Northern Arizona University

"Heat Pipe Demonstration Unit"

Prepared By:
Kaled Aleweehan
Waleed Almutairi
Abdullah Almutairi
Abdullah Ben Gheyam
Omar Alotaibi

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Project Sponsor:
Dr. David Trevas

DISCLAIMER

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Executive Summary

Our team was assigned a task of designing and building a heat pipe demonstration unit for a mechanical engineering laboratory class at NAU. First, we researched on different alternatives of working fluids, wicking materials, and heat pipe materials which were available [4]. Then, we were testing these alternatives in consideration with pressure and thermal conductance. We determined the optimum combination of these parameters that will result to high heat pipe efficiency. We designed a heat pipe using the chosen materials and tested it through laboratory experiments.

Objectives of this project included learning about heat pipes through hands on laboratory experiments. It allowed the team to learn 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 calculated the effective thermal conductivity for the heat pipe and compared it to with high thermal conductivity alternatives.

The project has implemented by stating the project and then determined the existing designs, and determine the customer requirements, engineering requirements and QFD as well. After that different ideas have generated, and these ideas have sorted out using the customer requirements and use the methods Pugh chart and decision matrix.

Final design has selected as the heat pipe with the thermocouples, and the design has then implemented. The developed model used the glass tube and copper covers. It used the thermocouples to determine the temperature and used the syringe to insert the fluid. The fluid used for this purpose is water and it used the vacuum pressure to evacuate the air.

The device has then tested after implementation and results have shown that all the tests have passed successfully. It passed the engineering requirement targets as well.

ACKNOWLEDGEMENT

This project was a success and it would not be possible without the help of a lot of people. First we would like to acknowledge out professor Dr. Sarah Oman for all support and guidance. We would also like to thank the client Dr. David Trevas to give us the opportunity to take this project and for his time and patience with every task. Finally, we would like to appreciate all the team members for all the efforts for keeping up the team spirit.

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1 BACKGROUND

1.1 Introduction

Demonstration units were used in laboratory classes in the Mechanical Engineering Department at Northern Arizona University (NAU) to teach students engineering principals. Our project was to build a heat pipe demonstration unit, which will help students understand the basic principles of heat transfer and thermodynamics. The term heat pipe is pretty self-explanatory. A heat pipe is a vacuum pipe that filled with a liquid. Apart from the plain pipe a wicking material is added that transfers heat much faster than a stand-alone pipe because it uses conduction and convection as opposed to conduction alone [1]. Conduction and convection both processes occur at the same time which causes the heat pipe to increase the transfer rate. Conduction process occurs when two medium interlinks with each other and in the heat pipe, conduction process occurs because of wicked material and convection is the process which occurs naturally because of the difference in temperature of the medium.

The heating pipe innovation is the premise of the all radiators dependent on autonomous vanish circuit. The heating pipe innovation has demonstrated records in the distinctive territories, for example, space, warm capacity, tackling of sustainable power source, heat recuperation of different procedures, residential vitality effective cooling frameworks and in microelectronics. The principle issues in the radiators dependent on a free vanish circuit were the low heat exchange and the commotion of bubbling fluid inside the warm board amid task.

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. The working liquid when comes in contact with the part of the pipe with high temperature, vaporizes while keeping the pipe at that same temperature. 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 [2]. 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. Heat pipes are commonly used in electronics and space applications, where rapid heat transfer to remove heat from the system is necessary [3].

Heat pipe are instruments that are widely used in several field. These instruments can be used in several sizes and for many purposes. Hence the idea of building a heat pipe was very interesting. The sponsor for this project was our instructor, Dr. David Trevas. While building this project we realized that this instrument has taught us a lot about how HT works also it gives us a firsthand experience at working on an actual instrument rather than a theoretical study of heat transfer. It also gave us a feel of the industry, how the client's demands are taken and how engineering requirements need to be done based on the customer needs and how the project timeline is decided and worked on. This project was also beneficial to the stakeholders such as mechanical engineering students and faculties at NAU because this can serve as a preliminary analysis and a guide for further studies in heat pipes. It also gives them details and ideas of how heat pipes work.

1.2 Project Description

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2 REQUIREMENTS

This section contains the requirements needed to design a heat pipe in mechanical engineering laboratory. This includes 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.

The House of Quality (HoQ) was a tool that determines the factors that were deemed important by the customers. It takes into consideration the seven management and planning tools. With the help of this, there was a smooth transition between the customer's requests to creating engineering requirements. To finalize the requirements, the engineering requirements should be in limits, so the team should have upper and lower targets for them. This methodology will make accurate data for the team while doing the project.

2.1 Customer Requirements (CRs)

Customer requirements (CRs) were generated by meeting with our client and discussing what was most important for this project. Additional CRs were taken by looking at existing designs for heat pipes and what their advantages were disadvantages. Table 1. Below contains the CRs for the project.

Table 1. Customer Requirements.

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

The above-mentioned customer requirements were the basis on which this project was built. The team weighed the CRs based on their importance. The highest weight of 0.17 was given to variability. This was given the higher weight because it is fundamental to everyday usage. Following variability comes durability and accuracy at 0.16. This is because the heat pipe must be durable to withstand the thermal load for long time. The next weight comes in at 0.14 for ease of assembly. This was assigned the weight of 0.14 because they were important for the product to be installed easily and be user friendly. The next lowest weight comes from safety at 0.13. This was because safety of the human being was very important especially in mechanical engineering laboratory. The lowest weighted requirement was manufacturability and operate in various conditions, with a weight of 0.11. This was because while cost was 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 was 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 were targets that should be accomplished by the team in designing the pipe. For instance, the setup time was 1 min. When the team finished the design and had some changes because of the fact that the targets considered at the start were not real and were not achievable because it was not reality-based, the targets were moved forward to achieve optimum performance.

Table 2. Engineering Requirements.

ERs	Description	Targets
Operating temperature range	The materials must be able to withstand the maximum operating temperatures of 200°C.	>200 degrees Celsius
Reliability	Gives the same performance for a period of time	>5 years
Set-up time	Able to set up the experiment within 1 min.	<1 min
Size	Volume of the set up useable	3 cubic feet
Light Weight	Light weight to utilize it in better way	3 Kg

2.3 Testing Procedure

There were different procedures to test the requirements. These testing procedures have used at the end of project to test if the requirements have achieved or not. Testing procedures explained the methodology used to do the testing which include the apparatus and equipment as well.

1 Durability

To test the durability, a maximum amount of pressure was subjected to the device. A vacuum pressure with a gauge was used in the pressure test. In this case the device was able to withstand maximum pressure applied to it hence a conclusion was made that it is durable. Also, high quality materials were used and this guaranteed durability of the device.

2 Accuracy

The device was supposed to give similar results after conducting numerous tests. The device was subjected to a lot of tests and the results obtained were similar. In case there were variations, they showed a very small error which was insignificant.

3 Manufactural

This requirement was tested during the actual making of the device and since it was possible then it was manufactural.

4 Safety

The product was not supposed to harm the user and hence safety tests were conducted by looking for any leakages and also for protruding and sharp features. Since there were no leaks and sharp or protruding points, the device was considered to be safe.

5 Ease to Assemble

In order to determine the ease of assembly the team embarked on doing the actual assembly. They did it without any difficulties and hence a conclusion was made that it was easy to assemble.

6 Variability

To test for variability, the device was subjected to different temperatures which were then measured using a thermometer with thermocouples. The results revealed that there was no significant variation.

7 Easy to Measure

Various measurements were made by use of a variety of devices. For instance, angles were measured by use of a protractor. Measurement and observations were easy to make.

2.4 House of Quality (HoQ)

House of quality is a table of matrix, which tells the factors that were important to the customers. Therefore, it was vital to relate engineering requirements with the CR's and see which engineering requirement was most important from the list and which must be focused on. 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 was most important and lowest percentage of RTI was least important engineering requirement.

In Table 3, the team related the customer requirements to the engineering requirements. A high number in the intersection of the row for CR and column in ER dictates the strength of relationship between the two. For example, durability has a relationship of 9 with material melting point while it has only 1 with set- up time. This means that the material melting temperature will greatly affect the durability while set-up time will not affect it. This was done in all CRs and ERs. A strength number of 8-10 means that it has strong relationship, 5-7 was moderate relationship, and 1-4 was weak relationship. Also seen in the HOQ was the importance number, the higher the number, the more important the customers feel about that certain aspect. For example, durability has an importance number of 9. This means that the customers greatly desire a durable product. This was basically a reflection of the CRs. The number in each column was multiplied by its corresponding importance number then it was summed. The number with the highest column sum means that the ER in that column must be prioritized by the team in designing the heat pipe.

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

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	3	5
Upper Target Limit		200	5	1	3	5
Lower Target Limit		50	3	0.5	1	3
Units		C	Years	Min	ft^3	Kg

3 EXISTING DESIGNS

This part included the research that the team has conducted into what subsystems already exist for the heat pipe. Researching these systems was mainly done by searching for previously done thoroughly for the heat pipe.

3.1 Design Research

Research has done by searching over the internet using Google and searched through the google scholars. In google scholar's different searches have done in order to get some design research. After that few searches have done on different online platforms including IEEE website and other libraries, to find some existing designs. For the project extensive research has done to find the articles related to the project.

The main objective of this capstone design project was 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 [5]. Then, measure and report the response-time and temperature profile along the heat pipe and calculate the effective thermal conductivity for the heat pipe compared with high thermal conductivity alternatives. Finally compare different scenarios for the wick materials.

3.2 System Level

This section discusses the different existing designs of heat pipes. However, it is important to have a prior in-depth understanding of the internal processes that happens in a 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 [7]. Three sections characterize a heat pipe, the evaporator, the condenser, and the adiabatic section [8]. Evaporator part sinks the heat from the high temperature side and converts the coolant or the working fluid to vapor inside. First, it will vaporize then by latent heat, the fluid will condensate. At low temperature, the latent heat will allow the vapor to condensate. The condensate will go back to the evaporator using the wick. However, in case that the pipe has no wick, it will utilize gravity to return [9].

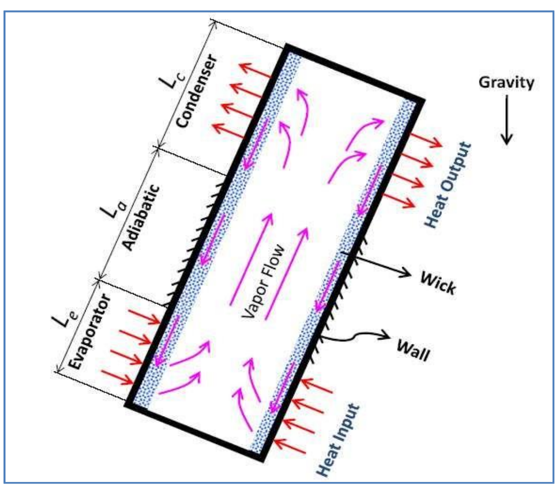

Figure 1. Schematic view of Heat Pipe [27]

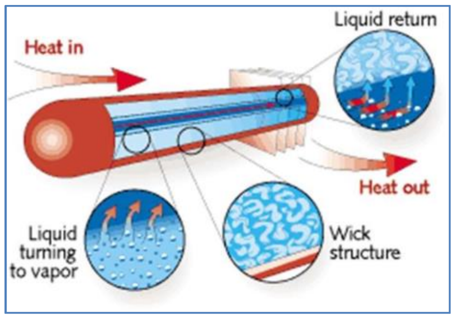

Figure 2. The Structure and functioning of a heat pipe. [28]

Heat pipes can transport a wide range of power. This will depend mainly on the design on which the pipe was created as well as the application that it aims to provide. For a given thermal gradient, heat pipes were 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 dramatically decrease. Therefore, it was very important to design the heat pipe to safely transport the required heat. Heat transfer capability of the heat pipe was depending on several limiting factors viscosity, capillary pumping, flooding and boiling.

3.2.1Existing Design #1: Grooved base type

This design, as shown in Figure 3 has a heat exchanger that allows flat pipes to be connected. This was very helpful in this design since it was basically a combination of the local heat sink and the remote heat sink. The remote heat sink was incorporated to maximize the thermal performance [7]. This design was lighter and cheaper compared to other designs. This type was usually used for slightly flattened heat pipes. Compared to the next type to be discussed which was the mounted grooved type, it does not have a base plate. Thus, the pipe can pass through along the middle of the stack.

Figure 3. Grooved base type Heat Pipe [4].

3.2.2Existing Design #2: Grooved mounted block type

The second existing design is shown in Figure 4. The heat pipes are mounted in holes. These holes are typically bigger by 0.1 mm [7]. If the pipes are more round at the heat source, a thicker grooved mounting plate is needed as seen in Figure 4. This type, however, has some thermal issues. These thermal issues make this existing design a good opportunity to improve it with the new way of grooved.

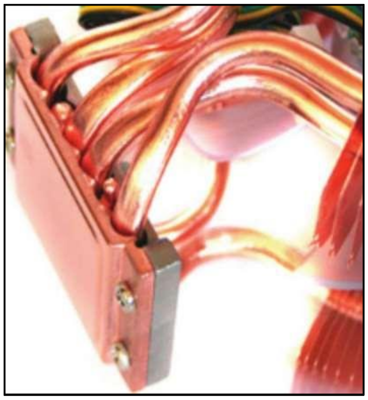

Figure 4. Grooved Mounted Block Type Heat Pipe [4].

3.2.3Existing Design #3: Direct contact type

The third existing design was shown in Figure 5. Sometimes, much heat was lost because of the base plate and extra TIM layer, thus, additional flatting and machining was needed to enable more fluid to touch the surface as seen in Figure 5 [7]. This was a good heat sink since it can decrease the temperature by as much as 2 to 8 degrees Celsius. Although this type decreases the thermal resistance, it doesn’t dissipate heat as effective as the other types.

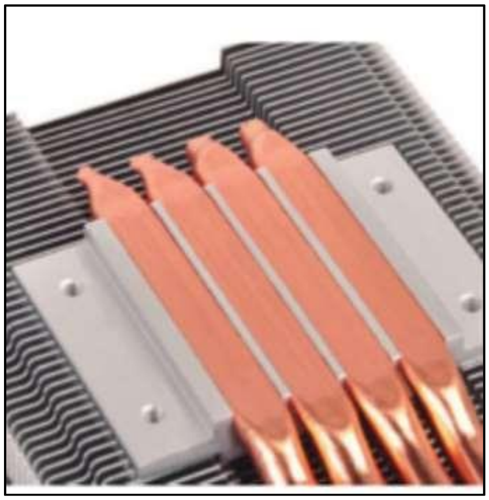

Figure 5. Direct Contact Type Heat Pipe [4].

3.3 Functional Decomposition

Functional decomposition was a process of decomposing the complete working module for the project. This was the expected working of product, observed after seeing the existing designs. There were two types of functional decomposition, one was a black box model and the second was a functional model. Black Box model shows the inputs and outputs of the system in the form of material, energy, and signal. The functional model shows the internal working of the project and shows the processes that use 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 was the internal working of system. It only focuses on the inputs going into the system and outputs that were coming out form the system. The Black Box model shows the inputs as "Material (Hand, Wick materials, and Liquid), Energy (Electric Energy), Signal (On/Off, Temperature dial, and pressure)" and the outputs as "Material (Hand), Energy (Heat and cool), Signal (On/Off, Temperature Reading pipe)". Black Box model has shown in Figure 6.

Figure 6. 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. For our project system, it will take the heat into the pipe, that heat the liquid present in the pipe. It will convert the liquid into vaporize liquid and then vapors will move towards the condenser to get cool, at the same time some of the vapors raise the temperature of wicking material and cool down the vapors by absorbing the heat. The vapors go to the condenser also gets cooled and release the cooling and the cycle restart again by absorbing the heat and cool down the system.

Shown in Figure 7 was a model 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.

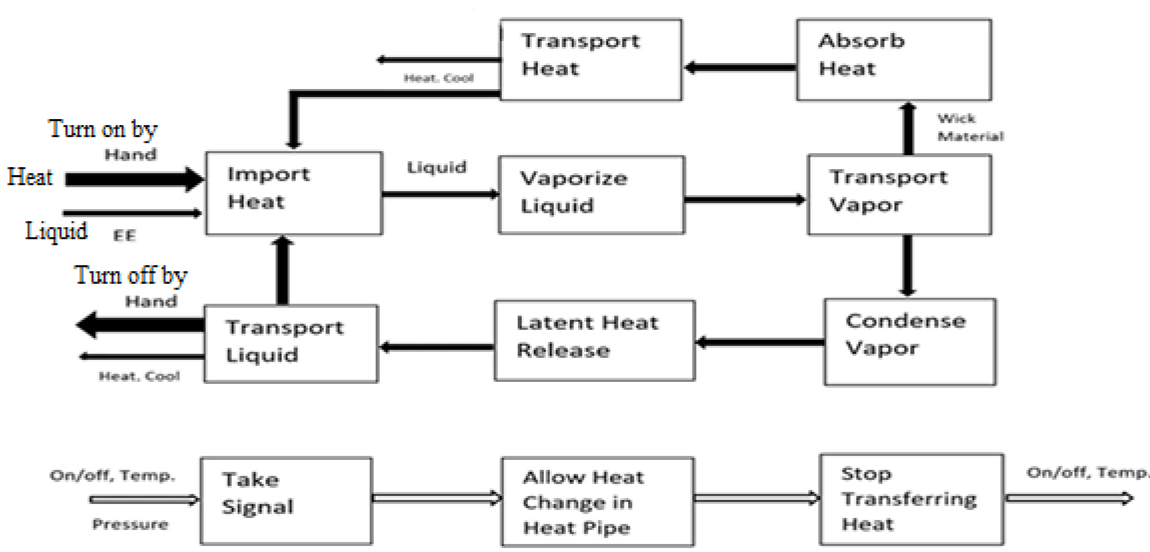

Figure 7. Functional Decomposition Model.

In the above figure 7, there is a hand at the input which turns on the heat pipe and then heat will import into the pipe and the liquid will also come into the pipe for transferring the heat. And when the process will complete, hand will use to turn off the heat pipe, that's why hand has mentioned as the input and output.

3.4 Subsystem Level

The Heat pipe setup construction can be broken down into the main subsystems which are the heat pipe material, wick material, and working fluid. It has a few options for design that the team had to consider when picking a design.

3.4.1 Subsystem #1: Heat pipe material

Heat pipe material was important because it will dictate the working temperature and pressure of the pipe. It will provide a vessel so that the working liquid will not leak.

3.4.1.1 Existing Design #1: Copper

Copper pipes were durable, lightweight and easy to work with which makes it a typical choice. It was corrosion-resistant. It was also less expensive while being environmentally friendly and these pipes are already available [9].

Figure 8. Copper pipe [29]

3.4.1.2 Existing Design #2: Aluminum

Aluminum pipe were usually used for high-temperature piping. It was usually used in spacecraft thermal control.

Figure 9. Aluminum pipe [30]

3.4.1.3 Existing Design #3: Iron

Iron pipe has high machinability and good wear-resistance. It was more preferred for high pressure loads.

Figure 10. Iron pipe [31]

3.4.2 Subsystem #2: Wick Material

In this section, the different types of wick materials that can be used in heat pipes were further discussed. Consideration of the wick material to be used was very important because it can improve the condenser's heat transfer rate, which was directly proportional to the heat pipe's efficiency.

3.4.2.1 Existing Design #1: Grooved wick type

In this design, see Figure 11, a grooved heat pipe was a copper tube with a series of shallow grooves on the inside face of the pipe. The performance of heat pipes with axial groove wicks was very good, provided that the application does not call for a significant adverse elevation against gravity. For systems that employ up to 40 W/cm^2 of radial heat flux, this design was usually used.

Capillary action was affected by the grooves on the inside of the heat pipe. The efficiency of this design depends on the shape of the grooves. Manufacturing costs were low with this type of heat pipe because the grooves were easier to make, however the technique was much more susceptible to gravity and can be orientation specific in use.

Figure 11. Grooved Wick Type Heat Pipe [10]

3.4.2.2 Existing Design #2: Metal mesh (felt) wick type

As shown in Figure 12, the wick of this type was a metal mesh. The mesh was adhered to the inside wall of the pipe. This will allow heat transfer by capillary forces in the wick. This was one of most commonly used type of wick. Its heat transfer capability was greatly affected by the number of layers and mesh counts used in the wick.

Sometimes a metal felt based wick structure was used which was held in support by a metal foam.

Usually, copper and stainless steel were used to manufacture the metal mesh. By varying the pressure on the 13 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 were capable of operating in gravity-aided and horizontal orientations and were 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.

The few times we have dissected a heat pipe here this was the kind of metal wick structure we discovered. In a freshly cracked open heat pipe the wick would be slightly wet.

Figure 12. Metal Mesh (felt) Wick Type.

3.4.2.3 Existing Design #3: Metal sintered powder wick type

In metal sintered powder, see Figure 13, the sintered powder sticking to the inside walls of the pipe. This transfer the cooling fluid by a process called capillary action. It was important to be knowledgeable on this design well because this was a powerful design especially when dealing with designs that were not in the direction of gravity. This design allows very tight bends in the heat pipe.

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Figure 13. Metal Sintered Powder Wick.

3.4.3 Subsystem #3: Working fluid

Working fluid was important because it will transfer heat by through evaporation and condensation. It gives the heat pipes high effective thermal conductivity. A liquid’s pumping capability was measured by Merit number. The higher the Merit number, the better.

3.4.3.1 Existing Design #1: Water

Water was the most common, cheapest and safest cooling fluid in existent. It has the highest Merit number among all other cooling fluids at around 1.77894E+12.

3.4.3.2 Existing Design #2: Ammonia

Ammonia was usually used in high temperature heat pipes like a spacecraft thermal control. It was also used together with an aluminum pipe. It has around 3.19972E+11 Merit number at 20 degrees Celsius.

3.4.3.3 Existing Design #3: Methanol

It usually used as an alternative when water and ammonia were not available or suitable with the heat pipe material. It has around 3.17293E+11 Merit number at 20 degrees Celsius and was the third highest among other fluids.

4 DESIGNS CONSIDERED

In this section different design ideas have implemented, related to the project and these designs are following the customer requirement as well. These designs were then narrowed down to final design on the basis of given requirements for the project. These designs have generated using different concepts of heat sinking that can use for the project.

4.1 Design #1: Extruded heat sink

One of the most effective way of sinking heat was through extruded heat sink (see Figure 14). 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 was the sketch of heat sink.

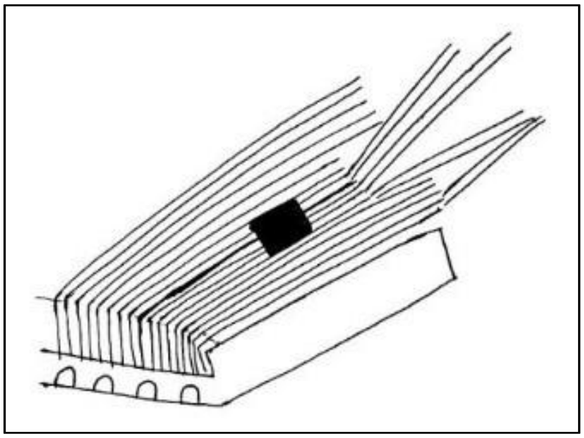

Figure 14. Extruded Heat Sink.

Typical Benefits:

- Readily Available
- Easy to manufacture to custom specifications Including groove for heat pipe

Potential Pitfalls:

- Dimensions were limited.
- Fin height limited ~20x fin width
- Base and fins were same material, usually aluminum

4.2 Design #2: Die cast heat sink

It was 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 Figure 15.

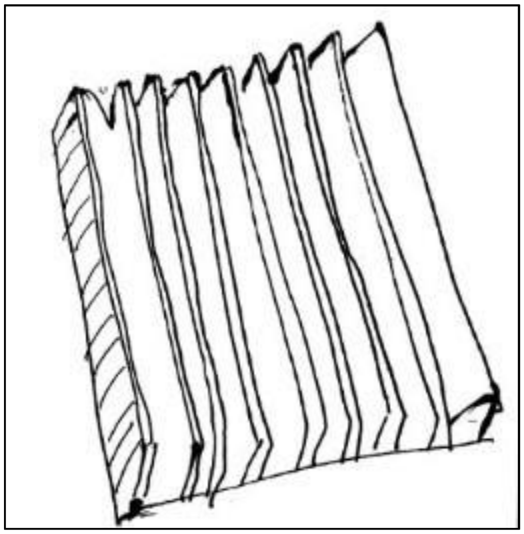

Figure 15. Die Cast Heat Sink.

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 was 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 Figure 16.

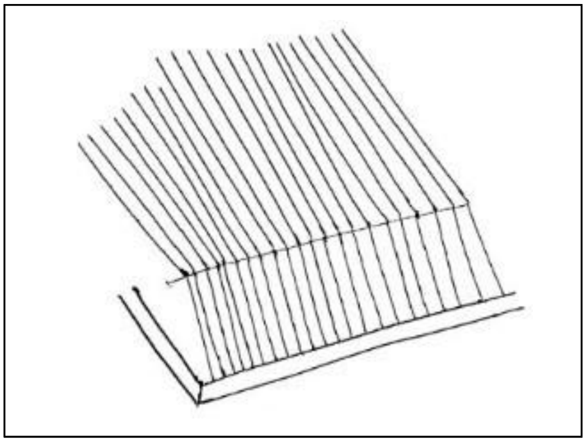

Figure 16. Bonded Heat Sink.

Typical Benefits:

- Large heat sink sizes
- Base and fins can be of different materials.

Potential Pitfalls:

- If fins were epoxied in place, added thermal resistance.

4.4 Design #4: Skived

It was a single form of block with cooper plating uses in it. It provides high cooling system because it was made up of skiving, with the stamped or folded fins. It can see in Figure 17.

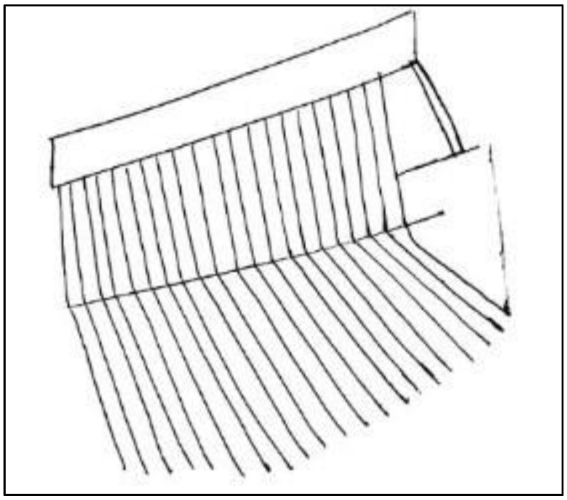

Figure 17. Skived Heat Sink.

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 were packed from both the sides and the fins have formed in the same way as a zip was present. There was 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 Figure 18.

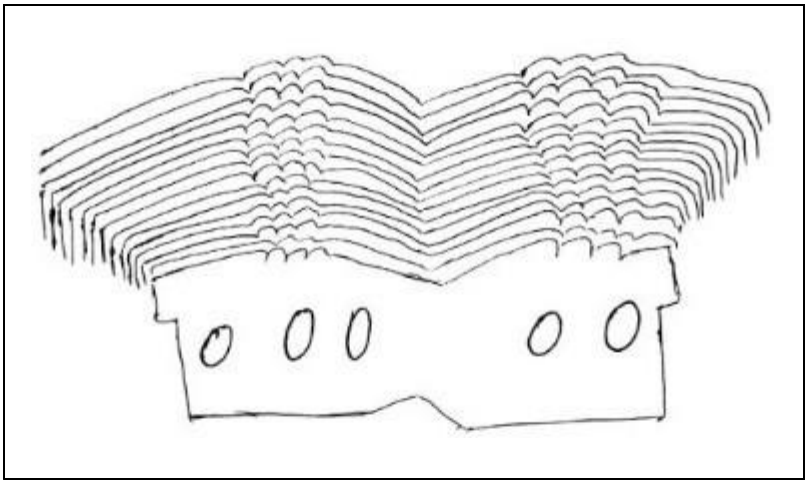

Figure 18. Zipper Heat Sink.

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.

-Refer to the Appendix for the other available heat sink designs.

5 DESIGN SELECTED – First Semester

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 was built on (HoQ) analysis. Also, the concepts mentioned in the previous section were 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.

The paragraph also describes the various parts in the heat pipe setup that helps complete this research and study. It also talks about the chosen alternatives for this study.

5.1 Rationale for Design Selection

Pugh chart has used to narrow down the results for the selection of final design. And the criteria for the selection of final design used in Pugh chart was customer requirements. And the results of Pugh chart can see in the Appendix C. After that decision matrix has used to select the final design, and the selected design for decision matrix were the top three designs of Pugh chart.

From Pugh chart we got the top three designs Die cast, Bonded, and Skived designs. These designs have used in Decision matrix. Decision matrix also used the same criteria to select the final design and the decision matrix has shown below in the table 4.

Table 4. Decision Matrix,

Weight / Criterion		Die cast			Bonded			Skived		
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

Final design selected from the decision matrix was Skived Heat sink pipe as it got the highest marks in decision matrix. And after that we have finalized that we will use wick structure and the reason of using wick structure was given as, it was vital to consider the role that the heat pipe was used. If a heat pipework in conditions with favorable gravitational force and a few bends, the grooved wick heat pipe was 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 was the optimum wick structure. 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 was the electronics applications which required such combination (see Figure 19).

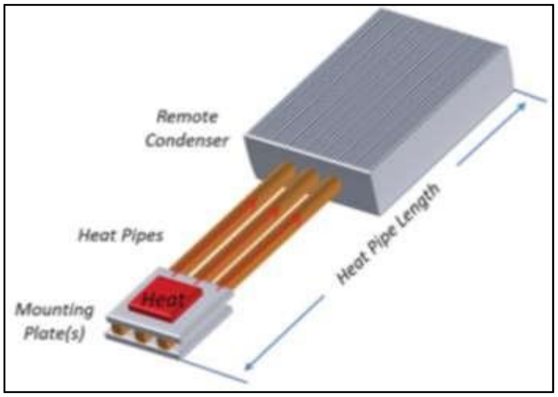

Figure 19. Heat Pipe Design Selected.

5.2 Design Description

There are five components that the team has considered as discussed earlier. These were the working fluid, heat flux, wick materials, pressure and thermal conductance. This section will focus on the chosen alternative for each of the components.

5.2.1 Prototype Design

For the prototype as shown in Figure 20, the heat pipe material that was used was copper. This comes with copper caps and a valve on the right side (see Figure 20). The length of the pipe was 2ft with an extension of 0.25in for capping the pipe. By extension means the cap will cover the pipe and it will be outside the length of pipe and provide around an extra part of 0.25 in. A candle was used as a heat source while a vacuum was used to control the pressure inside the pipe. A thermometer with thermocouple wires was also used to measure the temperature. The considerations used in choosing these features and specifications was further discussed in the next sections.

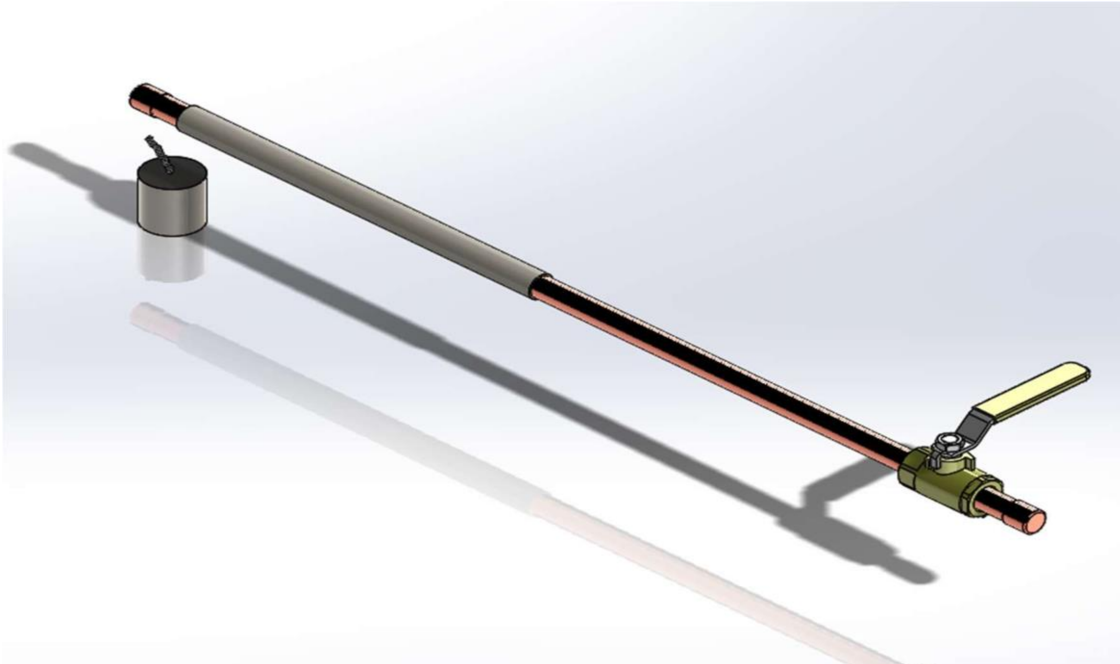

Figure 20. Heat pipe prototype

In this prototype, the team used all the materials listed in the bill of materials in Appendix D Table2. Most of the materials will come from HomCo Lumber and Hardware and Walmart while the thermometer and automotive kit were ordered from Amazon and ToolDiscounter respectively.

To understand the pressure changes, the boiling point analysis has done and according to that analysis

$$\ln\left(\frac{P_2}{P_1}\right) = -\frac{\Delta H_{vap}}{R}\left[\frac{1}{T_2} - \frac{1}{T_1}\right] \qquad (1)$$

Now putting the values again into the equation as

$$T_B = \left(\frac{1}{T_o} - \frac{R \ln \frac{P}{P_o}}{\Delta H_{vap}}\right)^{-1}$$

It proves that when the external pressure has reduced then the boiling point has reduced as well which means both were linking directly with each other.

5.2.2 Full Design

After implementing the first prototype, the team identified that glass can be a superior alternative to copper for obtaining a higher heat flux. For this project, a heat pipe made of quartz glass was exploited, as depicted in Figure 21. This pipe consists of at least 99.9% silica and has a high melting point. It can be used at temperatures of up to 1200°C since its softening point was not reached until 1683°C [19]. The pipe's outer diameter was 25 mm, its inner diameter was 22 mm, and its length was 2.5 ft., with an extension of 0.8 ft.

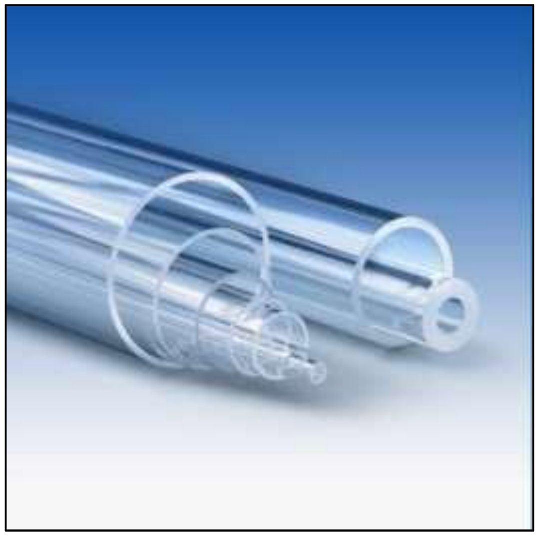

Figure 21. Quartz glass heat pipe

Besides, heater band can be used as an alternative heat source as it does not involve open flames, as portrayed in Figure 22. The device has a nozzle temperature of 537°C and has at least 275 watts at 120 volts.

Figure 22. Heater Band.

Each component of the heat pipe and the rationale behind choosing the best material will also be discussed in detail. Also, we will use 4-way valve instead of 2-way valve. Below figure 23 show the full design.

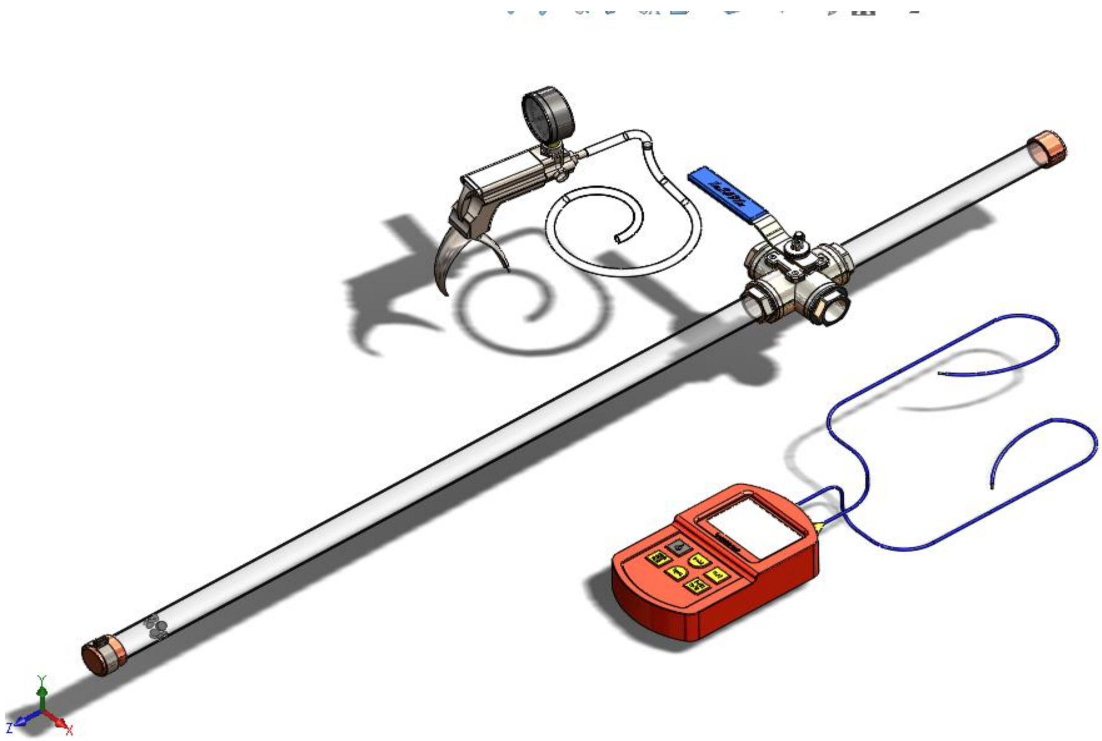

Figure 23. Full Design

5.2.2.1 Heat pipe material

Different materials have considered for the pipe manufacturing like aluminum, steel and copper. The analysis has done on the thickness of material as well and from the analysis it has found that thickness of material varies along with the heat transfer in reverse order as showing in the figure 24.

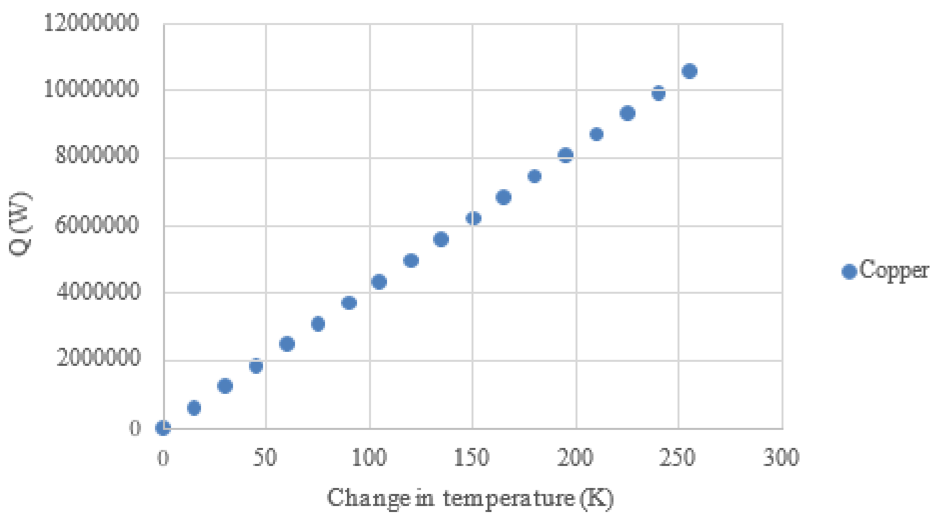

Figure 24. Effect of change in temperature on Q

Analyzing the materials, it has found that copper has highest rate of heat transfer comparing with the aluminum and it has depicted in the figure 25 as well.

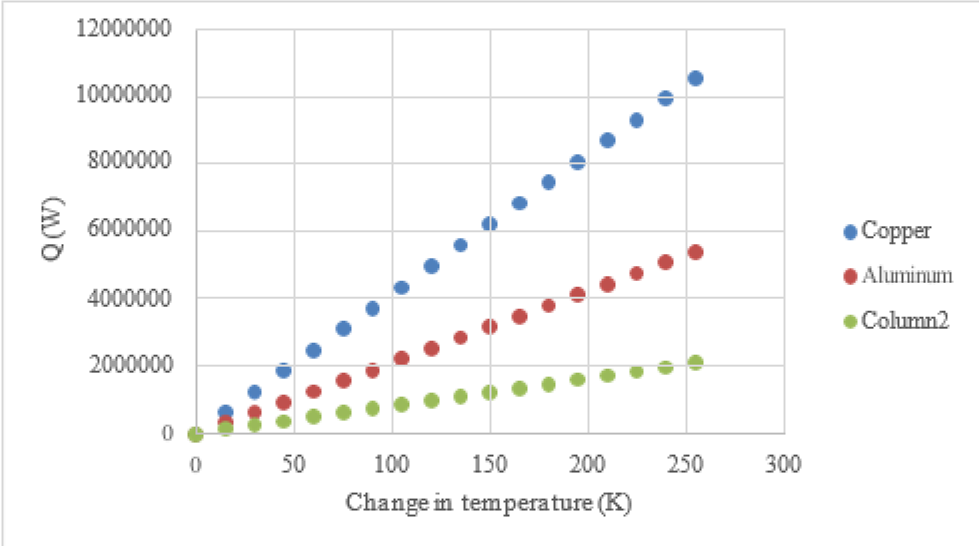

Figure 25. Q of a standard pipe

Based on the Monotaro.ph, the cost of a copper pipe compared to an aluminum and iron pipe was much lower which was $5.99 per piece [13]. The team conducted an experiment with the initial prototype; however, it was discerned that the glass pipe would be more appropriate for the project since it could result in a higher heat flux. Thus, for the full design, the team was relying on a quartz glass pipe instead of the initially planned copper.

5.2.2.2 Wick material

The heat pipe considered in this project was made of copper with water as working liquid. The parameters used in this analysis were shown in Tables 7-9.

Table 5. Copper heat pipe parameters.

Copper Pipe data			
total length	lt	0.3	m
inner radius	ri	0.01	m
Axial Angle	Ψ	30	Degree
thermal conductivity	λm	394	W/m C

Table 6. Properties of Water as working fluid at 100.

$Liquid\ density\ (\rho l)$	958	kg/m3
$Surface\ Tension\ (\sigma)$	0.00589	N/m
$Latent\ Heat\ (\lambda)$	2258000	J/kg

$Liquid\ Viscosity\ (\mu l)$	2.80E-04	Ns/m2

Table 7. Compatible wick data.

$Compatible\ Wick\ Type$	250 mesh	
$Wire\ diameter$	0.000045	m
$Layers$	Single, double & Triple	
$Wick\ length\ (Leffective)$	0.26	m
$Wick\ Permeability\ (Kwick)$	3.02E-11	m2
$Wick\ Area\ (Awick)$	8.48E-06	m2
$Pore\ size\ of\ wick\ (rc)$	2.00E-05	m

Heat pipes fluids were ranked by the Merit number which as shown in formula 1:

$$N = \rho * \sigma * \frac{\lambda}{\mu} \quad (3)$$

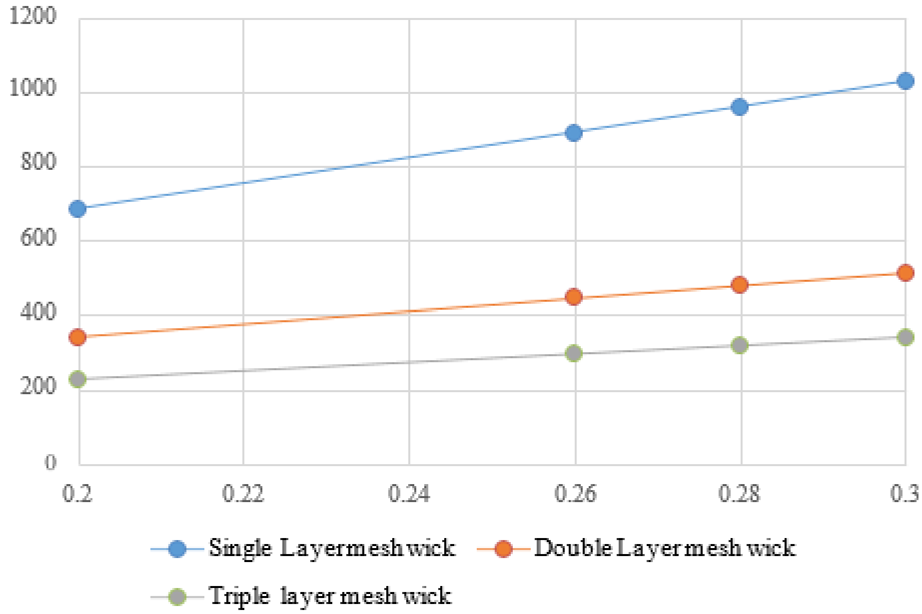

Figure 26. Pressure drop vs wick were and effective length.

Table 8. Heat transfer vs wick area and effective length.

Single Layer mesh wick	L Effective	Amount of Heat Transfer
	0.3	1.29

	0.28	1.39
	0.26	1.49
	0.2	1.94
Double Layer mesh wick		
	0.3	2.59
	0.28	2.77
	0.26	2.99
	0.2	3.88
Triple layer mesh wick		
	0.3	3.88
	0.28	4.16
	0.26	4.48
	0.2	5.83

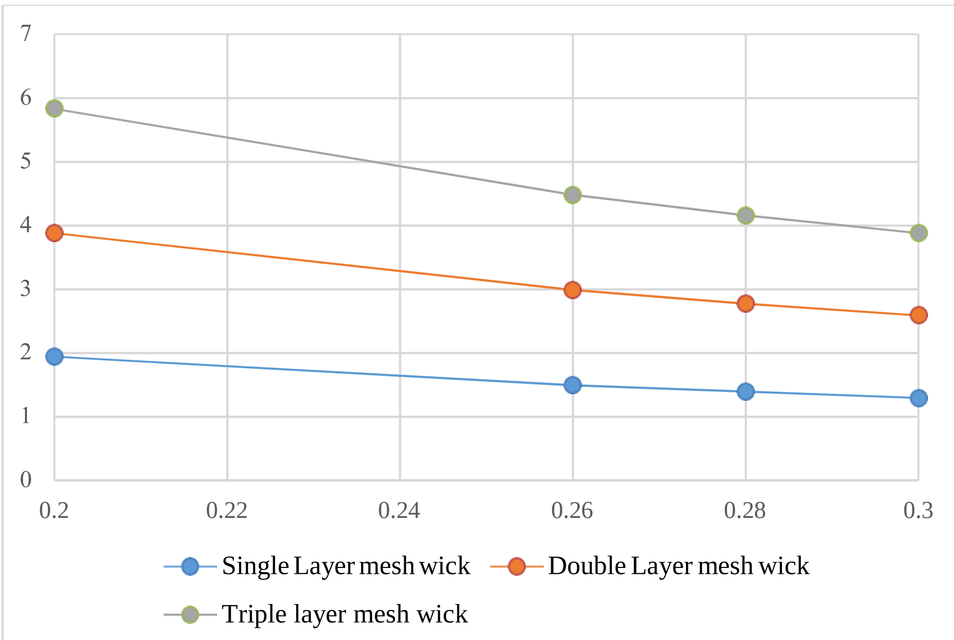

Figure 27. Pressure drop vs wick were and effective length

Hence, for this project, the team will use a cotton cloth in the form of a wick.

5.2.2.3 Working fluid

The selection of the heat pipe determines its overall performance in terms of heat flux or transfer. Various types of heat pipes can be modified using forced convection to increase their performance. The design features of the pipes were responsible for their advantages and disadvantages. In addition to the material used and the dimensions of the pipe, the fluid also has an impact on the overall heat transfer rate. High liquid density and latent heat were preferred as the fluid flow needed to transport the same energy was reduced. A high surface tension was also favored since it increases the pumping capability. However, for the liquid viscosity, a lower value was desired for lower liquid pressure drop [11].

The fluids that were typically used in heat pipes were water, ammonia, and methanol. Based on the preliminary study made by the team, water was chosen as the best cooling fluid. Its Merit number was computed as shown below. The values of the properties were taken at room temperature, that was, 25 degrees Celsius, which was summarized in Table 9.

Table 9. Thermophysical properties of water, ammonia, and methanol

Fluid	Density (kg/m3)	Latent heat (kJ/kg)	Surface tension (N/m)	Viscosity (Pa)	Convective heat transfer coefficient (W/m^2K)
Water	997.0479	808	0.072	0.000894	3000

Thus, water must be chosen as the fluid for the heat pipe.

5.2.2.4 Thermal conductance

The heat pipe operation was based on the phase transition and characteristics of a fluid as a component to transfer heat with high efficiency. Generally, the heat pipe was a sealed container in the form of a tube that contains a wick lining in the inside wall [17]. The wick serves to transport the working fluid in the heat pipe from one end to the other via capillary action. The heat pipes were desirable due to the following advantages; high thermal transportation capability, changeable thermal flux density, constant temperature characteristics and excellent isothermal performance [17]. The advantages have increased the applications e.g. in spaceflight, computers and heat reclamation from waste smoke.

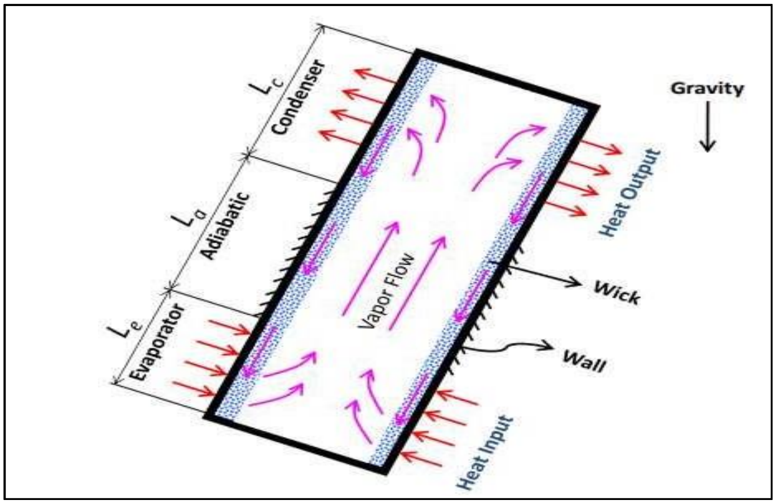

Figure 28. The schematic of the heat pipe

The purpose of the experiment was to assess the operation of fins in a general heat pipe system.

The experiment will compare the results for the materials used for creating fins.

The initial phase will entail the derivation of the relevant differential equation. Once the equation had been derived, the simulation code was created in MATLAB and run to produce the resultant graphs. The graphs would be used to compare the result of the experiment.

Consider a rod of 20 cm diameter and 25 cm length, in which the heated end would be 100°C and the temperature of ambient air would be 22°C.

Table 10. Temperature changes along the fins

Material	Initial Temperature (°C)	Final Temperature (°C)
Copper	100	68.69
Steel	100	38.34

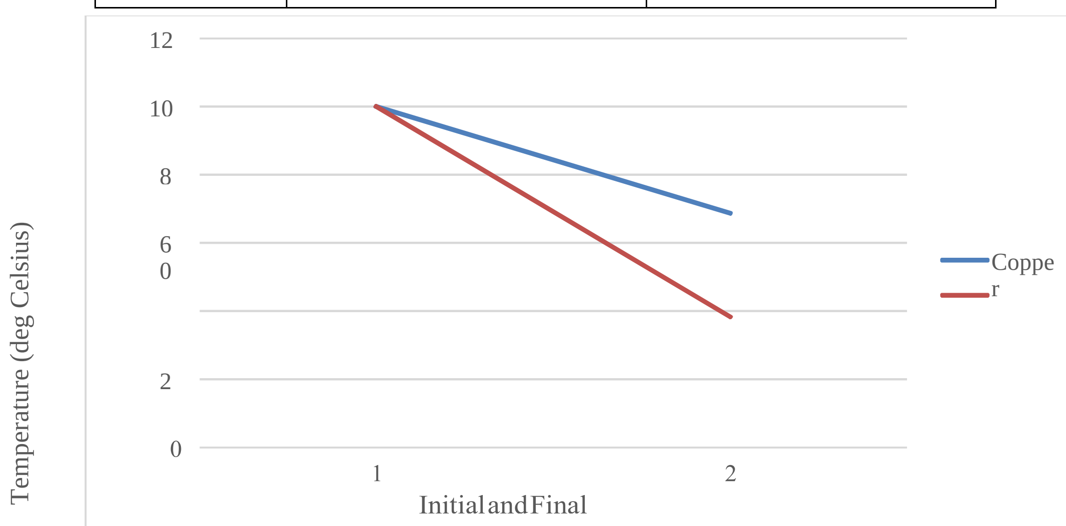

Figure 29: Change in the temperature along the fins.

6 PROPOSED DESIGN – First Semester

For the first semester, the proposed design, the team made use of a glass pipe with 22 mm and 25 mm inner and outer diameters, respectively. Since the pipe was special and was made of quartz glass, the material was sourced online from Technical Glass Products. Most of the products, such as the copper caps, valve, clips, wire trivet, coasters, stand, and water were readily available in either Walmart or HomCo Lumber and Hardware in Flagstaff. The electronic gadgets, such as the thermometer and timer were sourced from Amazon, while the automotive kit was procured from ToolDiscounter. Moreover, a special heating source, which was the heater band, was ordered from an online store called Omega. This store specializes in heating products. A summary of the materials bill was attached in Appendix Table 3.

6.1 Prototype Implementation

Shown in Appendix D Table.2 is the bill of materials for prototype design. The copper pipe outsourced from HomCo.com while the candle is from Walmart.com. Also, we used 2-way valve from HomCo.com as shown Figure 20.

Before embarking on the experiment, the team gathered the materials needed for the project: thermometer with thermocouples, water as a working fluid, syringe for measuring the liquid, vacuum to control the pressure, extension pipe, 2-way valve, and the copper pipe.

The first step was to vacuum the pressure in the pipe. Then, the valve was closed. The syringe was used to measure 10 mL of the working fluid, which was transferred to the extension pipe. The device was closed by attaching the pipe to the other side. The valve was also kept closed to maintain the pressure inside the pipe. The room temperature was checked for computational purposes and found to be 22°C. Subsequently, the thermocouples were connected to both ends of the pipe for measuring the temperature. As soon as the set-up was completed, and the working fluid flowed down the pipe, the heat source was utilized to increase the inside temperature. After 10 minutes, the reading was again taken using the thermometer with thermocouples.

6.2 Proposed Design Implementation

For the full design, the team allotted 16 weeks for its completion as shown in the Gantt chart in Table 13. This was done from the 18th of August 2018 to the 7th of December of the same year. The first week was allotted for the finalization of the design. The team needs to be sure that all aspects of the project was considered since most of the acquisition of some of the materials was done online. This was to ensure that all parts. Canvassing of the materials was also put in the first week because although the team has already established the sites where the materials was bought, the availability of the desired specifications was still subject for change. In the second week was the placement of orders in the online shop. There were three weeks allotted for the waiting of orders to arrive since some of the materials was from an online shop. The shipping was very variable since it will depend on the courier.

When the orders arrive, the team can now start to manufacture the full design. Two weeks was allotted for this to give way for some modifications on the material and some room for trial-and-error. The next stage was the testing. The team allotted a week for this. Then there were two sessions for the improvement of the full design. This was to ensure that the maximum efficiency was reached. The results of the first testing were used to improve the next version. Each improvement session was followed by a testing. Finally, two weeks was allotted to make the write-up for the project and edit it in case there was a modification from the original design.

The team decided to plan the implementation per week to cover all uncontrolled circumstances like scheduling among the members, other people using the laboratory, etc. As shown also in the Gantt chart, the project will finish two weeks earlier than schedule. These two weeks was an allowance in case the orders arrive late or if the team will need additional week for improvement and testing.

Table 13. Gantt Chart

Task Name	Team member	Start Date	End Date	Duration
Final Report Rewrite	All	8/18/2018	8/29/2018	11
Finalization of design	ALI	8/27/2018	9/3/2018	7
Canvassing of parts	All	8/27/2018	9/7/2018	11
purchasing parts	All	9/8/2018	9/28/2018	20
Progress Presentation	All	9/17/2018	9/17/2018	0
Hardware Review 1 (50% of the final project)	All	10/5/2018	10/5/2018	0
Individual Analytical Analysis	All	10/12/2018	10/12/2018	0
Testing the heater band	Waleed	10/14/2018	10/16/2018	2
Hook up the temperature controller	Waleed	10/14/2018	10/16/2018	2
Soldering the copper caps with copper pipes & Fittings	Kaled	10/15/2018	10/16/2018	1
Connect the copper pipes with glass pipe by silicon rubber	Kaled	10/17/2018	10/18/2018	1
Midpoint Report	All	10/19/2018	10/19/2018	0
Initial implementation on the final project	All	10/21/2018	10/25/2018	4
Improvements on the final project	All	10/27/2018	11/2/2018	6
Midpoint Presentation	All	10/31/2018	10/31/2018	0
Hardware Review 2 (100% of the final project)	All	11/2/2018	11/2/2018	0
Testing our final project	All	11/3/2018	11/16/2018	14
Final Draft of Poster	All	11/18/2018	11/30/2018	12
Final operation and Assembly Manual	All	11/18/2018	11/30/2018	12
Final Presentation	All	11/18/2018	11/30/2018	12
Final CAD Package and BOM	All	11/24/2016	12/5/2016	11
Final Report	All	11/24/2018	12/7/2018	13

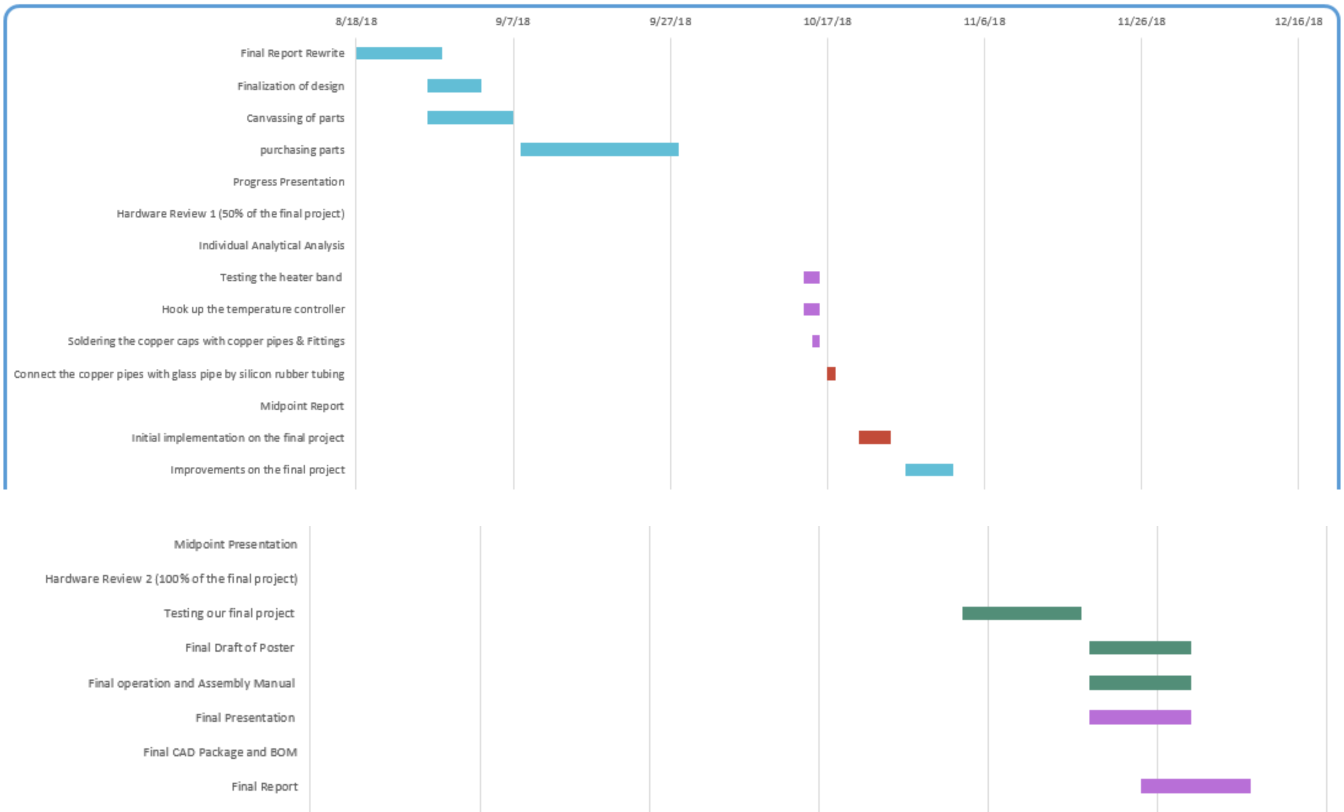

Figure 29B: Gantt chart

7.0 IMPLEMENTATION – Second Semester

In the second semester, the team was expected to continue with design implementation arrangement and plan as started earlier (first semester) in full compliance with the project timeline as stipulated in Gantt chart (Table 13). Once again, the procurement of materials was allocated two weeks before the commencement of the full design manufacturing process. This time was inclusive of shipping period, thereby covering any issue that may emanate from the retailer's end. The materials were received on time from all the vendors. A weekly implementation plan was scheduled to ensure that all undesired and uncontrolled circumstances were handled on time.

Common factors such as shared laboratory had to be factored in to make sure that everything runs smoothly without contravening other lab users. After acquiring all the necessary materials, the next step was to initiate the manufacturing process, minding all the necessary procedures and incorporating the proposed changes into the final design [21]. The design team settled on five components of the project, including the working fluid (water was the chosen variant), the heat flux is generated by a heater band (up to 380 W/m^2), wick materials (mesh wick was selected), as well as the preferred pressure and thermal conductance range [23].

There were some updates happened this semester in our proposed design. First of all, the team used two copper pipes instead of having a heat pipe contains just a long glass pipe due to thermal expansion. Since the glass tubing has a very low thermal conductivity and the copper has a high thermal conductivity. Second, the team added a silicon rubber tubing for connecting the glass pipe with the copper pipes instead of having a 4-way valve. Finally, the team added a connector in the condense end to be able to insert the working fluid and to vacuum the pressure.

7.1 Manufacturing

In every heat selection endeavor, several near successive steps are essential. The first one is the determination of the preferred temperature ranges, which is obviously characterized by the desired function [24]. In this project, the operating temperature range was between zero and 200℃., according to engineering requirements summarized in Table 2. A quartz glass tube capable of withstanding up to 1200°C of temperature was chosen as showing the table of BOM [25].

The second major step involves the selection of the preferred working fluid, which in this project was identified as water due to its favorable properties and ease of access. Material compatibility is the successive phase and is often determined from wick and material selection process [24]. A combination of mesh wick and water was advocated for in this project, while the favored materials were copper pipes and caps and glass tube. It is also essential to obtain or generate performance curves for various pipes to eliminate chances of uncertainties as an additional step in the endeavor [26].

The requirements of the heat transport system follow and are used to determine the diameter of the heat pipe, proposed lengths, and amount of heat pipes [21]. This was accomplished as detailed in the subsequent section. Other important parameters include the design geometry, physical constraints, such as the determination of the perfect shape and diameter of the pipes, mass constraints, cost of the project, and design margins. Lastly, the project must be able to cover ground test requirements at the desired levels. After successfully completing these steps, it was time to actualize the design [24].

The manufacturing process of the entire design was set to start after all the orders have arrived. This process was set to take at most two weeks, where one week was set aside for manufacturing and an additional week for design testing, correction, and improvement. A scale demonstrator was first constructed before starting the manufacturing process. All the necessary components were produced from a modern machine shop. This ensured that perfection was achieved, especially with specifics of pipe diameters and lengths to utmost efficiency [23]. The design was also implemented and manufactured from a modern machine shop, where all the tools necessary for the production were readily available.

The first step entailed soldering the two copper caps with the pair of copper pipes separately. The first copper cap was threaded to allow a soldered fitting inside the pipe so that it acts as the condensing section of the heat pipe. The next phase involved the linking of the glass pipe to the copper pipes using silicon. A rubber tubing was also added to make sure that the two units were well and tightly connected. Several changes were included in this manufacturing process as described in the subsequent section. Such include the 2-way valve system, which was dropped and replaced with the copper caps. In essence, the full heat design was implemented as shown in the figure below.

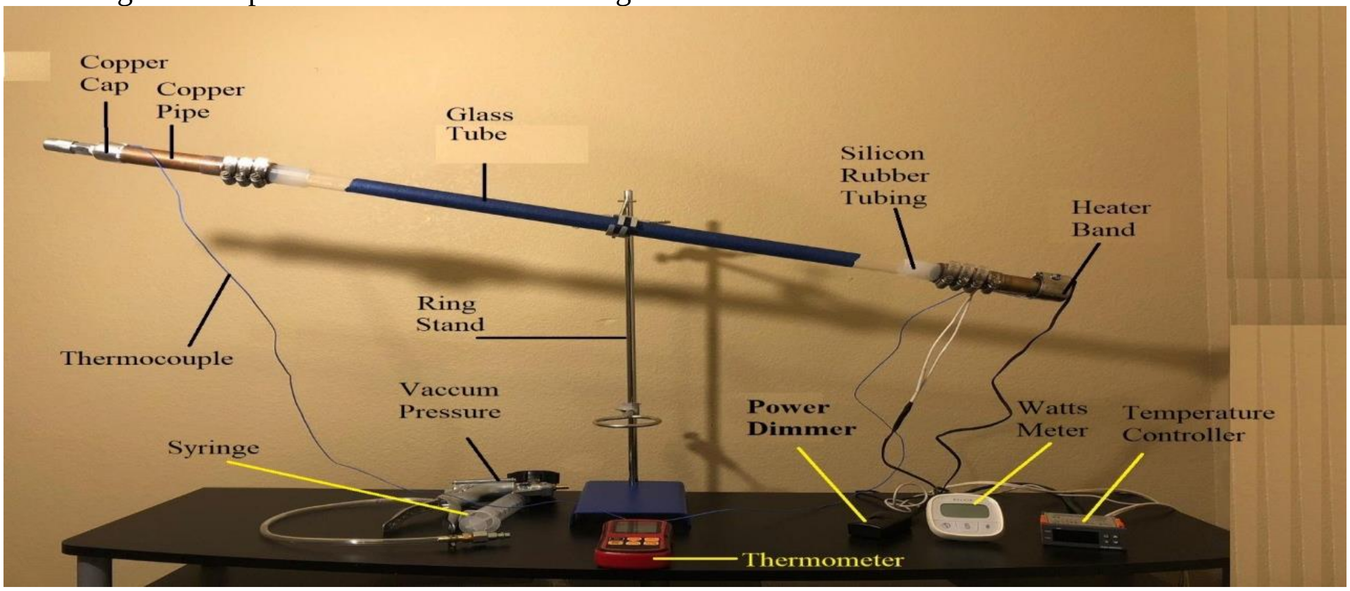

Figure 30. Full design assembly with changes.

According to Fig 30, the two copper pipes encloses the glass pipe from two sides, the cold side and hot side, and each copper pipe was fitted with a copper cap as shown in the figure. The copper tube from the left side (cold side) was 0.5 ft. long, while the one on the right-hand side (hot side) will be 0.4 ft. long. The glass tube will be 2.5 ft. long. Silicon rubber tubing was used to connect the copper pipe and the glass pipe from both sides (cold and hot sides) instead of the valve. Other parameters as proposed in the preceding sections were kept constant.

As indicated in Fig. 30, the cold side will also act as the condenser side, while the hot side will also act as the evaporation outlet. The copper cap in the hot side was fitted with a heater band, which consequently acted as the source of heat.

7.2 Design Changes

In the selected design, a copper pipes with a 4-way valve both procured from HomCo.com, and Walmart.com respectively were to be incorporated in the final design according to Fig 23. However, the 4-way valve was changed and disregarded in this final process. Instead, the copper cap from the condensed section was threaded as described above and used to secure capable fittings together, to allow the insertion of the working fluid (water) and to act as a means through which pressure inside the heat pipe would be vacuumed [21]. The design was improved further by the addition of a pair of copper pipes in both ends of the heat pipe, the hot side and the condensing side (cold). As described earlier, silicon rubber tubing was always instrumental in securing the copper pipes together, as well as linking the glass pipe with the two [25].

Another new design concept adopted in this final stretch was a ring stand. It was adopted from the thermo-fluids lab and used to secure the pipe in place. The stand was also instrumental in cases where various orientations and angles of the tube were desired as they were toggled easily, thereby achieving a particular position. A ring stand was selected because it has less contact with the heat pipe, thus making sure that thermal alterations were kept at a minimum [23].

Another essential parameter that was changed in the final design was the copper data. In the prototype demonstration section, the copper pipe used had a length of 1m, an inside radius of 0.0127 m, a thermal conductivity of 401 W/mK, and a temperature change of 50 K [25]. While most of these characteristics were kept constant, it was evident that the total length of the copper pipes was 0.4 feet as indicated on the final design (Fig 30), way different from the initial numbers. These changes were implemented to allow enough space for the fitting of the copper caps on both sides, as well as leaving an allowance for the silicon rubber tubing, which must be secured tightly to ensure that no heat was lost along the way. In so doing, small spaces must be created as stipulated in Fig 30.

8.0 TESTING

The device has manufactured and after manufacturing the product multiple tests have done on it. Testing is important to done on the device to see the working of product, if it fails some of the tests or all the tests then redo the manufacturing and solve the issues in it so that the device will keep working perfectly fine. For the device we have manufactured, different type of testing has done it.

8.1 Weight Testing

Firstly, weight of the device has measured and to do so we have used weight scale. Reason for testing of weight is that, it is important according to our engineering requirements that it must be light weight therefore we have tested the weight first. To measure the weight on weight scale, the stand has placed on the weight scale and then leave it along standing on the weight scale and it can see in the fig 31. Recorded the weight scale measurement and it was around 1.172 Kg, so the device is easy to use and carry and it can see in fig 31.

Fig 31: Weight Testing

As 1.2 kg device can easily carry by single person and it can easily move from one place to another place hence this test has passed. And engineering requirement has achieved as well because the requirement was stated that the weight must be less than 5 kg so from the testing results it has found that weight is just 1.2 kg which is far less than 5 kg and engineering requirement has fulfilled as well.

8.2 Set Up Time Test

This is a test to assemble the device and make it ready for use and to do this test we used the timer only to record the time of set up the apparatus completely. The timer has started when the vacuum pressure was starting connected with the pipe and it can see in the fig 32.

Fig 32: set up time start

When the connector connected, then insert the water into the pipe using the syringe and after that use the vacuum pressure to create the vacuum inside the heat pipe tube and after that it is ready to use. It took around 45 seconds to do this complete process, so the set-up time of this device is just 45 seconds to 1 minute. For doing this test, some attempts have failed as well because they took lot more time like inserting the syringe was causing the problem in few attempts and then connecting the vacuum pressure was not fine. Therefore, these attempts were failed but at the end a successful attempt has done, and it has done in such a short period of time like just 45 seconds to set up the device for use. This test has proved that the engineering requirement of Ease of Assembly has successfully achieved because assembling and this device and set up the device for use are easy and short time taking. It has measured that it took only 45 seconds to set up which is less than 1 min and engineering requirement stated the same thing hence this test has proved, and engineering requirement has fulfilled by the device.

8.3 Size Testing

This is another test performed on this device and to do this test we have used the foot scale. In order to measure the size of this device, firstly the height has measured and to do so place the scale at the bottom of stand and raise the scale to the copper pipe straight and measure the height as shown in fig 33.

Fig 33: Size Test

The height measured from the scale was around 31 inch which is roughly equal to 2.6 feet. And after measuring the height, length of tube rod has measured from one end to the other end as shown in fig 34.

Fig 34: Length Measurement

From the scale, length has measured around 39 inches which is roughly equal to 3.3 feet. Engineering requirement regarding the size state that volume is near around 3 cubic feet but if we count the volume of our device, it is longer than 3 cubic feet but actually, this is a stand and calculating the volume of stand through simple formula of width x height x length is vague because it will use lot of free space as well and make the total volume larger than 3 cubic feet but if we count only the cubic feet of tube or rod, it is quite lesser than 3 cubic feet and hence engineering requirement has successfully achieved as well.

8.4 Reliability and Accuracy Testing

This test has done to identify whether the device is working perfectly fine or not? What is the accuracy of result? How reliable the device is? To perform this testing, the device has run for multiple attempts and recorded the output on each attempt. There were 20 attempts performed for the reliability and accuracy test.

1. Temperature = 26.5
2. Temperature = 34.4
3. Temperature = 28.6
4. Temperature = 33.5
5. Temperature = 31.5
6. Temperature = 30.9
7. Temperature = 33.0
8. Temperature = 33.1
9. Temperature = 30.5
10. Temperature = 34.0
11. Temperature = 30.5
12. Temperature = 35.1
13. Temperature = 31.0

14. Temperature = 32.6
15. Temperature = 30.5
16. Temperature = 31.6
17. Temperature = 32.6
18. Temperature = 35.1
19. Temperature = 33.7
20. Temperature = 32.9

After performing these 20 tests and looking at the output values of each temperature, it can state the device is reliable because it didn’t fail in of the 20 attempts and it is accurate as well because the temperature is ranging mostly around 30 degrees. Hence engineering requirement has fulfilled as well by this design.

There was another engineering requirement Operating temperature range, and it didn’t test because there was no source to provide 200-degree Celsius temperature to the material and check if it can withstand with that temperature or not. In this way all the testing has done, and results have shown that device is fulfilling the engineering requirements which means it is fulfilling all the customer needs and it passed all the tests.

9.0 CONCLUSION

This was the design project in which we have developed the heat pipe and this heat pipe provide the heat within the tube to transfer the heat process. This heat pipe increases the heat transfer rate and help to increase or decrease the temperature quickly. The project was a capstone project and it started with defining the project and then identifying what to do in this project. And then develop the design ideas to make the final design and at the end, the design has manufactured properly. The device has some parts to assemble in order to operate it. It has tested through multiple ways to confirm whether it followed the engineering requirements or not. All testing has done according to the engineering requirements and the measured values of each test has than compared with the targeted value of engineering requirement. From the results it is clear that the design has followed all the engineering requirements which made it a successful design as requested by the client.

9.1 Contributor to Project Success

This project has done successfully and doing this project client has helped us a lot and simplifying our problem and issues so that we can cover up those issues. Along with the client, all team members have played their role in completing this project successfully. And because of the effort of all team members, the project has completed.

Our sponsor helped us a lot in manufacturing the device. Dr. David Trevas, played great role in completing this project successfully and he supported us all the times when different modules were not working properly and need to arrange some new items, he supported completely. In order to completely understand those who contributed to the project, the list has given with the details.

David Trevas – Project Client

He was the man who started this project and provided us the information to do the project and mentioned his requirements. We have met with him multiple times in order to understand what the project is and what should we do in it. He helped a lot all the times from start till end. He is the man who contributed to help in doing this project and completed this projected. With the help of Dr., we have selected the design as well. He helped us in selecting the materials, also helped us in assembling the parts and manufacturing of product.

Kaled Aleweehan – Project Manager

This is the person who managed the project completely. His role was dominating between the complete team. He organized everything for the project, he arranged the meetings, arranged the documentation, did the communication with others, work hard to make this project successful. Kaled was focusing on high quality work and he divided the work equally between the team members as well. He was not only managing the project, but he was also working on his own tasks. He asked the team members to work before the team and because of Kaled the project has finished earlier before the deadline.

Waleed Almutairi – Document Manager

He was organizing all the documents of project. This was the design project and design project depend on the documentation as well because lot of work need to do for it on the paper so the document manager Waleed has done the work perfectly. Because of his efforts we have able to finish the report and everything on time.

Abdullah Almutairi – Editor

He was the editor of project and he edit the report and all other documentation. He worked as well and played great role in completing the project. He also worked on hardware so he is also a man who contributed successfully to this project.

Omar Alotaibi – Budget Liasion

He managed the budget of project which was also an important part of project he performed well and managed the budget within the given range so he is also a person who contributed to the project.

Abdullah Ben Gheyam – Website Developer

He developed the website and arrange all the documentation of the project on the website. We were easily able to take the data from the website for the project and we can easily view the updates regarding the project on the website and it helped a lot in completing the project on time so Abdullah is also a person who contributed to the project.

9.2 Opportunities/areas for improvement

In the world of new technology, there is always a room of improvement present in all the fields and all the products and so do, it is present in our project. Although our project is working perfectly fine and there is no such fault or issue in it. But the area of improvement can identify in it, like

1. It can improve the filling method, as it is tedious to fill the water into the pipe using the syringe by attaching an external pipe and insert the pipe into the big hole pipe, which is tedious, so this can improve in it. It can change with something directly connects the water into the pipe and make this process fast.

2. The setup process can improve as well, like the devices we need to connect together for running, make a complete platform on which devices will hang with the stand and it will make easy to use the device when the components have their fixed defined location.

3. Another improvement in the system can make which is using the thermocouples wires, it can connect using a proper connector which will not let it disconnect while using and it will make its look more decent. Therefore, replace the tape with the proper connector to make it stable, strong and decent.

4. Further improvement in the project can be done by upgrading it and connecting the device with the LabVIEW so all the experiments performed on the project pass the data directly to software and further analysis can be done in LabVIEW. In this way, the device will become more sufficient to use and the data can analyze and imply the data as well. Graphs can plot through the LabVIEW and changes in the temperature can continually observe from the LabVIEW.

5. Another area of improvement in this device is adding thermocouples wires in it. Consider adding

two thermocouple wires in it cause gives the opportunity to get good reading regarding the temperature. High temperature and low temperatures can identify differently through different thermocouples.

6. Use of MATLAB software along with the LabVIEW for the analysis of data and develop the range of temperature data and then do the fitting to see the result accuracy and pattern of result for the device. With the help of MATLAB, the device can further improve and it can further use to improve the results.

With these improvements the device can make much better and its working capability can increase as well so causing these improvements is good for the device.

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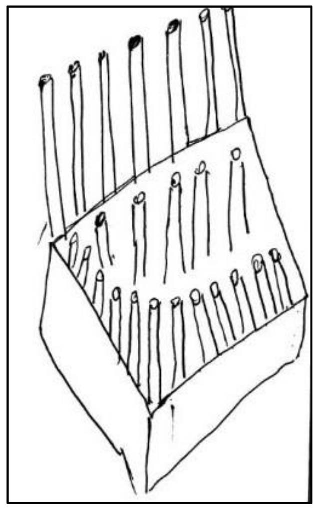
11 Appendices

11.1 Appendix A: Design Considered

11.1.1 Design #6: Forged Fins

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



Appendix Figure 1. Forged Pins Heat Sink

Typical Benefits:

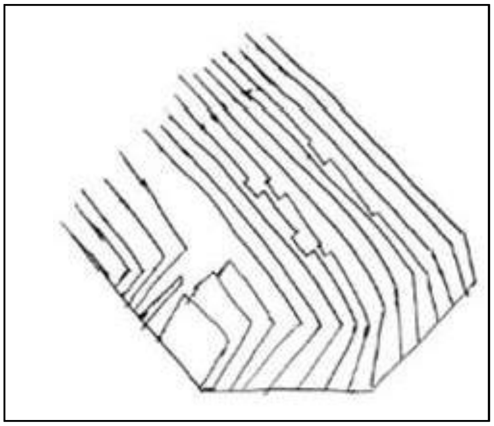
Fin design in many shapes (pin, square, oval, etc.)

Potential Pitfalls:

Usually reserved for higher volume products as tooling was expensive.

11.1.2 Design #7: Machined Fins

These were smaller type of heat sinks which formed from both aluminum and copper. These type of heat sinks were 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 were common in personal computers and showing in the following figure.



Appendix Figure 2. Machined heat Sink

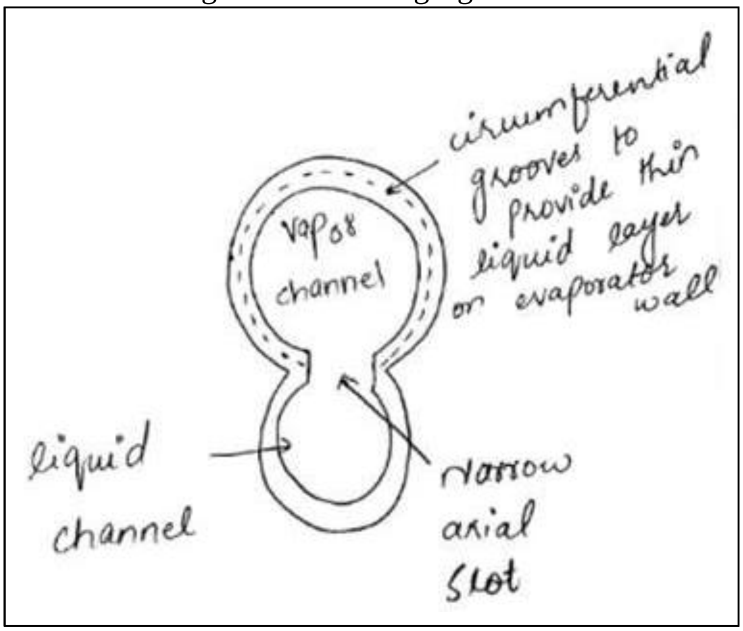
Typical Benefits:

High thermal
conductivity
Complicated designs
OK Potential Pitfalls:
None, other can cost.

Not good for high volume due to production time.

11.1.3 Design #8: "Mono-groove" Design

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



Appendix Figure 3. “Mono-groove” Heat Sink

Typical Benefits:

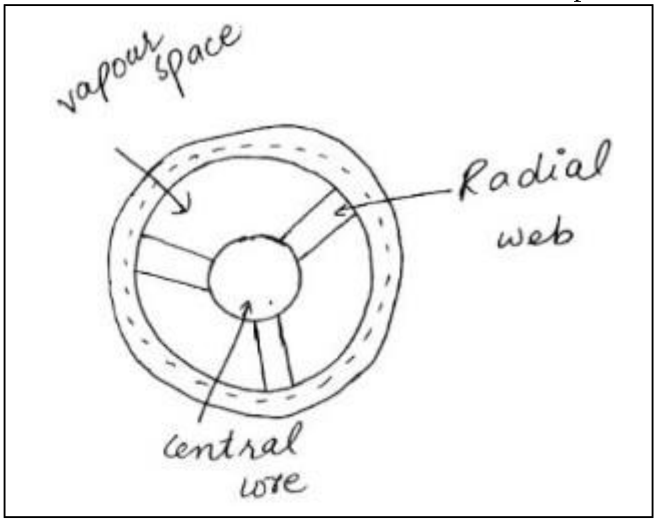
It has a large single groove that provides Relatively unrestricted longitudinal flow. Liquid was distributed on the evaporator wall By means of a secondary wick consisting of small Circumferential grooves or screen

Potential Pitfalls:

It has encountered difficulties during early Shuttle testing.

11.1.4 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.



Appendix Figure 4. Composite Wick Heat Sink

Typical Benefits:

More capacity can be obtained by using more layers of screen, to increase the wick flow area.

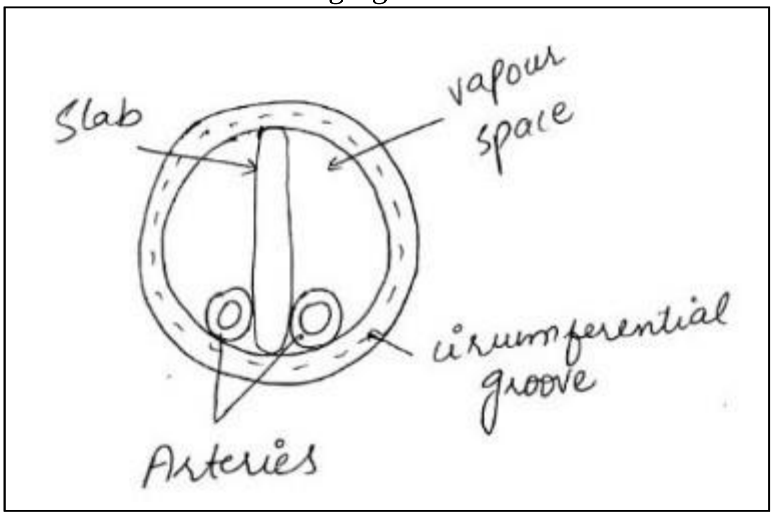
Potential Pitfalls:

Because the wick must be assembled of relatively fragile materials,

Care was required in building such a pipe, and no two supposedly identical Pipes will perform in exactly the same manner.

11.1.5 Design #10: Diode Heat Pipes

Diode heat pipes were considering to be the most advance form of heat sinks, in this kind of heat sinks there was 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.



Appendix Figure 5. 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 was made to transfer heat in the other, "wrong" direction, resulting in a diode action.

11.2 Appendix B: Preliminary Computation

$$d = 2\ cm = 2\ x\ 10^{\square\square}\ m$$

$$L = 25\ cm = 0.25\ m$$

$$T_{\square} = 100^{\square}C$$

Perimeter

$$\pi d$$

$$\pi d = \pi\ x\ 2\ x\ 10^{\square\square}\ m = 0.0623\ m$$

Area

$$\frac{\square}{\square} d^{\square}$$

$$\pi\ d^{\square} = \pi\ x\ (2\ x\ 10^{\square\square})^{\square} = 3.1415\ x\ 10^{\square\square}\ \boldsymbol{m}^{\square}\ 4$$

The boundary conditions in this case was as expressed below: At x = 0, $\theta = \theta_{\square}$

$$\theta_{\square} = T_{\square} - T_{\square}$$

$$\theta_{\square} = T_{\square} - T_{\square} = 100 - 22 = 78^{\square}\ C$$

At x = 0, $\frac{\square\square}{\square\square} = \theta_{\square}$

11.3 Appendix C: Pugh Chart

Appendix Table 1. Pugh Chart

Concept / Criteria	Ex-truded	Die cast	Bon-ded	Skived	Fin pack and zipper fins	Forged fins	Ma-chined fins	Mono groove	Com-posite wicks	Diode heat pipes
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

11.4 Appendix D: Bill of Materials

Appendix Table 2. BOM for prototype

Bill of Materials							
Team			Heat Pipe - Team 3				
Part #	Part Name	Qty	Functions	Material	Dimensions	Cost	Link to Cost estimate
1	copper pipe	1	vessel	copper	2 feet	$4.78	HomCo Lumber & Hardware @flagstaff
2	copper caps	2	cap	copper	ID= 0.5in , OD=0.63	$1.38	HomCo Lumber & Hardware @flagstaff
3	valve	1	control	copper/cuivre	1/2 in	$15.99	HomCo Lumber & Hardware @flagstaff
4	disconnected clip	1	clip	copper/cuivre/cobre	1/2 in	$1.99	HomCo Lumber & Hardware @flagstaff
5	foam pipe insulation	1	insulation	foam	70 in	$3.29	HomCo Lumber & Hardware @flagstaff
6	wire trivet	1	we used it as stand	n/a	7 in diameter (17.6 cm)	$4.72	Walmart
7	ms coasters	1	we used it as stand	n/a		$5.14	Walmart
8	utensil holder	1	we used it as stand	n/a	11.8 cm * 11.8 cm * 20 cm	$5.84	Walmart
9	candle	1	heating source	n/a	n/a	$0.50	Walmart
10	BRS Torch plumber kit	1	to flux the copper cap with the pipe	n/a	n/a	$22.99	HomCo Lumber & Hardware @flagstaff
11	LCD thermoemeter w' thermocouple wires	1	measure temperature	n/a	n/a	$24.79	Amazon
12	silverline elite automotive kit		to vacuum pressure	n/a	n/a	$49.95	ToolDiscounter
13	an extension copper pipe	1	extension	copper	1/4 in	FREE	HomCo Lumber & Hardware @flagstaff
14	syringe	1	to add and measure fluids	plasic	n/a	FREE	from our client
15	Water	1	cooling fluid	Water	1 liter	$0.35	Walmart
Total Cost Estimate:						$141.71	

Appendix Table 3. BOM for full design

Bill of Materials							
Team			Heat Pipe				
Part #	Part Name	Qty	Functions	Material	Dimensions	Cost	Link to Cost est.
1	Glass Pipe	1	Pipe	glass	ID= 22mm, OD= 25mm, L= 2.5ft	$23.00	https://technicalglass.com/pr s/fused_quartz_tubing/fused ing.html
2	Copper Caps	2	cap	copper	ID= 22mm , OD=26mm	$1.38	https://myhomco.com/produ
3	Copper Pipes	2	pipe	copper	ID= 22mm , OD=26mm	$5.20	https://myhomco.com/produ
4	Ring Stand	1	Hold the pipe	Stainless Steel	L= 24in, D= 2.5 in	$29.72	https://www.amazon.com/gp 00HUUWYIO/ref=oh_aui_deta _s00?ie=UTF8&psc=1
5	Silicon Rubber Tubing	1	Connect copper pipes with glass tubing	Silicon	2 feet long	$3.47	https://www.mcmaster.com/ rubber-tubing
6	Heater Band	1	Heating source	Stainless Steel	1.4" x 1.4 inch (inner Dia.H)	$8.99	https://www.amazon.com/gp 01A6N84FI/ref=oh_aui_detai s00?ie=UTF8&psc=1
7	Power Dimmer	1	Adjust the power	Plastic	Depth (in.) 1.53 Height (in.) 4.13	$11.97	https://www.homedepot.com 300-Watt-Incandescent-CFL- Tabletop-Dimmer-Black-R15- 10E/203812619?keyword=07 9&semanticToken=20030000 t%3A%7B078477603819%7D n%3A%7B0%3A0%7D+oos% 3A1%7D+qu%3A%7B078477 D%3Aqu
8	Watt Meter	1	Measure the power	Plastic	Cable lenth= 6 ft	$35.99	https://www.truegether.co ?id=USER.2e65aaef-0d87- 38e030767d66&gclid=EAI O67WE3wIVVx6tBh3hxAzs 98fD_BwE
9	LCD thermoemeter w' thermocouple wires	1	measure temperature	n/a	n/a	$24.79	https://www.amazon.com/ Thermometer-Dual-channe Temperature/dp/B07C2SK 14?ie=UTF8&qid=1543728 14&keywords=lcd+thermo hermocouple
10	silverline elite automotive kit	1	to vacuum pressure	Steel	n/a	$49.95	http://www.tooldiscounter play.cfm?lookup=MITMV8
11	Fittings	1	Able to add working fluid and vacuum pressure	Metal		$13	https://www.amazon.com/ 0000CBJKT/ref=oh_aui_de s00?ie=UTF8&psc=1
12	cotton cloth	1	wicking material	cotton	3 yards	$17.97	https://www.joann.com/se 25%20Cotton%20Fabric
13	Water	1	working fluid	Water	16.9 fl. Oz	$3.36	https://www.samsclub.com
14	copper sleeve	1	Hold the rubber tubing	Copper	1 in	$4.16	https://www.homedepot.c
15	Clamp	1	Hold the copper sleeve	Stainless Steel	1 1/4 in	$8.80	https://www.homedepot.c
16	syringe	1	to add and measure fluids	plastic	n/a	FREE	Got it from our client
Total Cost Estimate:						$241.75	