain the holes through which the heat pipes are mounted should be 0.1 mm larger than the pipe diameter. Had the pipe been completely round at the heat source, a thicker grooved mounting plate would have been required as seen in Figure (6).

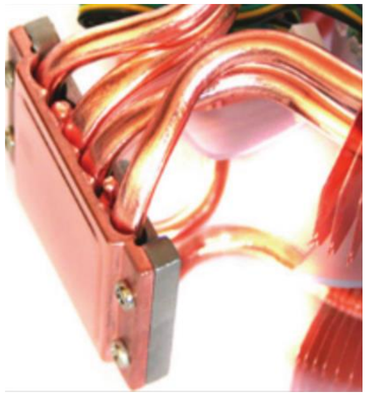

Figure 5: Grooved Mounted Block Type Heat Pipe

3.2.3 Existing Design #3: Direct Contact type Heat Pipe:

The third existing design is shown in figure (7), Now if conduction losses due to the base plate and extra TIM layer are still unacceptable, further flatting and machining of the heat pipes allows direct contact with the heat source as seen in Figure (7). Performance gains from this configuration usually lead to between a 2-8 °C reductions in temperature rise. In cases where direct contact of the heat source to the heat pipes is required a vapor chamber, which can also be mounted directly, should be considered due to its improved heat spreading capacity.

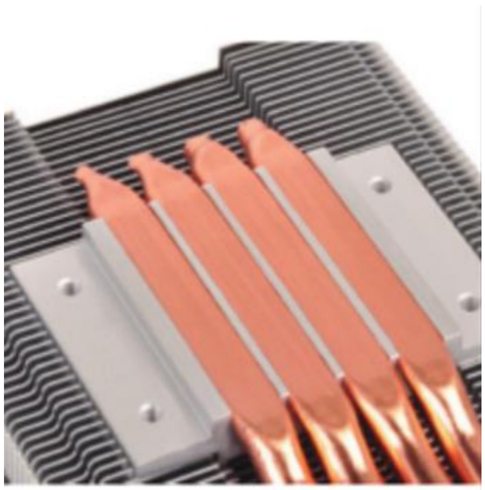

Figure 6: Direct Contact Type Heat Pipe

3.3 Functional Decomposition

Functional decomposition is a process of decomposing the complete working module for the project. This is the expected working of product, observed after seeing the existing designs. There are two types of functional decomposition, one is black box model and second is functional model. Black Box model shows the inputs and outputs of the system in the form of material, energy and signal. Functional model shows the internal working of the project and show the processes that uses by the product to convert the input into the output.

3.3.1 Black Box Model

The Black Box model shows the inputs and outputs of system. It doesn't matter what is the internal working of system. It only focuses on the inputs going into the system and outputs that are coming out form the system. The Black Box model shows the inputs as "Material (Hand, Electricity), Energy (Electric Energy), Signal (On/Off, Temperature dial)" and the outputs as "Material (Heat, Cooling System), Energy (Heat), Signal (On/Off, Temperature Reading pipe)". Black Box model has shown in figure 7.

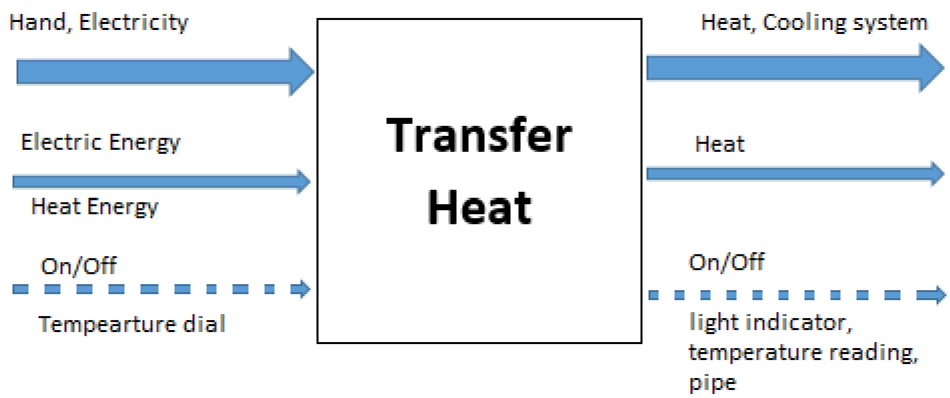

Figure 7: Black Box Model

3.3.2 Hierarchical Task Analysis

Functional model shows the inside of Black Box. It shows the inputs of system and all the processes that perform inside the system to produce the outputs. Functional model takes each step that performs inside the body of any product in the form of box and get the output.

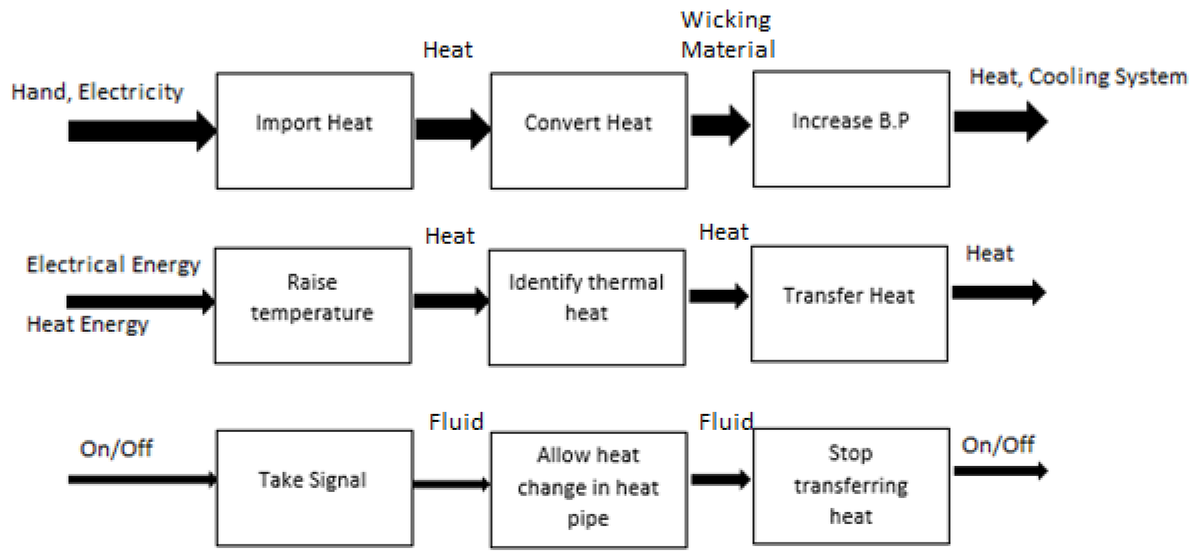

Figure 8: Functional Decomposition Model

Above model is showing the heat import first from the source into the pipe, and then covert that heat so that the source will get the cooling and heat will remain into the sink.

3.4 Subsystem Level

The Heat pipe setup construction can be broken down into one main subsystem which is the wick material subsystem and it has a few options for design that the Team had to consider when picking a design.

3.4.1 Subsystem #1: Wick Material

The followings section contains the options the team considered for the wick material. Each of the existing designs are types of wick material that have been used in the past for Heat pipe experimental setups. The team researched each option as well as compared to what other successful researchers have done in the past. The wick material is an important part because it is dramatically change and enhance the heat transfer modes at the condenser side. This is needed to prolong the efficiency of the heat pipe.

3.4.1.1 Existing Design #1: Grooved Wick Type Heat pipe:

In This Design a grooved heat pipe is a copper tube with a series of shallow grooves on the inside face of the pipe. These groove structures usually consist of axial or circumferential grooves on the inner radius of the pipe. These grooves can be created by extrusion or broaching. The cross sectional shape of the grooves can be rectangular, triangular, trapezoidal, or nearly circular.

Trapezoidal grooves are currently the most common type. The size of the grooves are large relative to those of a screen mesh or sintered metal wick, therefore the capillary pumping pressure is quite small. While the water is a liquid, it travels in the grooves and while it is a vapor it travels in the open space of the pipe. Heat pipes with grooved wick structures can operate in gravity-aided and horizontal orientations, and are capable of returning the working fluid against gravity at angles up to 5 deg. From horizontal.

The performance of heat pipes with axial groove wicks is very good, provided that the application does not call for a significant adverse elevation against gravity.

These heat pipes are typically used in applications with radial heat fluxes up to 40 W/cm2.

Capillary action is affected by the grooves on the inside of the heat pipe. Depending on the shape of the grooves, there is a difference in performance. Manufacturing costs are low with this type of heat pipe because the grooves are easier to make, however the technique is much more susceptible to gravity and can be orientation specific in use. In general, Thermal lab state that vertical orientation is best.

Figure 9: Grooved Wick Type Heat Pipe

3.4.1.2 Existing Design #2: Metal Mesh (felt) Wick Type Heat pipe:

In this type of heat pipe, the wick is in the form of metal mesh that is inserted into the pipe and made to be in contact with the inner walls of the pipe to facilitate capillary action. This type of wick is used in the majority of the mainstream products and provides readily variable characteristics in terms of power transport and orientation sensitivity, according to the number of layers and mesh counts used.

Sometimes a metal felt based wick structure is used which is held in support by a metal foam. Copper and stainless steel are the most common materials used to produce screen mesh. By varying the pressure on the felt during assembly, various pore sizes can be produced. By incorporating removable metal mandrels, an arterial structure can also be molded in the felt. These methods serve in increase the capillary strength of the wick which translates into even better heat pipe performance.

Heat pipes with screen mesh wick structures are capable of operating in gravity-aided and horizontal orientations and are capable of returning the working fluid against gravity at angles up to 5˚ from horizontal. These heat pipes can also be used in applications with radial heat fluxes up to 40 W/cm2.

More commonly used with CPU heatsinks is a multi-layered metal mesh wick, as seen here. The few times we have dissected a heat pipe here this is the kind of metal wick structure we discovered. In a freshly cracked open heat pipe the wick would be slightly wet.

Figure 10: Metal Mesh (felt) Wick Type

3.4.1.3 Existing Design #3: Metal Sintered Powder Wick Type Heat pipe:

In this type of heat pipe, capillary wick is made of sintered powder which adheres to the inner walls of the heat pipe. This acts to transport the fluid through capillary action.

Choosing a sintered structure as the heat pipe wick will provide high power handling, low temperature gradients and high capillary forces for anti-gravity applications. Very tight bends in the heat pipe can be achieved with this type of structure.

Powder particles are diffused together and to the tube wall to form a sintered wick structure. Copper powder is the most common material used to produce sintered wick structures. Sintered wick structures using smaller powder particles can lift the working fluid a greater distance than a wick structure fabricated with larger particles. The pumping capability of a sintered wick structure is superior to the capability of a screen mesh or grooved wick structure. A sintered wick heat pipe can be used in applications with radial heat fluxes up.

The working fluid in the heat pipe is drawn along the length by the capillary action of the porous sintered copper metal lining the inside of the tube. The sintered copper powder is formed in a bonding process so the material is actually hard (not loose). Manufacturing cost for this type of heat pipe is high.

Figure 11: Metal Sintered Powder Wick

4 DESIGNS CONSIDERED

There are numerous choices from zipper pack fins to extruded fin stacks designs, each with their own cost and performance characteristics. While heat sink choice can markedly affect heat dissipation performance of the heat pipe overall design, the biggest performance boost for any type of heat exchanger comes with forced convection. So below is a list of the considered design with typical benefits and potential pitfalls.

4.1 Design #1: Extruded Heat Sink

One of the most effective way of sinking heat is through extruded heat sink. In extruded heat sink an aluminum foil uses which cause the heat sink to operate in easy way and it sinks the heat quickly comparing with the other heat sinks. Following is the sketch of heat sink.

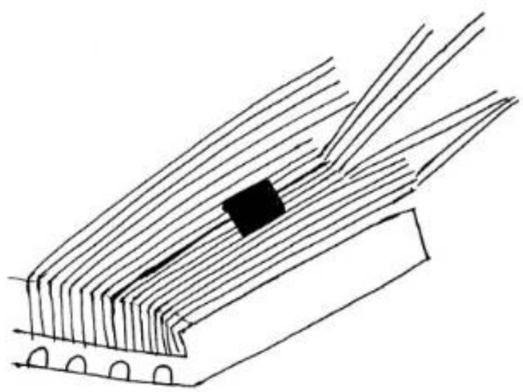

Figure 12: Extruded Heat Sink

Typical Benefits:

Readily Available

Easy to manufacture to custom specifications

Including groove for heat pipe

Potential Pitfalls:

Dimensions are limited.

Fin height limited ~20x fin width

Base and fins are same material, usually aluminum

4.2 Design #2: Die Cast Heat Sink

It is a type of heat sink which provide cooling to the system in which casting process happens, like the molten form of any material need the cooling so at that place heat sink play its role and cover heat evolve from the system. It can be seen in the figure.

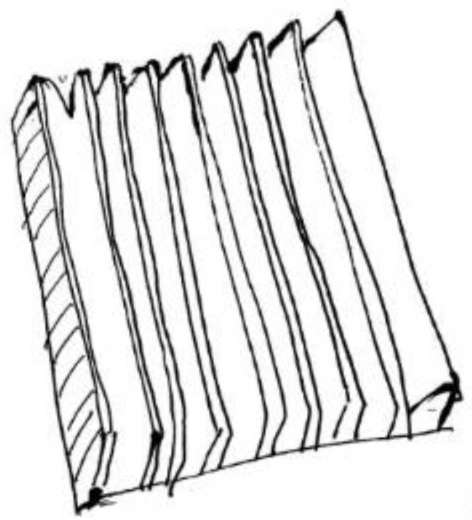

Figure 13: Die Cast Heat Sink

Typical Benefits:

Net Shape

Low Weight

Easily customizable

Potential Pitfalls:

Lower thermal conductivity

Potential for porosity.

Not generally used with heat pipes.

4.3 Design #3: Bonded Heat Sink

In this design concept, bonded heat sink is present, this type of heat sink forms by the combination of plates with a great bonding present in them. The plates join together closely to form a linking system which sinks the heat as showing in the figure.

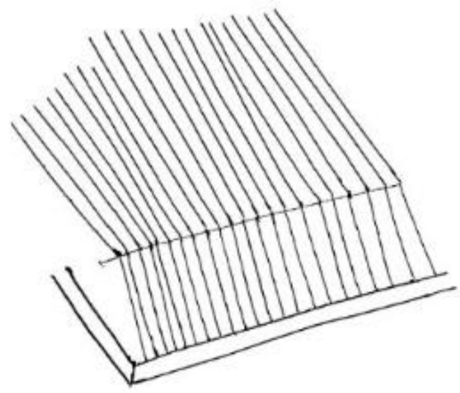

Figure 14: Bonded Heat Sink

Typical Benefits:

Large heat sink sizes

Base and fins can be of different materials.

Potential Pitfalls:

If fins are epoxied in place, added thermal resistance.

4.4 Design #4: Skived

It is a single form of block with cooper plating uses in it. It provides high cooling system because it is made up of skiving, with the stamped or folded fins. It can see in the following figure.

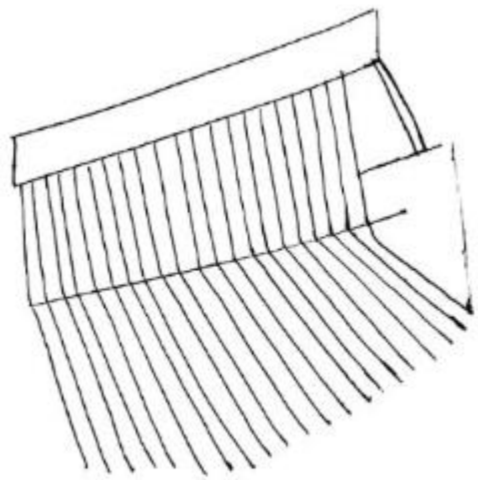

Figure 15: Skived Heat Sink

Typical Benefits:

Fin and base from solid piece of metal, usually copper

High density fins possible.

More design flexibility than extrusion

Potential Pitfalls:

Base maybe thicker than needed, thus higher weight.

Fins damage easily.

4.5 Design #5: Fin Pack and Zipper Fins

In this type of heat, all the fins are packed from both the sides and the fins have formed in the same way as a zip is present. There is a bend in the finds to make a look like zip. Zipper fins provide high cooling system because of its unique packing which have the capability to sink heat quickly and provide cooling quickly and it can be seen in the following figure.

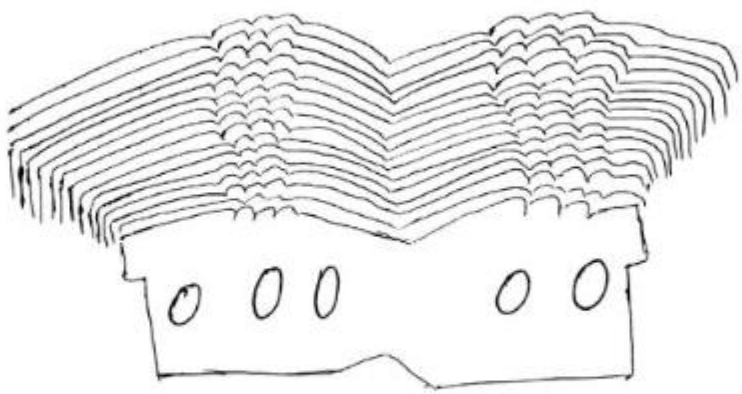

Figure 16: Zipper Heat Sink

Typical Benefits:

Low-high fin density.

Low weight.

High design options, including center mounted heat pipes.

Potential Pitfalls:

Generally, for fins less than 1 mm. thick.

5 DESIGNS SELECTED

In this section, the team will discuss the main design selected for this project, and a clear justification why as a team will adopt this design, justifying the use of each component through the setup project. This optimized selection process will mainly be based on Pugh chart and decision matrix and also the data extracted from house of quality which is built on (HoQ) analysis. Also, the concepts mentioned in the previous section are individual design concepts and the team evaluated them. After eliminating, the team selected the best 3 concepts from the Pugh Chart. After that, the team used the decision matrix to select our final design

5.1 Rationale for Design Selection

A Pugh Chart is considered a design tool. This chart is used to compare the designs with the other design criteria's. The left column includes the various design criteria's which the top horizontal row are the designs considered. The criteria's taken into consideration are Durability, Reliability, Manufacturability, safety, ease of assembly, variability and the ease of measuring. The design 9 here is considered as the datum design. The various rating for the criteria's based on the designs was make in each box and then summed at the bottom to obtain the ranking. In the end the sum of the positives with the lowest negatives is considered to be the Design 4 which again is considered an optimum design for this project (see appendix B).

The decision matrix in table 5 was created to compare the designs based on various criteria's and to conclude as to the best design for this project. The various criteria considered were the material melting temperature, the reliability, set up time, size and weight. Design 4 had a better rating in terms of the material melting temperature where the temperature was the highest when compared to the other designs but on a reliability scale the design 3 stood a better rating compared to the design 4. Design 3 also stood a better rating at the setup time followed by design 4 and then design 2. In the size and light weight criteria design 4 had the best rating compared to 2 and 3. When all these criteria were taken into consideration and calculated it was observed that design 4 had the best total rating of 88 making it the optimum choice for the project.

Table 5: Decision Matrix

Weight / Criterion		Design 2			Design 3			Design 4		
Material Melting Temperature	.235	80		18.8	85		19.9	95		22.3
Reliability	.214	70		14.9	90		19.3	80		17.1
Set-up Time	.186	85		15.8	88		16.4	78		14.5
Size	.248	79		19.6	84		20.8	95		23.6
Light Weight	.117	80		9.4	85		9.9	90		10.5
Totals	1			78.5			86.3			88
Relative Rank				3			2			1

Design Selected: Sintered powder metal wick – Inclined setup – Skived Heat sink.

It is important to select the proper wick structure for heat pipes based on their real application. If a heat pipework in conditions with favorable gravitational force and a few bends, the grooved wick heat pipe is a good choice because of its superior thermal performance. If a heat pipe has a complex geometry and works at a small or negative tilting angle, sintered powder metal is the optimum wick structure. For cooling electronic components in telecommunications devices and computer products, the sintered powder metal wick is the best choice because such applications require a compact heat sink size with many turns and bends. The high capillary pumping pressure achieved by using a sintered powder metal wick due to its small pore size, allows a heat pipe to operate in any orientation. Other wick structures do not work as well as well in non-vertical orientations because they cannot lift the returning working fluid along the length of the heat pipe against gravity. So, in our heat pipe we primarily decided to choose the combination of sintered powder metal wick – inclined setup – skived heat sink, the main that motivate us to choose this design is the electronics applications which required such combination.

The purpose of adding Heat sink to the project setup:

Integrating Heat-pipe (H.P.) with a heat sinks built with cooling fin assemblies will provide one of the most effective means of providing efficient cooling for power electronics components. The forced air cooled assembly shown opposite achieves an outstanding thermal performance.

With electronic components being the potential sites for heat generation due to their continuous miniaturization, it was identified that their life decreases by half for every 10 degree Celsius rise in temperature. This large amount of heat can be removed by use of different cooling methods available such as use of fans, blowers, heat exchangers or HEAT SINKS (H.S).

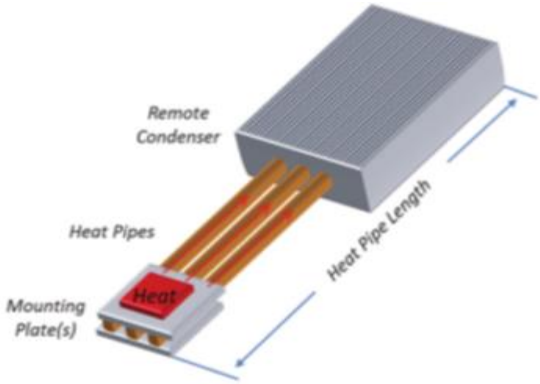

Figure 17: Heat Pipe Design Selected

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7 Appendices

Appendix A: Design Considered

Design #6: Forged Fins

Forged fins heat sink is design in which fins makes in specific pattern and each pattern repeats over the span. This type of heat sink is famous for specialized designs because these sinks develops according to the required shape and design, one of the design is showing in the figure.

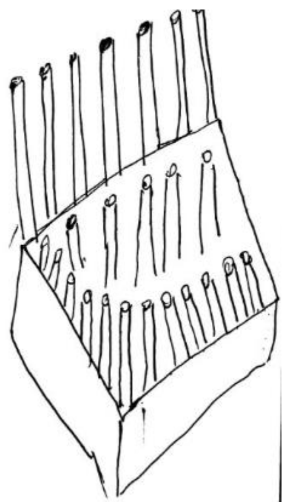

Figure 17: Forged Pins Heat Sink

Typical Benefits:

Fin design in many shapes (pin, square, oval, etc.)

Potential Pitfalls:

Usually reserved for higher volume products as tooling is expensive.

Design #7: Machined Fins

These are smaller type of heat sinks which formed from both aluminum and copper. These type of heat sinks are mostly common to use for electronic machines in which they just need to absorb small amount of heat energy and provide low level of cooling. These heat sinks are common in personal computers and showing in the following figure.

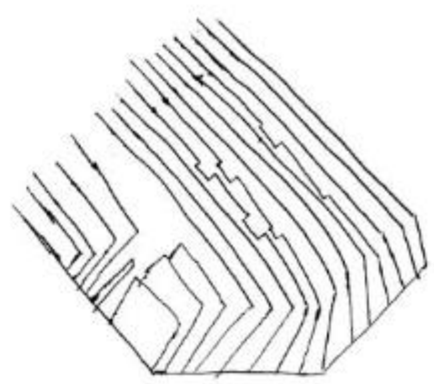

Figure 18: Machined heat Sink

Typical Benefits:

High thermal conductivity

Complicated designs OK

Potential Pitfalls:

None, other can cost.

Not good for high volume due to production time.

Design #8: "Mono-groove" Design

These type of heat sinks are common to use for aerospace machines where condensed form of cooling is requiring keeping the machines workings. In this type of heat sinks, liquid layers are present to provide the quick cooling without getting more heat from other sources. Mono-groove heat sink is showing in the following figure.

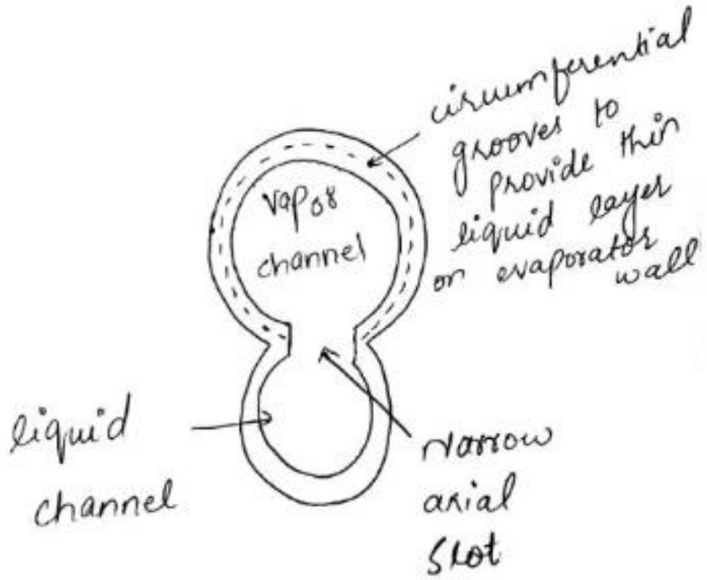

Figure 19: “Mono-groove” Heat Sink

Typical Benefits:

It has a large single groove that provides

Relatively unrestricted longitudinal flow.

Liquid is distributed on the evaporator wall

By means of a secondary wick consisting of small

Circumferential grooves or screen

Potential Pitfalls:

It has encountered difficulties during early

Shuttle testing.

Design #9: Composite Wicks

This design has the grooves as well in the radial web and cause the generate the cooling quickly in the system. Composite wicks use the radial shaped outer body with the liquid in it and circled body which cause the heat sink to absorb more heat in short period of time.

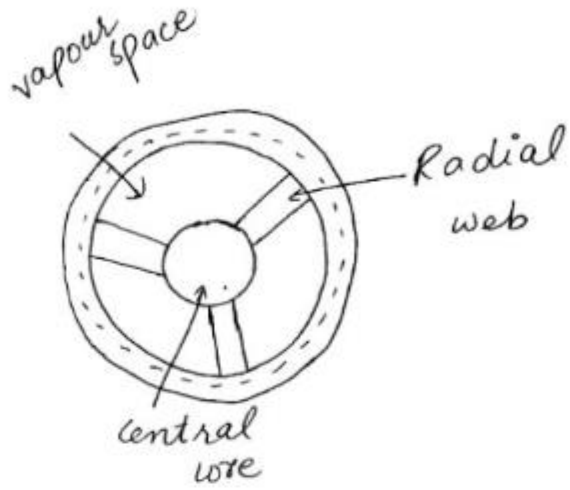

Figure 20: Composite Wick Heat Sink

Typical Benefits:

More capacity can be obtained by using more layers of screen,

To increase the wick flow area.

Potential Pitfalls:

Because the wick must be assembled of relatively fragile materials,

Care is required in building such a pipe, and no two supposedly identical

Pipes will perform in exactly the same manner.

Design #10: Diode Heat Pipes

Diode heat pipes are considering to be the most advance form of heat sinks, in this kind of heat sinks there is no reverse flow, which means the heat will not flow back to the system once it will sink by the diode pipe. In diode pipe, heat sinks through the pipe and stays remains inside the pipe and it can see in the following figure.

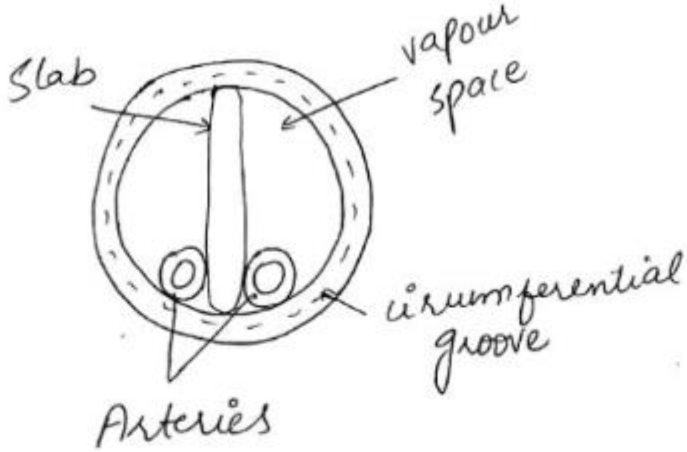

Figure 21: Diode Heat Pipes

Typical Benefits:

A constant-conductance heat pipe can be modified so that

Operation occurs normally in one direction

Potential Pitfalls:

When an attempt is made to transfer heat in the other, "wrong" direction, resulting in a diode action.

Appendix B: Pugh Chart

Table 6: Pugh Chart

Criteria \ Concept	Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7	Design 8	Design 9	Design 10
Durability	+	-	S	S	+	-	+	S	D	-
Reliability	-	+	+	+	S	-	-	-	D	+
Manufacturable	S	-	-	+	S	S	-	S	D	S
Safety	S	S	S	S	S	S	S	S	D	S
Ease of Assembly	-	+	+	-	-	+	-	+	D	-
Variability	-	+	S	+	+	-	+	-	D	-
Easy to Measure	-	S	+	+	-	+	+	S	D	S
∑ +	1	3	3	4	2	2	3	1	D	2
∑ -	4	2	1	1	2	3	3	2	D	2
∑ S	2	2	3	2	3	2	1	4	D	3