ANALYSIS AND FABRICATION OF HEAT PIPE AND THERMOSYPHON

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ABSTRACT:

Effective thermal conductivity of a heat pipe wick structure filled with a working fluid is measured. A simple evaluation method using a heating rod is described and the value of effective thermal conductivity is obtained by comparing the numerical results with the experimental ones. Full numerical simulation of heat pipes was performed for heat pipe under various operating conditions with water as working fluid. Two and three-dimensional models were developed assuming a laminar incompressible vapor core. Finally, a homogenous multiphase model referred to as volume of fluid modeling (VOF) was developed for simulation of a Heat pipe. A simple thermosyphon was fabricated. The thermal response time of a thermosyphon in comparison to a copper rod was observed. The response time and temperature profile along thermosyphon was measured. The effective thermal conductivity of it was calculated in a procedure like the heat pipe. Then the thermal conductivities of heat pipe and thermosyphon were compared. Using PRO-E/CATIA software we try to evaluate the design of the respective heat pipe. Later, we try to analyze the 3-D incompressible flow. The methodology of the project is to design the heat pipe system to carry out an analysis of the same using mechanical software based on the design and analysis of the heat pipe will be modeled.

Keywords: volume of fluid(VOF) modeling; thermosyphon; PRO-E; analysis;

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1. INTRODUCTION

Capillary-driven two-phase systems offer significant advantages over traditional single-phase systems. With the typically increased thermal capacity associated with the phase change of a working fluid, considerably smaller mass flow rates are required to transport equivalent amounts than in single-phase liquid or gas systems for a given temperature range. Moreover, heat transfer coefficients of two-phase systems are much greater than in single-phase flows and result in enhanced heat transfer. Lower mass flow rates and enhanced thermal characteristics provide the benefits of smaller system size (and weight) while providing increased performance. The thermal capacity of a single-phase system depends on the temperature change of the working fluid; thus, a large temperature gradient or a high mass flow rate is required to transfer a large amount of heat. However, a two-phase system can provide essentially isothermal operation regardless of variations in the heat load. Additionally, single phase systems require the use of mechanical pumps and fans to circulate the working fluid, while capillary-driven two-phase systems have no external power requirements, which make such systems more reliable and free of vibration. The best known capillary-driven two-phase system is the heat pipe, where a schematic of a conventional heat pipe is shown in Figure 1.

![Figure 1 Typical heat pipe construction and operation](image)

The concept of the heat pipe was first presented by Gaugler (1944) and Trefethen (1962), but was not widely publicized until an independent development by Grover et al. (1964) at the Los Alamos Scientific Laboratories. Heat pipes are passive devices that transport heat from a heat source (evaporator) to a heat sink (condenser) over relatively long distances via the latent heat of vaporization of a working fluid. As shown, a heat pipe generally has three sections: an evaporator section, an adiabatic (or transport) section, and a condenser section. The major components of a heat pipe are a sealed container, a wick structure, and a working fluid. The wick structure is placed on the inner surface of the heat pipe wall and is saturated with the liquid working fluid and provides the structure to develop the capillary action for liquid returning from the condenser to the evaporator section. With evaporator heat addition, the working fluid is evaporated as it absorbs an amount of heat equivalent to the latent heat of vaporization, while in the condenser section; the working fluid vapor is condensed. The mass addition in the vapor core of the evaporator section and mass rejection in the condenser end results in a pressure gradient along the vapor channel which drives the corresponding vapor flow. Return of the liquid to the evaporator from the condenser is provided by the wick structure.
Due to the two-phase characteristics, the heat pipe is ideal for transferring heat over long distances with a very small temperature drop and for creating a nearly isothermal surface for temperature stabilization. As the working fluid operates in a thermodynamic saturated state, heat is transported using the latent heat of vaporization instead of sensible heat or conduction where the heat pipe then operates in a nearly isothermal condition. This nearly isothermal condition offers benefits of transporting copious amounts of heat efficiently, decreasing the overall heat transfer area and saving system weight. The amount of heat that can be transported using latent heat is typically several orders of magnitude greater than transported by sensible heat for a geometrically equivalent system. Additionally, no mechanical pumping systems are required due to the capillary-driven working fluid. Given the wide range of operating temperatures for working fluids, the high efficiencies, the low relative weights, and the absence of external pumps in heat pipes, these systems are attractive options in a wide range of heat transfer applications.

Table 1 Heat Pipe working fluids

<table>
<thead>
<tr>
<th>Working fluid</th>
<th>Triple point(K)</th>
<th>Critical point (K)</th>
<th>Useful range(K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>54.3</td>
<td>154.8</td>
<td>55-154</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>63.1</td>
<td>126.2</td>
<td>65-125</td>
</tr>
<tr>
<td>Ethane</td>
<td>89.9</td>
<td>305.5</td>
<td>100-305</td>
</tr>
<tr>
<td>Butane</td>
<td>134.8</td>
<td>425.0</td>
<td>260-350</td>
</tr>
<tr>
<td>Methanol</td>
<td>175.2</td>
<td>513.2</td>
<td>273-503</td>
</tr>
<tr>
<td>Toluene</td>
<td>178.1</td>
<td>593.9</td>
<td>275-473</td>
</tr>
<tr>
<td>Acetone</td>
<td>180.0</td>
<td>508.2</td>
<td>250-475</td>
</tr>
<tr>
<td>Ammonia</td>
<td>195.5</td>
<td>405.6</td>
<td>200-405</td>
</tr>
<tr>
<td>Mercury</td>
<td>234.3</td>
<td>1763</td>
<td>280-1070</td>
</tr>
<tr>
<td>Water</td>
<td>273.2</td>
<td>647.3</td>
<td>273-643</td>
</tr>
<tr>
<td>Potassium</td>
<td>336.4</td>
<td>2250</td>
<td>400-1800</td>
</tr>
<tr>
<td>Sodium</td>
<td>371.0</td>
<td>2500</td>
<td>400-1500</td>
</tr>
<tr>
<td>Lithium</td>
<td>453.7</td>
<td>3800</td>
<td>500-2100</td>
</tr>
<tr>
<td>Silver</td>
<td>1234</td>
<td>7500</td>
<td>1600-2400</td>
</tr>
</tbody>
</table>

Gravity assisted heat pipes or wickless heat pipes are highly efficient heat transfer devices often referred to as thermal superconductors or thermal short circuits. The efficient thermal conductivity of thermosyphon exceeds that of copper 200-500 times [1]. A two phase closed thermosyphon is a passive heat transfer device containing the working fluid in closed container. It is used to transport a large amount of heat at a high rate with small temperature difference between the sink and source. This is achieved by making use of the highly efficient thermal transport process of evaporation and condensation. The thermal performance of two phase closed thermosyphon (TPCT) has been extensively studied for a long period of time. The behavior of TPCT filled with water, ammonia, toluene and conventional refrigerants like R11 and R12 in a steady state situation are well known and numerous experimental and analytical works are available in the literature [2-8]. The use of refrigerants as working fluids is easy for certain applications because they work with positive work.

The literature survey revealed that the many of the research work deals with the TPCT filled conventional refrigerants like R11, R12 and R22. However, knowledge of thermal performance of TPCT filled with alternate refrigerant is of great importance since the conventional refrigerants are banned due to their potential to deplete the ozone layer. Very few investigations are made to study the thermal behavior of TPCT filled with R134a, which
Payakaruk et al., studied experimentally the effect of dimensionless numbers (Bond numbers, Froude numbers, Weber numbers and Kutateladze numbers) on heat transfer characteristics of an inclined thermosyphons. Copper thermosyphons with R\textsubscript{22}, R\textsubscript{123}, R\textsubscript{134a}, ethanol and water as the working fluids are employed to predict heat transfer characteristics of an inclined closed two phase thermosyphon at normal conditions. The effect of thermosyphon inner diameter, fill ratio, aspect ratio and inclination angle is also studied.

Faghri et al., reported the performance of a thermosyphon filled with R\textsubscript{134a}. They concluded that the heat flux transferred increased with high coolant mass flow rates, high fill ratios and greater temperature difference between bath and condenser in this experimental work, the evaporator was immersed in a water bath to maintain constant temperature on evaporator side. This type of TPCT can be termed as temperature controlled thermosyphon.

Abou- Ziyane et al. has investigated the effect of vibration on thermosyphon filled with R\textsubscript{134a}. They found that minor or no effect is experienced with R\textsubscript{134a} below the boiling limit and enhancement up to 250\% existed above the boiling point.

The evaporator section of a thermosyphon covered with a heater to supply the required flux can be termed as flux controlled thermosyphons. The experimental studies of a flux controlled thermosyphon filled with R134a are not easily found in literature. Hence the thermal behavior of R134a thermosyphon was undertaken in this work. This paper considers the effect of controlling variables (Heat input, Coolant mass flow rate and coolant temperature) on thermal performance of a flux controlled R\textsubscript{134a} thermosyphon.

WHY WE ARE COMPARING THE HEAT PIPE WITH THERMOSYPHON?

- General purpose of the heat pipe and thermosyphon to transfer the heat from one position to the other.
- The heat pipe is very costly than compare with the thermosyphon.
- We have comparing the thermal conductivity of the thermosyphon with the heat pipe so that we provide the heat transfer equipment with the less cost.
- When compare with the thermosyphon the manufacturing method of the heat pipe is more complex.
- We try to reduce the cost of manufacturing with the most efficient heat Transfer with the high thermal conductivity.

2. EXPERIMENTAL DETAILS

2.1. Heat Pipe CAD Model designed using CATIA

Commonly referred to as a 3D Product Lifecycle Management software suite, CATIA supports multiple stages of product development (CAX), including conceptualization, design (CAD), engineering (CAE) and manufacturing (CAM). CATIA facilitates collaborative engineering across disciplines around its 3DEXPERIENCE platform, including surfacing & shape design, electrical, fluid and electronic systems design, mechanical engineering and systems engineering.

CATIA facilitates the design of electronic, electrical, and distributed systems such as fluid and HVAC systems, all the way to the production of documentation for manufacturing. The Heat Pipe model is designed using CATIA, which is shown in the fig. 2.1.
Thermosyphon CAD Model designed using CATIA

Figure 2.1 Heat Pipe (3D shell) with thickness of 2mm

Figure 2.2 Thermosyphon (Wick less Heat Pipe)

Analysing the Thermosyphon Using ANSYS WorkBench

ANSYS have the wide range of applications in the finite element problems.

- It is used to find out the design considerations i.e. what the type of meshing we need to provide the accurate results
- In the ANSYS part the boundary considerations requirements are compulsory i.e. which face is needed to be fixed and what amount of force we need to apply at what particular point
- In the ANSYS we find out the stresses development what amount of deformations taking place without manufacturing the equipment to save the expenditure over it.

Thermosyphon model which has developed in the CATIA has been imported to the ANSYS workbench, and the mesh has been applied, which is shown in the figure 2.3.
Figure 2.3 Thermosyphon Mesh Model

The heat pipe cad model developed in CATIA has been imported in the same way as Thermosyphon and mesh has been applied using ANSYS for applying the input parameters, which is shown in the figure 2.4.

Figure 2.4 Heat Pipe Mesh Model

At different temperatures, the representation of the thermosyphon is shown in the figure 2.5.
The trajectory of the input parameters applied to the thermosyphon mesh model for the number of iterations is shown in the figure 2.6.

In the same way, the analysis is carried out on the heat pipe, and for the different temperatures of the heat pipe, it is shown in the figure 2.7, and the graphical representation of the position of the heat pipe for different temperatures has been shown in the figure 2.8.
Manufacturing of Thermosyphon (Wick less Heat Pipe)

Initially, material for the thermosyphon is selected as copper (preferably), and the copper pipe is made with two side opening. One of the side is closed with cap of parent material type by welding and the pipe is filled with level of 30% and not more than 50% to provide an area for the condensation. The other end of the pipe can be closed by thumb and pipe is heated to change the phase of water to vapor. Side closed with thumb will be opened for small period to
form vacuum of certain level and then that side will be closed with cap to elevate vapor which leads to a perfect wick less heat pipe. The thermosyphon which is manufactured by using the procedure elucidated above is shown in the figure 2.9.

![Figure 2.9 Thermosyphon (Wick less Heat Pipe)](image)

**Practical Evaluation of the Heat Pipe (Wick)**

The specifications of the heat pipe are given by:
- Length of the Heat Pipe = 300 mm
- Diameter of the Heat Pipe = 30 mm
- Area of the Heat Pipe = 176.25 mm²
- Evaporator Length = 150 mm
- Condenser Length = 150 mm
- Effective Length of Heat Pipe = 125 mm
- Wick Material = Copper
- T1 = Avg. Evaporator Temperature
- T2 = Avg. Condenser Temperature

The experiment is conducted for the different values of the T1 and T2 as shown in the table 2.

<table>
<thead>
<tr>
<th>T1</th>
<th>30</th>
<th>36</th>
<th>40</th>
<th>43</th>
<th>50</th>
<th>57</th>
<th>62</th>
<th>65</th>
<th>70</th>
<th>75</th>
</tr>
</thead>
<tbody>
<tr>
<td>T2</td>
<td>29</td>
<td>32</td>
<td>33</td>
<td>34</td>
<td>35</td>
<td>43</td>
<td>46</td>
<td>49</td>
<td>55</td>
<td>62</td>
</tr>
</tbody>
</table>

![Figure 2.10 Heat Pipe Experimental Setup](image)
Practical Evaluation of Wick less Heat Pipe

![Image of heat pipe experimental setup]

**Figure 2.11 Heat Pipe Experimental Setup**

The temperature of the thermosyphon and the water at regular intervals of two minutes is shown in the table 3.

<table>
<thead>
<tr>
<th>Sl. No.</th>
<th>Thermosyphon Temperature(°C)</th>
<th>Water Temperature(°C)</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>34</td>
<td>38</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>35</td>
<td>38</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>44</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
<td>46</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>43</td>
<td>49</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>44</td>
<td>51</td>
<td>10</td>
</tr>
<tr>
<td>7</td>
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<td>53</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>46</td>
<td>55</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>48</td>
<td>57</td>
<td>16</td>
</tr>
<tr>
<td>10</td>
<td>48</td>
<td>59</td>
<td>18</td>
</tr>
<tr>
<td>11</td>
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<td>61</td>
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<td>51</td>
<td>63</td>
<td>22</td>
</tr>
<tr>
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<td>65</td>
<td>24</td>
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<td>14</td>
<td>52</td>
<td>66</td>
<td>26</td>
</tr>
<tr>
<td>15</td>
<td>52</td>
<td>68</td>
<td>28</td>
</tr>
<tr>
<td>16</td>
<td>52</td>
<td>69</td>
<td>30</td>
</tr>
<tr>
<td>17</td>
<td>52</td>
<td>70</td>
<td>32</td>
</tr>
</tbody>
</table>

3. RESULTS AND DISCUSSION

3.1. Comparision of Temperature drop of Thermosyphon and Heat Pipe Using ANSYS

After importing the Thermosyphon CAD Model and Heat Pipe CAD Model which are designed in CATIA are analyzed using ANSYS Workbench and the positions of the thermosyphon and the heat pipe with respect to total temperature mixture are shown in the figure 3.1 and 3.2.
3.2. Evaluation of Effective Thermal Conductivity

The analysis of the thermosyphon and heat pipe carried out in the ANSYS Workbench gives the position i.e. effective length, which is used to evaluate the effective thermal conductivity of the thermosyphon and heat pipe as follows.

From the Fourier Law of Heat Conduction,

\[ Q = K \cdot A \cdot \frac{dt}{dx} \]

Where

- \( Q \) = Heat input
- \( K \) = Effective thermal conductivity
- \( dt \) = Temperature distribution
- \( dx \) = Effective length
- \( A \) = Area through which heat flows
- \( dt \) = (average evaporator temperature-average condenser temperature)

**Heat Pipe:**

Average evaporator temperature=168\(^0\)K
Average condenser temperature=60\(^0\)K
Q=52.8 KW
A=114.5 mm\(^2\)
52.8= \( K_{\text{eff}} \times 0.000706 \times (11.6/0.125) \)
\( K_{\text{eff}} = 1100 \text{ W/m}^0\text{K} \)
**Thermosyphon:**

\[ X = 23728 \]

\[ 35.95 = K_{\text{eff}} \times 176.25 \times 4.091 \times (6/145) \]

\[ K_{\text{eff}} = 4930.72 \text{ W/m}^2\text{K} \]

3.3. Graphical Representation of Temperatures of Thermosyphon and Heat Pipe w. r. t. Time

The graph has been plotted against temperature and time where series 1 represents temperature variation of the heat pipe and series 2 represents the temperature variation of the thermosyphon in the graph 1.

**Graph 1** Temperature (°C) vs Time (Minutes)

4. CONCLUSION

It has been revealed conducting series of experiments, that thermosyphon is having higher effective thermal conductivity value compared to heat pipe which leads to maximum heat transfer from one point to other. It has been observed that thermosyphon is reaching steady state in less time when compared to heat pipe. The temperature drop is also less in thermosyphon compared to heat pipe.

REFERENCES


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