CLOSED LOOP THERMOSYPHON

PREPARED BY

Syed Tawsif Islam – 1810004
Partho Kundu – 1810011
Ananya Dipita Bhakta – 1810019
Mohammad Samir Hassan -1810027

Abstract:

Heat exchanger is a system to transfer heat from a high temperature source to any lower temperature surface. This attribute makes them the perfect method to cool down powerful modern-day processing units used in our computers. Thermosyphon is such an equipment that uses a passive method of heat transfer which primarily includes natural convection and conduction. Our design has aimed at finding the cheapest, most lightweight and compact alternative to already existing high end thermosyphons in the foreign market. Extensive market research and secondary calculations have been done to find the best possible combination of dimensions and material and finally coming up with the most optimum design with a target of reaching a steady state temperature difference in minimum time. The provided design has adequate scalability for further modifications which might be necessary based on varying uses across different computers.

Introduction:

Syphon is primarily known as any device which allows fluid to flow upward above the surface of the reservoir. This uses no pump and instead relies on the age-old theory of gravity pulling it downward. The fluid is finally discharged at a level lower than the surface it originally came from. The uphill flow of fluid can be carried out using two different processes applicable and used based on different scenarios.

The traditional theory focuses on the reduction of pressure at the top of the siphon. The atmospheric pressure pushes the liquid from the upper reservoir into the reduced pressure at the top and then over.

On the other hand, these can also be done using natural convection. The circulation can either be done with either an open loop or closed loop. This circulation can be open-loop, as when a heated transfer tube positioned at the bottom of the tank transports a substance from a holding tank to a distribution point—even one mounted above the originating tank—or it can be a vertical closed-loop circuit with a return to the original container. Its objective is to reduce the complexity and expense of a typical pump while still transferring liquid or gas.

When heat transmission to the liquid causes a temperature difference between one side of the loop and the other, natural convection of the liquid begins. Due to the phenomenon of thermal expansion, there will be a proportional difference in density across the loop for any temperature difference. As a result of being less dense and buoyant, the warmer fluid on one side of the loop is more mobile than the cooler fluid on the other. The cooler fluid will sink below the warmer fluid, while the warmer fluid will float above it. Heat rises is a common phrase used to describe this natural convection process. The system's heated liquid is moved upward by convection at the same time as cooler liquid returning by gravity replaces it.

Problem Statement:

A single-phase double tube thermosiphon cooler is used as a processor cooler. It consists of a 60x60x25 mm3 copper container and two copper pipes. The diameter of the pipes is 12.7 mm (about 0.5 in). The working fluid enters the pipes through two inlets in the container. Due to the density difference hot fluid moves up the pipe and dissipates heat with the help of the rectangular fins attached to the pipes and cold fluid comes down and enters the container. The processor to be cooled supplies 150W. Water is used as the working fluid which operates between 45°C and 54°C. Design a finned surface having the appropriate number of fins, with an overall effectiveness of 4 that can keep the processor from overheating. Take the length of fins 25 mm and cross-sectional area 55mm×0.45mm respectively. Determine the mass flow rate of water and efficiency of the thermosyphon cooler. Take the width and thickness of fins 55mm (about 2.17 in) and 0.45mm (about 0.02 in) respectively. A 30-cfm fan is attached to the fins to induce a cross flow that accelerates the heat exchange between air and water. Calculate the overall heat transfer coefficient in the water to air heat exchange process.

Take properties of water at 50°C and air at 30°C

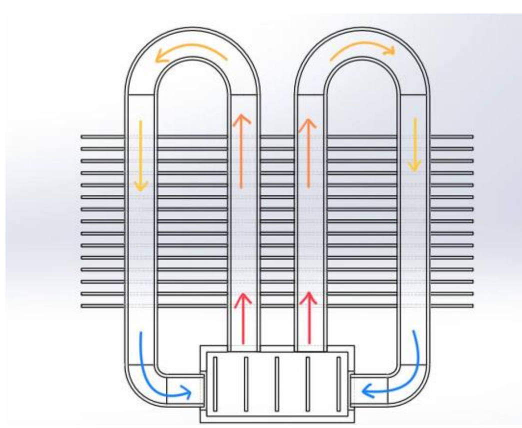

Fig 1: Thermosyphon

Design Objectives

- **Working fluid selection:** To maintain a single phase inside the thermosyphon cooler, a fluid with a high boiling point is required. Taking this into consideration, water is selected as the working fluid for our design. Besides, water has a high specific heat which is preferred in a heat exchanger because water is able to absorb heat without increasing much in temperature, better than any alternatives available in the market.

- **Optimum mass flow rate:** Since we're relying on natural convection and buoyancy for circulation instead of pumps, it won't be able to achieve high mass flow rate. So, the chosen fluid must be able to achieve the required temperature time and reach steady state temperature difference with little mass flow rate. This requires the fluid to have high heat capacity at constant pressure.

- **Material selection:** Material selection is primarily based on the thermal and mechanical properties. After extensive market research, we found copper to be the most appropriate choice for our design.

    - **Thermal Properties:** The method of heat transfer involved in a thermosyphon cooler includes heat conduction. The heat absorbed from the cooler is first conducted through the material and then transferred to water by convection. So high thermal conductivity is the most desirable attribute in the material to be used. Copper has the highest thermal conductivity among the options available in the market, therefore is the most suitable choice for our design. For a similar purpose and some manufacturing conveniences, the same material is also used for fins.
    - **Mechanical Properties:** Copper is known for its malleability and ductility. It can be easily formed into tubes, containers etc. without breaking. It can also withstand a significant amount of pressure. So, there are many manufacturing advantages in working with copper. These properties make copper the most preferable material for our project.

- **Baffle design:** To prevent the mixing of hot and cold fluid inside the container and to maintain a unidirectional flow from bottom to top, baffles are attached inside the container. These baffles do not contribute to the heat transfer process directly.

- **Cost Analysis:** We have prioritized a compact design with a minimum amount of material. There are also some adjustments in the manufacturing process to reduce waste material and cost. Even though some other available materials might be cheaper, we need to consider the cost to efficiency ratio because based on its use, the priority is to keep the processing chip unit cool and prevent overheating.

- **Maintaining fin length and number:** Since the thermosiphon is exclusively designed for processing units inside our computers, we must consider the size of the casing. It must be compact and achieve the required heat transfer with a minimum number of fins ensuring no bulkiness. The fin extension length from the tubes must not cross the inner edges of the casing. This is done in order to take up as little space as possible and prevent it from blocking other components.

- **Overall heat transfer coefficient:** Since this is essentially a water to air cross flow heat exchanger, the objective is to keep the overall heat transfer coefficient of such configuration within the optimum range of 600-750 W/m^2K for best heat transfer between the two fluids and ensure reaching steady state temperature using minimum surface area of the tubes.

Design Strategy:

Market survey: The first step in our approach to designing the thermosiphon was to survey the hardware shops of Old Dhaka to make a list of all the available materials which could be used for our design along with their costs and availability. Another list was made of all the available fluids that are commonly used in cooling CPUs.

Material selection: Based on the data obtained from our calculation of the thermosiphon, we plotted the graphs of mass flow rate and total efficiency against the thermal conductivity of different materials. The cost to efficiency ratio of these materials were also plotted which allowed us to determine the best available material for this use. Copper was selected as the material for both container and fins for highest efficiency and ease of manufacturing.

The graph shows how we get the highest efficiency of our heat exchanging device if we use this.

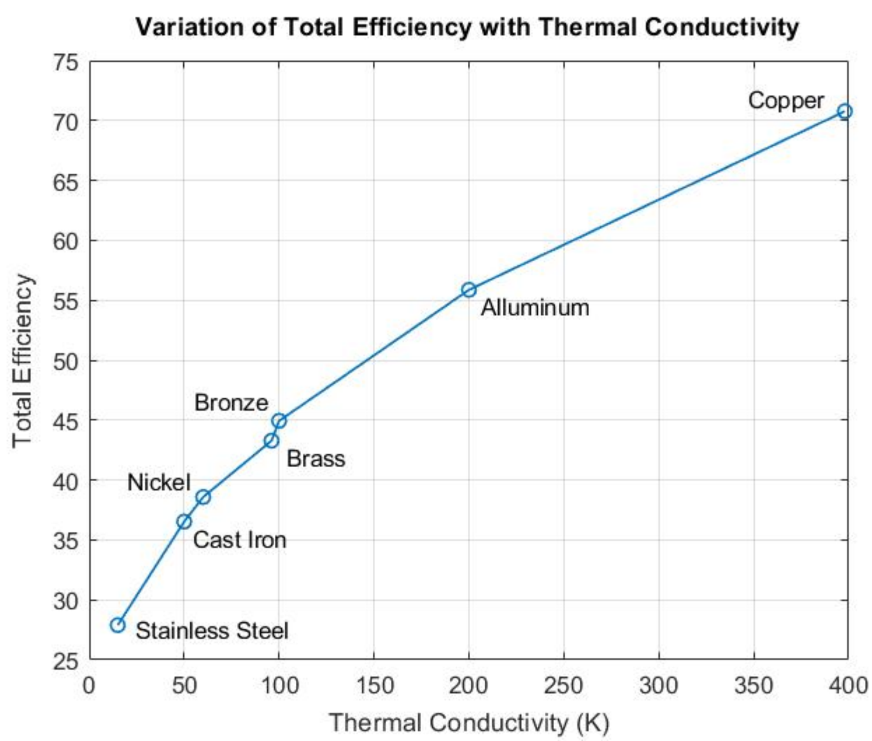

Fig 2: Variation of total efficiency with respect to thermal conductivity

From figure 3, we deduced that the optimum mass flow rate which is neither too high that it is impossible through natural convection nor is it too low that it would take a long time to reach saturation temperature.

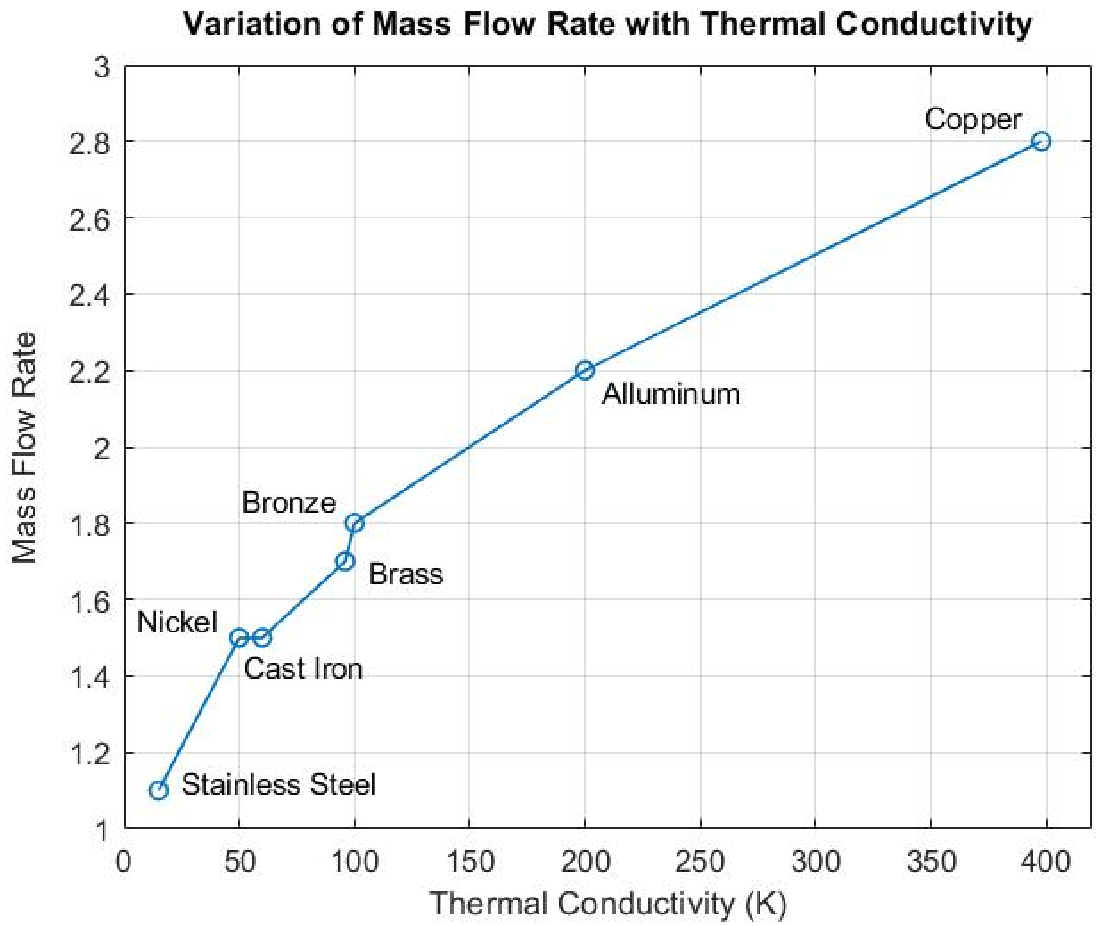

Fig 3: Change of mass flow rate with respect to thermal conductivity

If we had used other materials instead of copper, this would increase the number of fins for the same value of dissipated heat and temperature drop making it a bulky structure and even harder to manufacture.

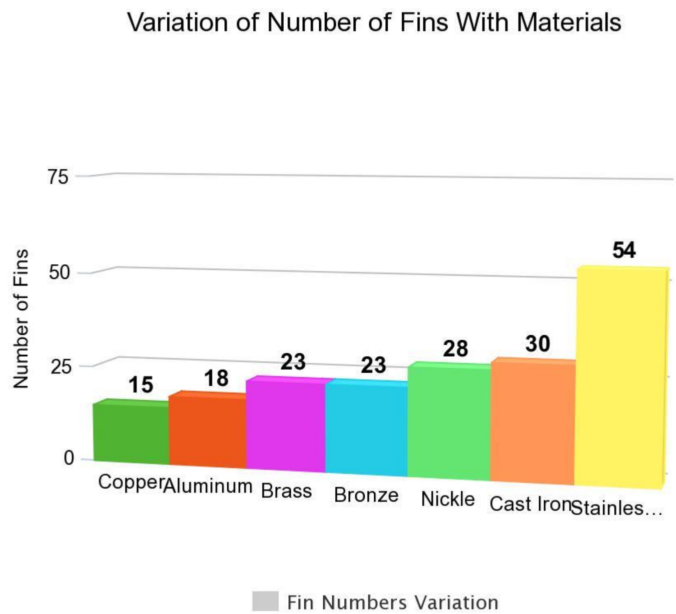

Fig 4: Change of number of fins based on the material used

Fluid selection: Since we're using no other external pumps and only relying on buoyancy, we won't be able to achieve high mass flow rate. So, to attain the required heat transfer the specific heat of the fluid must be high. Moreover, as we're using it for a high wattage CPU which will generate a lot of heat, we made sure the boiling point of the fluid is higher than the maximum possible temperature of the chip. Water was selected for the fluid.

According to figure 5, only water is able to provide the mass flow rate necessary due to its extremely high specific heat. For other available fluids, in order to achieve the same temperature drop the mass flow rate needs to be a lot higher, which is very unlikely to be attained through natural convection.

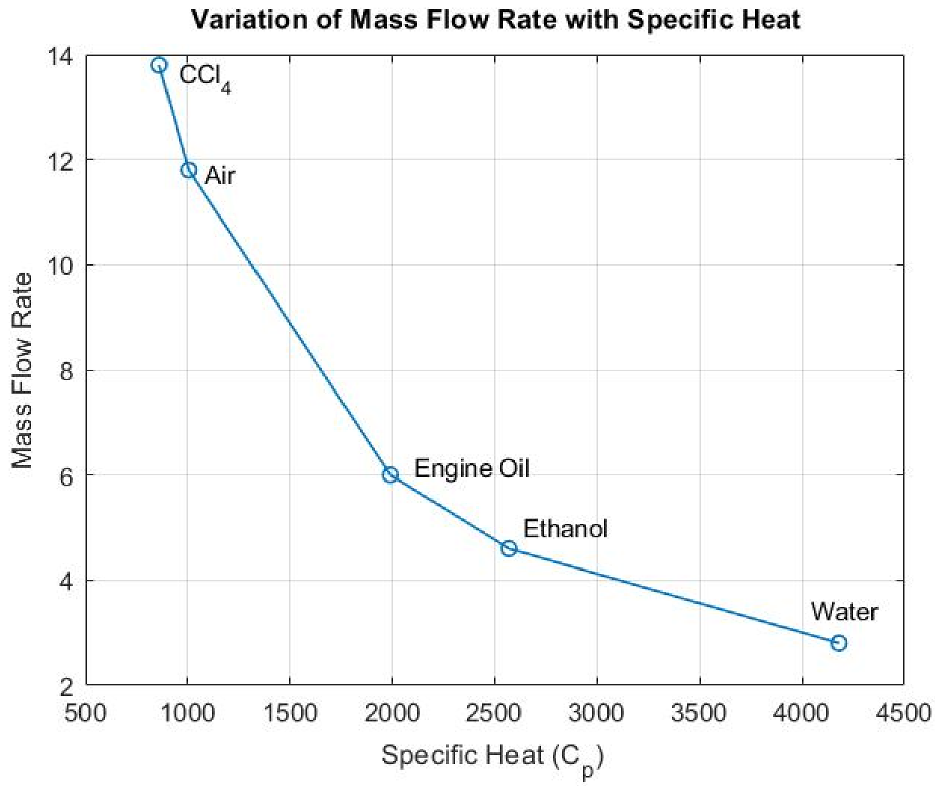

Fig 5: Change of mass flow rate with change of specific heat

CAD Model: The CAD model of the thermosyphon was done based on the selected parameters and keeping in mind the design restrictions based on market research and use of the device. It was done using SOLIDWORKS 2021 software.

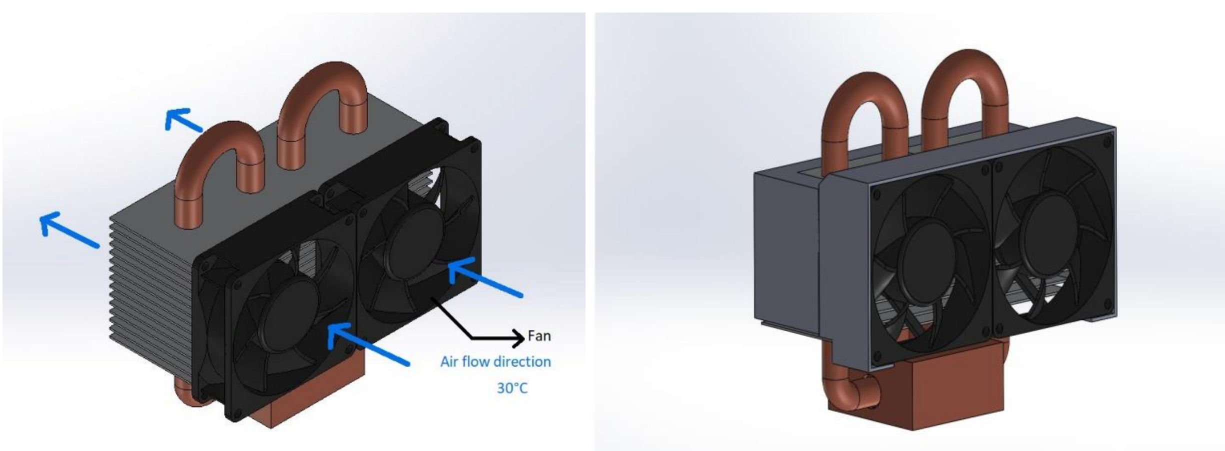

Fig 6: CAD model showing air flow and fan brackets

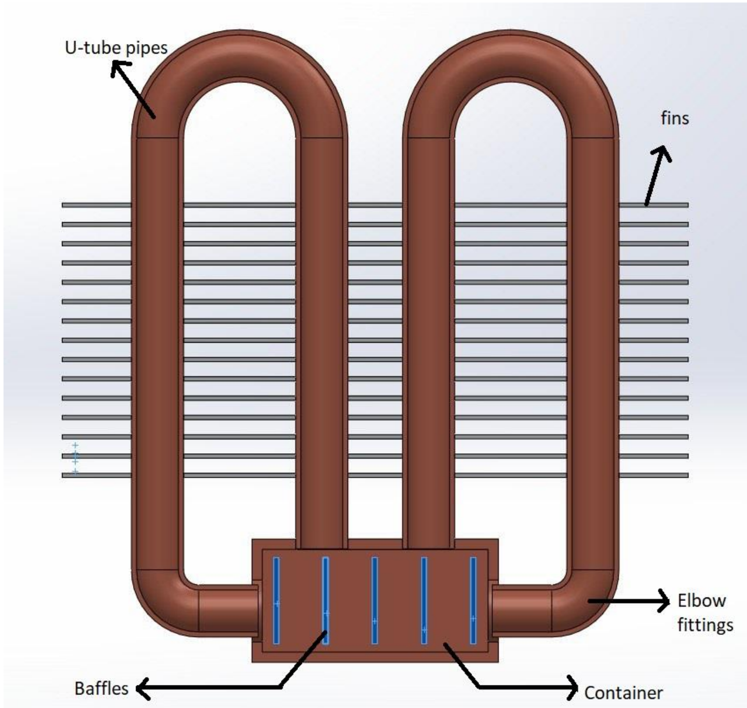

Fig 7: Cross Sectional View of CAD Model

Design Factors and Components Considered:

- **Process requirements:** The main mode of heat transfer inside the container is natural convection. So due to the absence of external pumping power, mass flow rate cannot be increased to a substantial value. Comparing the mass flow rate needed for the specified temperature drop, it is observed that water needs the least mass flow rate which can be easily achieved with natural convection.
- **Dimensions:** The dimensions are selected according to the already available processor coolers in the market. The idea is to make it compact, lightweight and least costly processor cooler.

- **Container:** Heat is transferred from the source to the water through the container wall. So, the wall thickness should be small for effective heat conduction. But if the wall thickness is too small, the container shape can deform under excessive heat. After all the considerations, an optimum value of 3 mm wall thickness is selected for the container.
- **Pipe:** Similar factors were considered while choosing the pipe diameter. A small diameter could deform under the excessive heat produced during manufacturing process and a large diameter could compromise the compact and lightweight design. So, 0.5-inch diameter (about 12.7 mm) was the most suitable choice for the design.

- **Number of tubes:** We have kept 2 U-tubes for effective circulation to take place.
- **Number of baffles and baffles spacing:** We used 5 baffles inside the container to ensure unidirectional flow. The baffles are placed at 12 mm spacing from each other. A small distance of 2 mm is kept at the bottom and at the top to accommodate cold and hot fluid. There is also a small distance of 2.8 mm at the two inlets to prevent any obstacle during circulation.
- **Strength:** The objective is to prevent any deformation under excessive heat and stress, especially during the manufacturing process. The dimensions and material were chosen accordingly.

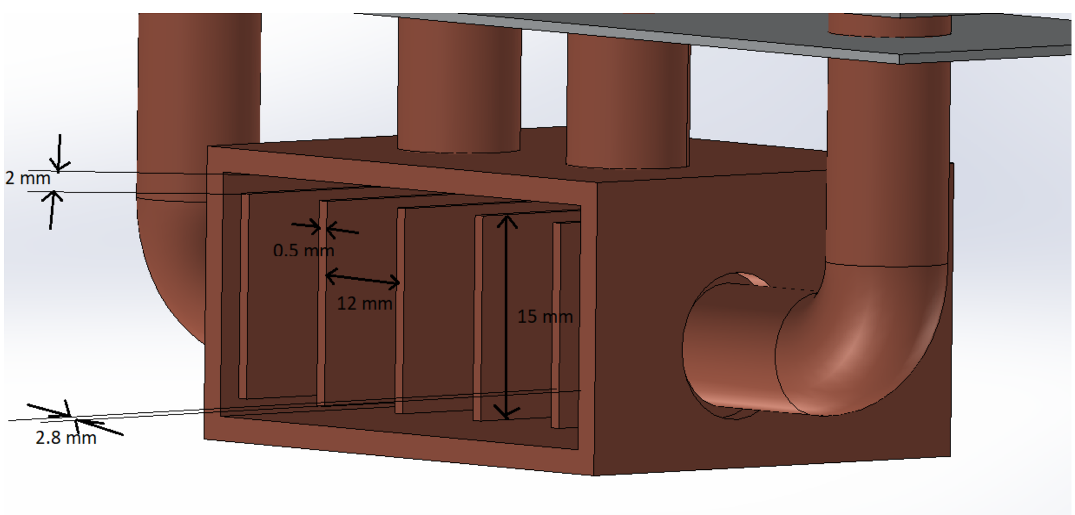

Fig 8: Baffle dimensions inside the container

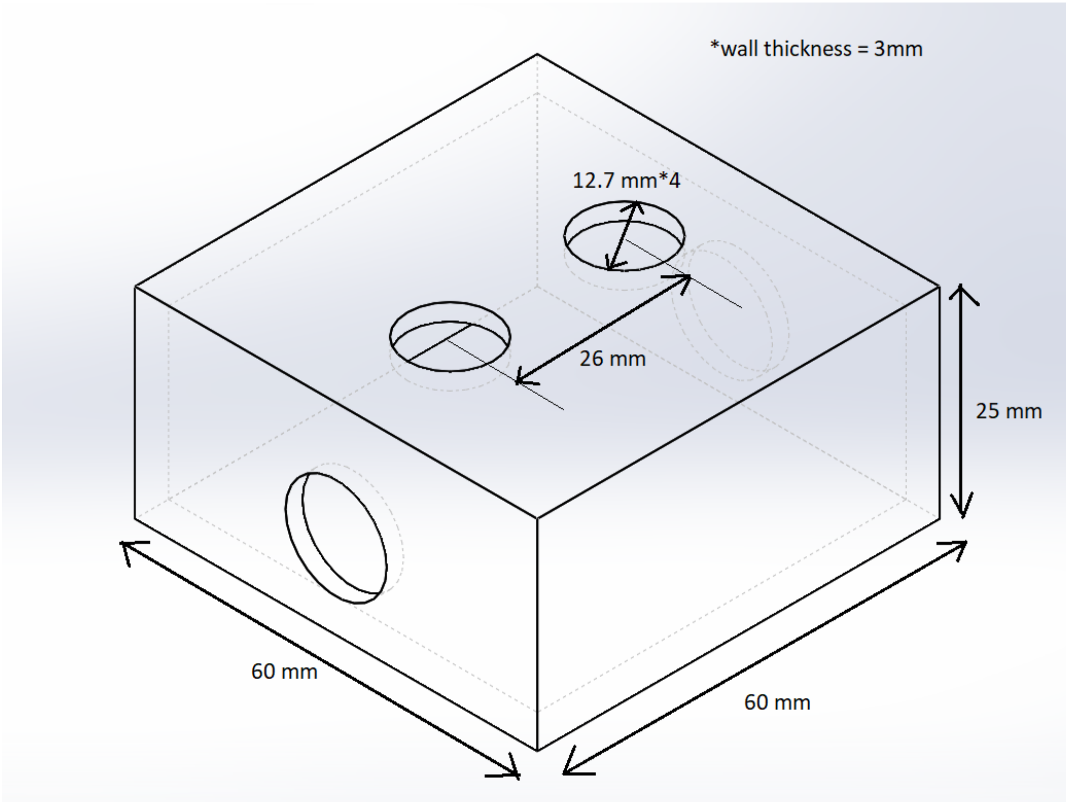

Fig 9: Container and tube dimensions

Methodology:

After selecting the appropriate material and fluid, they were purchased accordingly. With the help of two-dimensional drawings of our design, the copper plates were cut according to size using the shear machine.

Five baffles were cut from a large copper plate for this. The bottom container, which acts as the reservoir of our thermosiphon was made by the bender machine. Five slots were cut into the container where the baffles were placed and later used silver soldering to make the joints permanent. This was used since the baffles are very thin and there was the risk of melting if we had gone with regular welding.

Fig 10: Baffle manufacturing

Holes were drilled into the top and side surfaces of the container. The heated fluid enters the tubes through the holes on the top and the side ones are used for the cold fluid to reenter the container.

The bottom surface of the container was attached with the edges using TIG welding and made sure the corners were air tight.

Four tubes were force fitted on each hole and connected between themselves using elbows and U-tubes. But since we had to make sure there was no passage of air through any of the joints, we permanently attached them using acetylene gas welding.

Fig 11: Welding of tubes with inlet and outlet holes

Before permanently welding them, fins were inserted through the pipes, keeping minimum distance between them. The target was to insert as many fins as possible in order to achieve the necessary heat transfer but also to make sure it won't turn too bulky for modern day computer casings.

A 30 CFM fan was attached to the side of the fins using a 3D printed casing which allows forced convection along the width of the fins so that the heat is dissipated quickly.

Economic Analysis:

The aim of the design was to replicate the use of already existing high end, expensive thermosyphons/ CPU coolers using locally available cheap and easily manufacturable components. We have also ensured to avoid a bulky design at any cost.

If we had gone with any other material other than copper, then the number of fins of would have increased for the same amount of heat transfer in possibly more time. This would also lead to a larger design size and end up taking more space inside the computer casing and reduce the space for other components.

The cost breakdown of our project is as shown below:

Component Name	Quantity	Cost (BDT)
2.5mm Copper Sheet	200mmx100mm	600
12.7mm Copper Tube	500mm	200
0.45mm Copper Sheet	152mmx900mm	1200
Copper Tube U-Bend	2 Pcs	140
Copper Tube L-Bend	2 Pcs	100
Pb-Sn Solder	1 spool	100
Ag Solder	1 rod	200
Thermometer	2 Pcs	160
Labour Cost		1000
Total		3700

Calculation:

$$m = \sqrt{\frac{hp}{kA_c}} = \sqrt{\frac{h \times 2(w+t)}{k \times w \times t}} = \sqrt{\frac{100 \times 2(55+0.45) \times 10^{-3}}{398 \times 55 \times 10^{-3} \times 0.45 \times 10^{-3}}} = 33.55$$

$$\eta_{fin} = \frac{\tanh(mL)}{mL} = \frac{\tanh(33.55 \times 25 \times 10^{-3})}{(33.55 \times 25 \times 10^{-3})} = 0.82$$

$$A_{fin} = n_{fin} \times 2 \times 25 \times 10^{-3} \times 55 \times 10^{-3}\ m^2 = 2.75 \times 10^{-3} n_{fin}\ m^2$$

$A_{unfinned} = \pi dl -$ Surface area of pipe attached to pipe

Here, length of pipe = $l = 2h + \frac{\pi d}{2} = 2 \times 125 \times 10^{-3} + \frac{\pi \times 12.7 \times 10^{-3}}{2} = 0.27\ m$

Surface area of pipe attached to pipe = $2 \times \frac{\pi d}{2} \times t \times n_{fin}$

$$= 2 \times \frac{\pi \times 12.7 \times 10^{-3}}{2} \times 0.45 \times 10^{-3} \times n_{fin} = 1.795 \times 10^{-5} n_{fin} m^2$$

$$A_{unfinned} = \pi \times 12.7 \times 10^{-3} \times 0.27 - 1.795 \times 10^{-5} n_{fin}$$
$$= 0.01077 - 1.795 \times 10^{-5} n_{fin} m^2$$

$$\dot{Q}_{finned} = \eta_{fin} \times \dot{Q}_{fin,max} = \eta_{fin} \times h \times A_{fin} \times (T_b - T_\infty)$$

$$= 0.82 \times 100 \times 2.75 \times 10^{-3} n_{fin} \times (54 - 30)$$

$=5.412 n_{fin}$ W

$$\dot{Q}_{unfinned} = h \times A_{unfinned} \times (T_b - T_\infty)$$

$$= 100 \times (0.01077 - 1.795 \times 10^{-5} n_{fin}) \times (54 - 30)$$

$=25.848-0.04308 n_{fin}$ W

$$\dot{Q}_{total} = \dot{Q}_{finned} + \dot{Q}_{unfinned} = 5.412 n_{fin} + 25.848 - 0.04308 n_{fin}$$

$$A_{no\ fin} = \pi dl = \pi \times 12.7 \times 10^{-3} \times 0.27 = 0.01077\ m^2$$

$$\dot{Q}_{no\ fin} = h \times A_{no\ fin} \times (T_b - T_\infty) = 100 \times 0.01077 \times (54 - 30) = 25.848\ W$$

Effectiveness of fin,

$$\varepsilon = \frac{\dot{Q}_{total}}{\dot{Q}_{no\ fin}}$$

Or, $4.1 = \frac{5.412 n_{fin} + 25.848 - 0.04308 n_{fin}}{25.848}$

Or, $n_{fin} \approx 15$

$\dot{Q}_{total} = 5.412 n_{fin} + 25.848 - 0.04308 n_{fin} = 106.38W \approx 107\ W$

Efficiency of thermosyphon cooler

$$\eta = \frac{\dot{Q}_{total}}{\dot{Q}_s} = \frac{107}{150} = 0.713\ (71.3\%)$$

Mass flow rate:

$\dot{Q}_{total} = \dot{m}_w \times C_{p,w} \times \Delta T$

Or, 107= $\dot{m}_w \times 4181 \times (54 - 45)$

$\therefore\ \dot{m}_w = 2.84 \times 10^{-3} kg/s$ = 2.84 g/s

Overall heat transfer coefficient:

Fan capacity, Q = 30 cfm = 0.0142 m^3/s

$\therefore\ \dot{m}_{air} = \rho \times Q = 1.164 \times 0.0142 = 0.0165\ m^3/s$

$\dot{Q}_{total} = \dot{m}_w \times C_{p,w} \times \Delta T_w = \dot{m}_{air} \times C_{p,air} \times \Delta T_{air}$

Or, $2.84 \times 10^{-3} \times 4181 \times (54 - 45) = 0.0165 \times 1007 \times (T_{out} - 30)$

$\therefore\ T_{out} = 36.4°C$

$\Delta T_1 = T_{h,in} - T_{c,out} = 54 - 36.4 = 17.6°C$

$\Delta T_2 = T_{h,out} - T_{c,in} = 45 - 30 = 15°C$

$$\Delta T_{lm,CF} = \frac{\Delta T_1 - \Delta T_2}{\ln\frac{\Delta T_1}{\Delta T_2}} = \frac{17.6 - 15}{\ln\frac{17.6}{15}} = 16.27°C$$

Assuming a correction factor of 0.95 for the cross flow,

$$\dot{Q}_{total} = UAF\Delta T_{lm,CF} = U \times \pi dl \times F\Delta T_{lm,CF}$$

$$107 = U \times \pi \times 12.7 \times 10^{-3} \times 0.27 \times 0.95 \times 16.27$$

U= $642.6\ W/m^2°C$

The standard value of overall heat transfer coefficient for air to water heat exchangers is between 600-750 $W/m^2°C$

Final Results:

Fin efficiency = 0.82

No. of fins required= 15

Thermosyphon cooler efficiency = 71.3%

Mass flow rate of water = 2.84 g/s

Overall heat transfer coefficient, U=642.6 $W/m^2°C$

MATLAB CODE:

```
format long;

eff=4.1;    %%effectiveness
k=398;      %%thermal conductivity
L1=25e-3;   %%fin_length
h=100;      %%convection coeff
t=0.45e-3;  %%thickness

fin_width=0.055;

Cp=4181;

max_temp=54;
t_atm=30;
req_temp=45;

tube_dia=12.7e-3;

perimeter= 2*(fin_width+t);
cross_area=fin_width*t;
m=sqrt((h*perimeter)/(k*cross_area));

fin_eff=tanh(m*L1)/(m* L1);  %%fin efficiency

finned_area= 2 * L1 *fin_width;

unfinned_tube=3.14*(tube_dia)*((2*0.125)+(3.14*(tube_dia/2)));

unfinned_area= unfinned_tube-((tube_dia/2)*3.14*t*2);
a=((tube_dia/2)*3.14*t*2);
Q_finned= fin_eff *h *finned_area * (max_temp-t_atm);

Q_unfinned=h * unfinned_area * (max_temp-t_atm);

Q_total= Q_unfinned +  Q_finned;
```

```
Q_no_fin=h*unfinned_tube*(max_temp-t_atm);

fin_number=((eff*Q_no_fin)-h*(max_temp-
t_atm)*unfinned_tube)/((Q_finned)-h*a*(max_temp-t_atm));

fin_number=ceil(fin_number);

thermosyphon_eff= ((eff*Q_no_fin)/150)*100;

mass_flow_rate= Q_total/(Cp*(max_temp-req_temp));


%%air mass flow rate

fan_capacity=0.0142; %%in cubic meter per second
mass_flow_rate_air=1.164*fan_capacity;
final_temp_air=(Q_total/(1007*mass_flow_rate_air))+t_atm;

%%calculating overall heat trasnfer coeff using LMTD

T1= max_temp-final_temp_air;
T2=req_temp-t_atm;

LMTD=(T1-T2)/(log(T1/T2));

factor=0.95;
overall_heat_transfer_coeff=Q_total/(3.14*tube_dia*0.27*0.95*LMTD);
```

Practical Test Results:

Even though our problem is rated for 150 W, due to our heat source not being able to produce the same amount of power, we conducted tests for varying voltages to monitor the temperature drop achieved between the ends of the inlets and outlets of the thermosyphon. The test data has been plotted in figure 13. The temperature difference achieved by each configuration kept increasing with time initially and later gradually reached a saturation value. With the variation of wattage, time taken to reach steady state values changed as well.

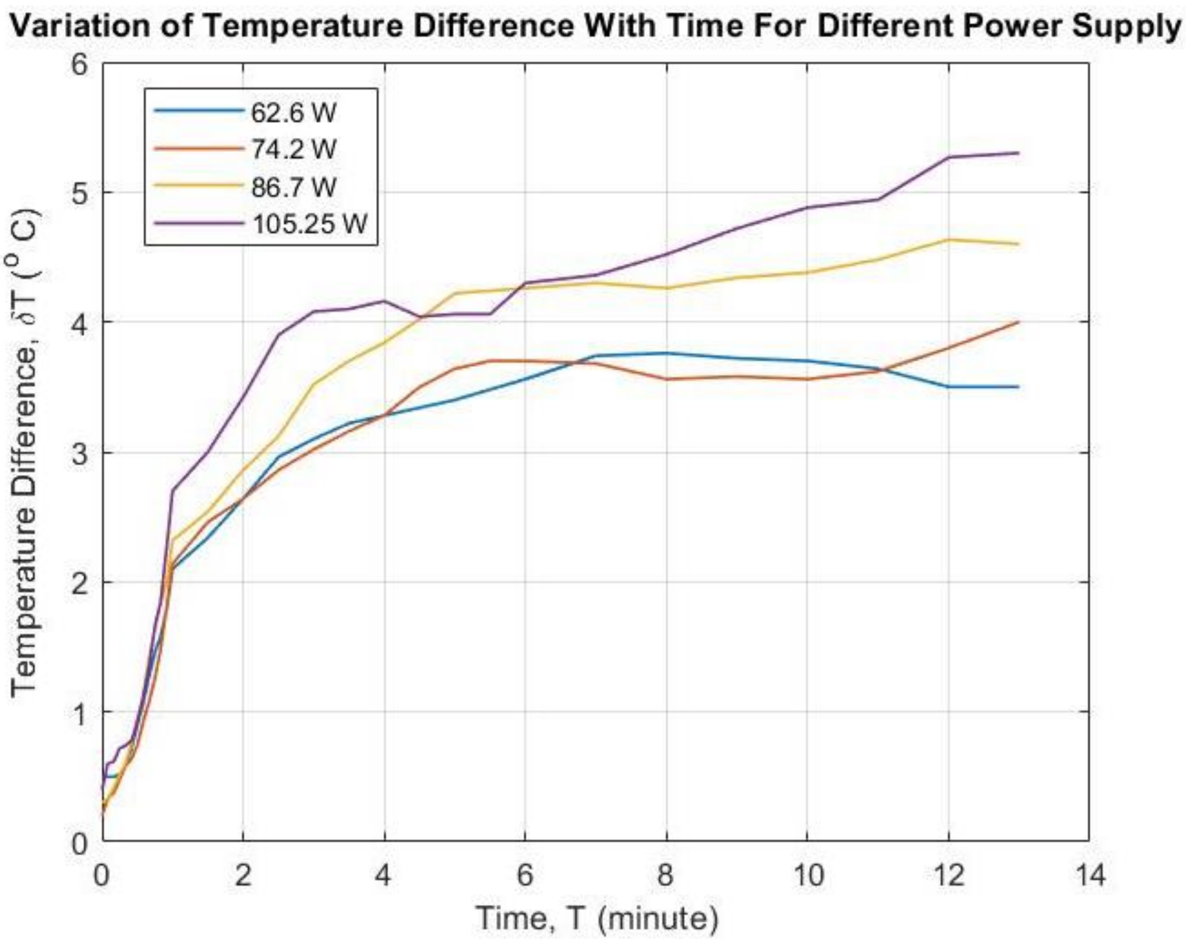

Fig 12: Change of temperature difference with time for different wattage

It is to be noted that all the temperature data from our experimental tests have been measured using a thermistor type thermometer connected with the tubes using thermal paste having an error of $\pm 1℃$

Conclusion: Our designed and manufactured thermosyphon was able to keep up with the required temperature drop despite minimum costs and subpar manufacturing facilities. This design can be scaled and improved further through more tests under higher rated load and change the dimensions based on the processing units and their requirements.