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Parametric Study On Heat Pipe & Performance Optimization

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Abstract: ***Heat pipes are effective and reliable thermal solution, especially in high heat flux applications and also in the situations where heat load is changing. This chapter will focus on heat pipe design and compare the different situations and parameters which are affecting the heat pipe because of its ability to transfer more heat without any external power source. The project focuses on the effect of different parameters on the heat pipe. Main objective is to study the effect on heat pipe limits by different working fluid, different temperature conditions and different wick material.***

Keywords: Heat pipe, Wick structure, Capillary limit, Sonic limit, Arterial Depth

1. Introduction

A heat pipe is a simple device having no moving parts that can transfer large quantities of heat over large distances at a constant temperature without any external inputs.

The original idea of the heat pipe was developed in 1944 by Gaugler1 and in 1962 by Trefethen. Gaugler patented a very lightweight heat transfer device which is similar of the heat pipe. But his work didn't get much attention.

After some years National Laboratory again invented the same model for their space program and its applications.

Heat pipes are two-stage stream heat exchange device where procedures of fluid to vapor and the other way around circle between evaporator to condenser with high viable heat conductivity. Because of the high heat transport limit, heat exchangers with heat pipes have turned out to be considerably smaller than conventional heat exchangers in taking care of high heat motions. With the working liquid in a heat pipe, heat can be consumed on the evaporator area and transported to the condenser where the vapor gathers, discharging the heat to the cooling media. Heat pipe innovation has discovered expanding applications in improving the heat execution of heat exchangers in microelectronics; vitality investment funds in heating, ventilating, and aerating and cooling (HVAC) frameworks for working rooms, temperature control frameworks for the human body; and other modern divisions including shuttle and different sorts of atomic reactor advances as a completely inborn cooling contraption. The heat pipe is an independent structure that accomplishes high heat vitality conductance by methods for two-stage liquid stream with slender flow.

2. Working of Heat Pipe

A heat pipe is essentially a fixed thin tube containing a wick structure lined on the internal surface and a little measure of liquid, for example, water at the soaked state. It is made out of three areas: evaporator segment toward one side, where heat is absorbed and the liquid is vaporized; a condenser segment at the end side, where the vapor is condensed and heat is rejected; and the adiabatic segment in the middle of, where the vapor and the fluid move between two sections separately. The operation of a heat pipe depends on the thermodynamic properties of a liquid vaporizing toward one side and gathering at the end side. At first, a wick of the heat pipe is immersed with fluid and the centre area is loaded with vapor, as shown in Figure

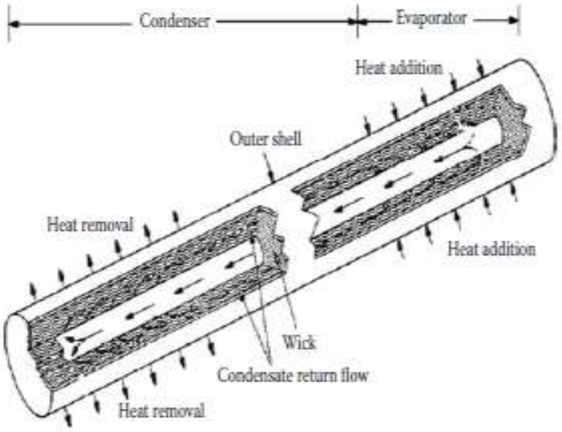

Figure1: Working of heat pipe

3. Design Methodology

In design of heat pipe we need to consider boundary limits which are explained below

1) Capillary limit

The ability of capillary to provide fluid transfer for a given working fluid is limited. It is called the capillary limitation. This limit is the most commonly occured limitation in the operation of heat pipes working under low temperatures. It occurs when the pumping rate is not sufficient to provide enough liquid to the evaporator section.

The maximum capillary pressure depends on the physical properties of the wick and working fluid. If we want to increase the heat transfer above the capillary limit then it will cause dry out in the evaporator section.

Normally heat transfer is found out from the pressure drop as shown below

$\Delta P_{c,m} = \Delta P_v + \Delta P_l + \Delta P_{norm} + \Delta P_{axial}$
Where
Vapour pressure drop $\Delta P_v = \frac{C(f_v Re_v)\mu}{2r^2 A \rho h_{fg}} L_{eff}\, q$

where fv = friction factor of vapor (4.19a)
Re = Reynolds number of vapor
μ = absolute viscosity of vapor
r = hydraulic radius of the vapor path
A = cross-sectional area of vapor path
ρ = vapor density
hfg = latent heat of vaporization
q = heat transfer rate

Liquid pressure Drop $\Delta P_l = \frac{\mu}{K A_w h_{fg} \rho_l} L_{eff}\, q$

Where μ = absolute viscosity of liquid
K = wick (or artery) permeability
Aw = wick (or artery) cross-sectional area
hfg = latent heat of vaporization
ρ = liquid density

Normal hydrostatic pressure drop $\Delta P_{norm} = \rho_l g d_v \cos\psi$

Where dv is the diameter of the vapor portion of the pipe and Ψ is the angle the heat pipe makes with respect to the horizontal

Here we assume that heat pipe is in horizontal so axial pressure drop is zero

2) Sonic limit
Vapor flow attains sonic velocity while leaving the evaporator, maximizing the flow. Too high power at low operating temperature. High mass flow rate causes sonic flow conditions and generates a wave that maximizes the flow and restricts ability to transfer heat.[1]

$$Q = A\rho\, h_{fg}\left(\frac{\gamma RT}{2\,(\gamma + 1)}\right)^{1/2}$$

where γ is the specific ratio

3) Boiling limit
When very high heat fluxes are reached, boiling may start in the wick structure. Bubbles become trapped in the wick, blocks the liquid return and results in evaporator drying. Maximum heat transfer rate is obtained by following equation[1]

$$Q = \frac{4\pi L_{eff} k_{eff} T_v \sigma}{h_{fg} \rho_v \ln\left(\frac{R_i}{R_v}\right)}\left(\frac{1}{R_n} - \frac{1}{R_c}\right)$$

where Rn is the nucleation cavity radius, which is approximately 0.254 μm

4) Entrainment Limit
Liquid droplets may get picked up in the vapor flow, it Causes drying of evaporator wick and Maximum heat transfer rate due to entrainment is obtained by following equation[1]

$$Q = A h_{fg}\sqrt{\sigma \rho_v / 2 r_{h,w}}$$

where r h,w is the hydraulic radius of the wick

4. Calculation

Here we have taken one sample problem for design.

A heat pipe is required which will be capable of transferring a minimum of 15 W at vapor temperatures between 0 and 80 0C over a distance of 1 m in zero gravity (a satellite application) . Restraints on the design are such that the evaporator and condenser sections are each 8 cm long , located at each end of the heat pipe , and the maximum permissible temperature drop between the outside wall of the evaporator and the outside Hall of the condenser is 6 0 C. Because of Height and volume limitation, the cross - sectional area of the vapor space should not exceed 0 . 197 cm 2 The heat pipe must also with ¬stand bonding temperatures.[1]

To find out maximum heat transfer we prepare spreadsheet and all the calculations are done.

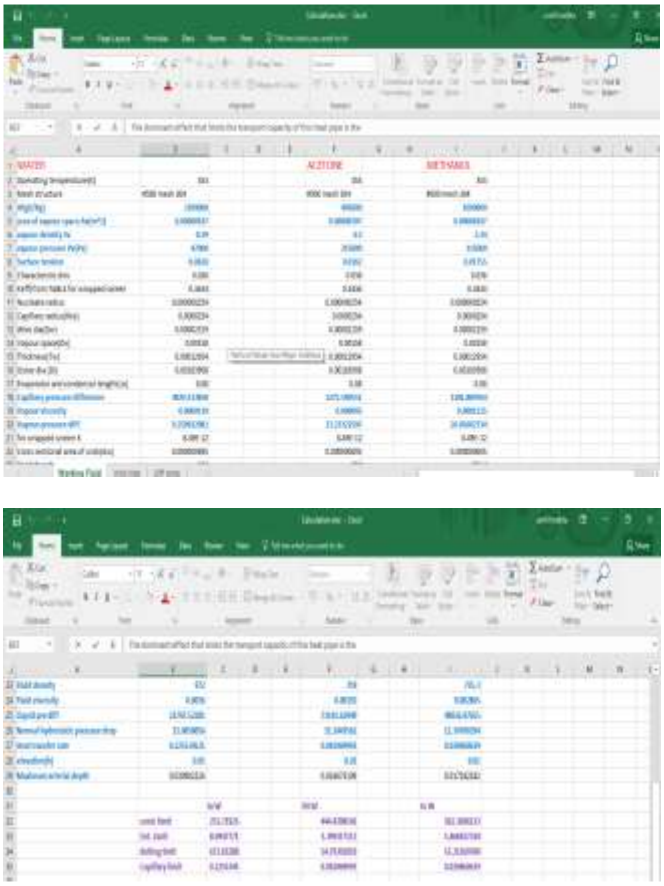

Figure 2: Calculation for different working fluids

From above equations we can find out all the limits and maximum heat transfer is achieved as 0.2244 W which is not feasible as per requirement so we have to improve the design to achieve 15 W. so we consider maximum arterial depth.

The maximum arterial depth δ has a significant physical meaning when a heat pipe starts its operation on the ground. The capillary force must overcome the gravity and allow the working fluid moving toward the evaporator from the condenser through the arterial channel. Once the arterial channel is filled with the working fluid, the capillary radius (either artery or wick) at the evaporator not the arterial depth, then governs the flow.

$$\delta = \frac{1}{2}\sqrt[2]{\left(h^2 + \frac{8\sigma\cos\theta}{(\rho l - \rho v)g}\right.} - h$$

So new vapour pressure drop is found out by previous equation only value of K is changed.

$$K = \frac{2r^2}{fRe}$$

Where $r = \frac{\delta}{\delta + w}$ width is taken as 1 mm

By this calculation we get improved heat transfer as 36 W which is greater than required heat transfer so our design is feasible.

Now for different wick material and working temperature for same working fluid water calculation is done which is shown here.

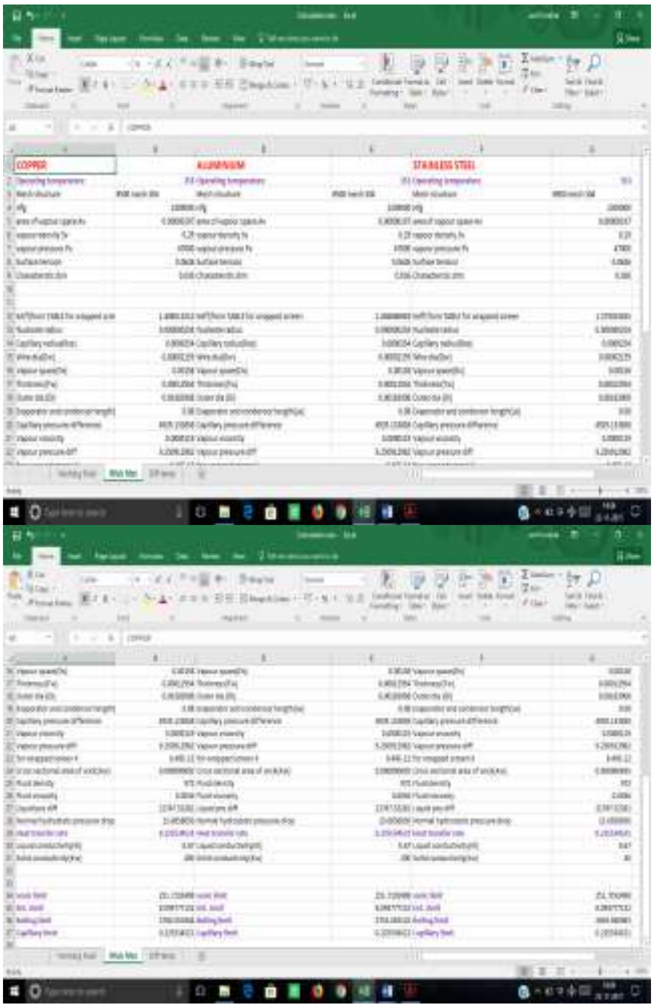

Figure 3: Calculation for different wick material

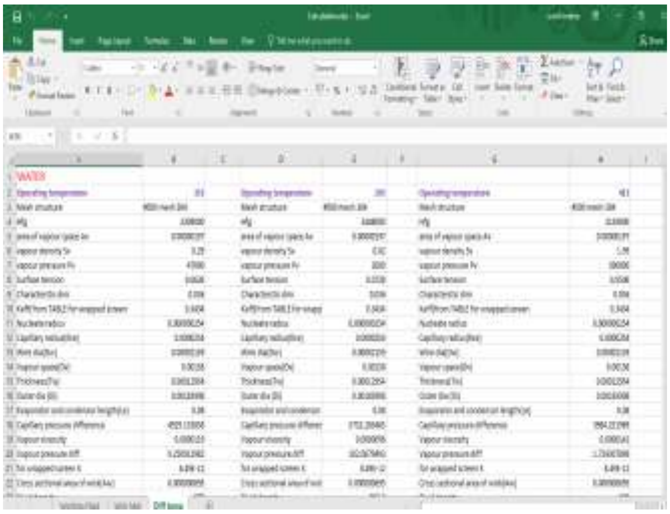

Figure 4: Calculation for different temperature of same working fluid(a)

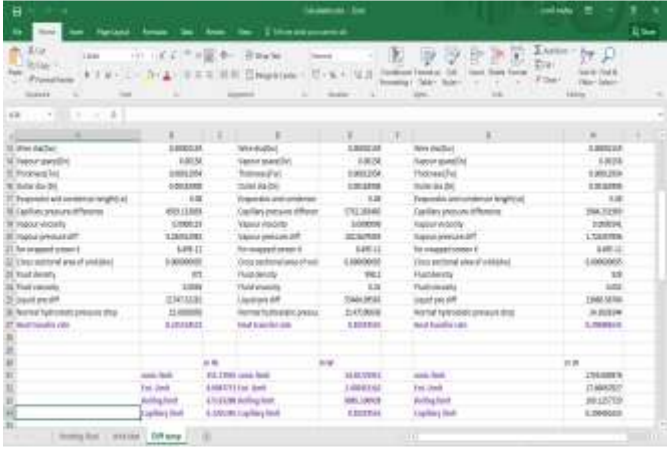

Figure 5: Calculation for different temperature of same working fluid(b)

5. Results

From above calculations we come to know that water best suitable for given application. Different limits are found out from the above calculation. Comparison of different limits for different conditions is shown in graphical manner as below.

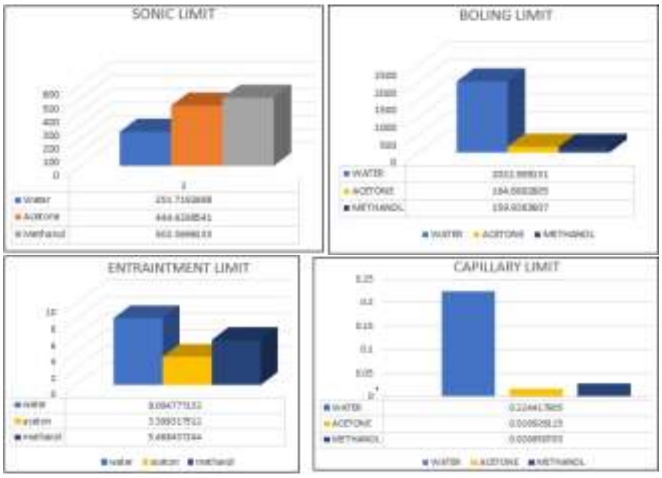

Figure 6: Comparison of different limits for different working fluids

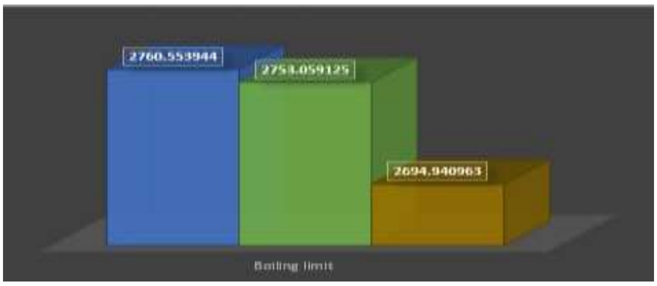

Figure 7: Comparison of different limits for Different wick material

Figure 8: Comparison of limits for same working fluid at different working temperatures

6. Conclusions

From above discussion we conclude that the heat pipe is characterized by Very high effective thermal conductance. The condenser surface of a heat pipe will be operating at uniform temperature. When a local heat load is applied, more vapor will condense and maintaining the temperature at the original level.

From the above tables and graphs, it is clear that water has the highest temperature gradient and high heat transfer coefficient among the three working fluids. The Heat pipe with a water as a working fluid is an advantage as it is readily availability and cheap in cost. From the above four limits, the limit having least heat transfer rate will be deciding factor for the heat pipe design. To get more heat transfer further calculation is to be done to meet our requirements.

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