

PASSIVE CAR CABIN COOLING SYSTEM

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ABSTRACT: In today's world, cars are the most important form of transportation for an individual besides the public transport. The number of vehicles on the road is increasing on a daily basis and drivers experience difficulty in getting an indoor or roof parking space especially during peak hours. As a result, they have no choice except to leave their car in an open space parking. Under such circumstances, temperature inside the car increases. This causes the car to heat up and creates an intense sense of discomfort for passenger when they get inside the car later. As a solution for this deplorable condition, a passive car cabin cooling system is proposed. The purpose of this passive cabin cooling system is to help cool off the cabin of the car parked without a shade. Thus, the aim of this project is to develop a product that is capable to cool the passenger cabin without operating the car's engine, using a highly efficient kind of heat exchangers known as heat pipes. A heat pipe is an evaporation-condensation device for transferring heat in which the latent heat of vaporization is utilised to transport heat over long distances with a corresponding small temperature difference. The advantage of using a heat pipe over other conventional heat exchange methods is that large quantities of heat can be transported through a small cross-sectional area over a considerable distance with no additional power input to the system. Materials used are also of low cost and has high durability. This car cooling system is used to maintain the temperature inside the car at ambient temperature even under very hot conditions. As a result, once the user starts the car, the air conditioner doesn't have to work too hard in order to bring the temperatures to a comfortable level.

KEYWORDS: Heat pipes, Thermosyphon, Passive device, Thermal radiations, Heat exchanger.

I.INTRODUCTION

A heat pipe is an evacuated cylindrical sealed tube containing a working fluid. It is divided into three sections such as evaporator section, adiabatic section and condenser section. Heat and mass transfer of the working fluid occurs inside the heat pipe primarily due to the transfer of latent heat, in and out of the heat pipe. There are many different kinds of heat pipes but for simplicity purpose, this paper considers the two phase closed thermosyphon heat pipe incorporating a six layered screen mesh wick. Figure 1 shows the schematic of the heat pipe. The thermosyphon, a type of heat pipe has been used for many years and various working fluids have been employed. One limitation of the basic thermo-syphon is that in order for the condensate to be returned to the evaporator region by gravitational force, the latter must be situated at the lowest point. The basic heat pipe differs from the thermosyphon in that a wick, constructed for example from a few layers of fine gauze, is fixed to the inside surface and capillary forces return the condensate to the evaporator (see Fig 1(b)). In the heat pipe the evaporator position is not restricted and it may be used in any orientation. If, of course, the heat pipe evaporator happens to be in the lowest position, gravitational forces will assist the capillary forces. The term „heat pipe“ is also used to describe high thermal conductance devices in which the condensate return is achieved by other means, for example centripetal force, osmosis or electro hydrodynamics.

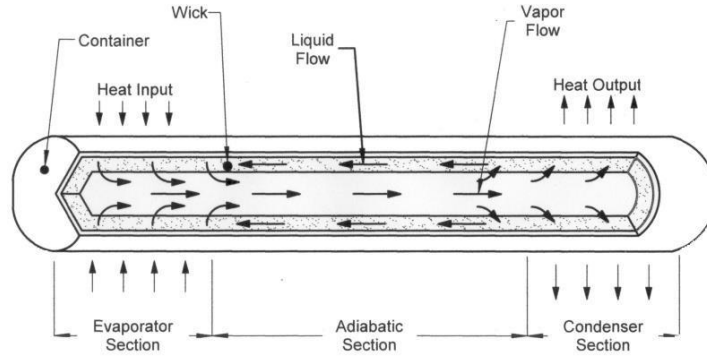


Figure 1: Schematic of the heat pipe

II. GEOMETRICAL CONFIGURATIONS

The heat pipe design is an iterative process and the selections or calculations are usually repeated several times. Depending upon the space restrictions of the car, several different configurations of heat pipe can be manufactured. Table 1 gives the design requirements of the heat pipe and Figure 2 gives the heat pipe geometry and dimensions.

Table 1: Design requirements of heat pipe

Design type	1:2:1 10.16
Heat pipe length (l_{hp})	cm
Evaporator length (l_e)	02.54 cm
Condenser length (l_c)	02.54 cm
Adiabatic length (l_a)	05.08 cm
Outer diameter of heat pipe (d_o)	01.58 cm
Inner diameter of heat pipe (d_i)	01.39 cm
Wall thickness (t_w)	00.17 cm
Vapor space radius (r_v)	00.69 cm
Surface area of heat pipe (A_{hp})	01.53 cm ²
Area of vapor space (A_{vs})	00.38 cm ²
Capacity (Q)	300.0 W
Operating temperature range($T_{min} - T_{max}$)	300 K – 343 K

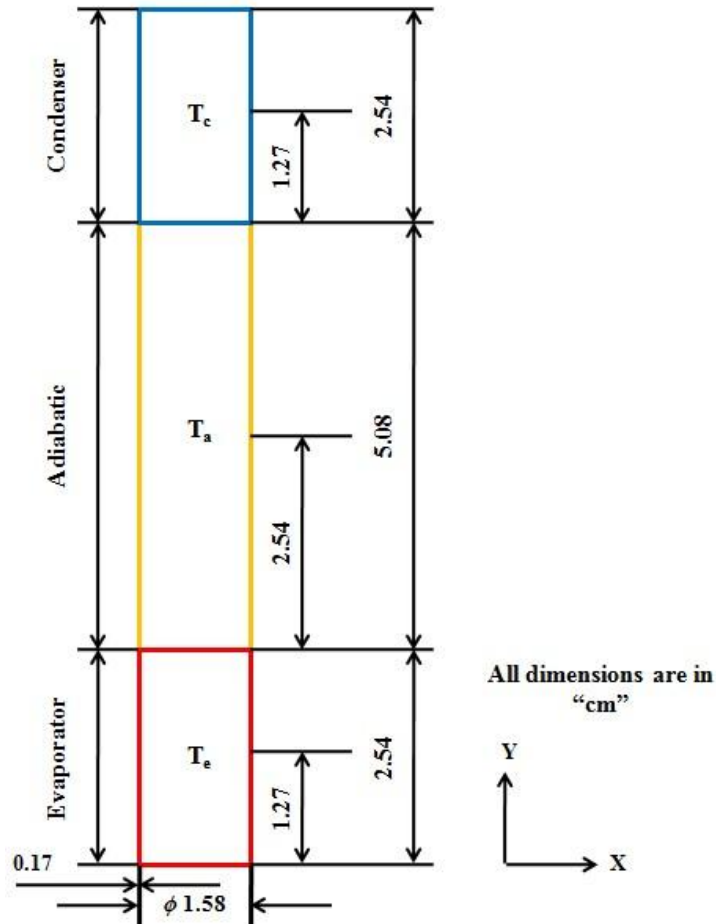


Figure 2: Heat pipe geometry and dimensions

In order to make sure that the heat pipe operates satisfactorily, the limitations of the heat pipe must be evaluated. There are five different limitations that are critical to the performance of the heat pipe. They are viscous limit, sonic limit, entrainment limit, capillary limit and boiling limit. Figure 3 shows the different limitations to be considered as a function of temperature and axial heat flux

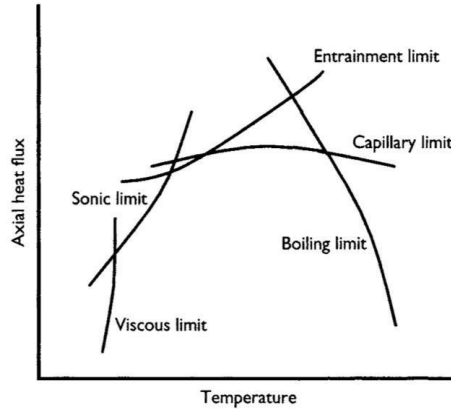


Figure 3: Operating limits of the heat pipe

A.Viscous Limit

The vapor pressure difference between the evaporator and condenser end is very small at low temperatures, then the viscous forces may be dominant. During startup when the temperatures are low, the dominant viscous forces prevent the operation of the heat pipe until the working range is achieved. The criteria for the consideration of viscous limit is given by (1)

$$(\Delta P_v/P_v) < 0.1 \tag{1}$$

Viscous limit is of minimal importance for normal temperature applications according the Handbook of heat transfer.

B.Sonic Limit

The sonic limit is to be considered at the minimum working temperature. Equation (2) is used to calculate sonic limit

$$q_s \leq \rho_v L \sqrt{\frac{\gamma R T_v}{2(\gamma v \rho_1)}} \tag{2}$$

Table 2: Sonic Limit Heat Flux

Water	1.448 KW/cm ²
Methanol	5.870 KW/cm ²
Acetone	4.660 KW/cm ²

The heat pipe has a circular cross section and is required to transport 300 W, so the actual heat flux is 0.048 KW/cm². Comparison with the sonic limitations of various working fluids as shown in table 2, we can see that the limit is not going to be reached for the fluids. **C.Boiling Limit**

The degree of superheat ΔT required to cause boiling in the evaporator is given by (3). ΔT is evaluated at maximum temperature, as the lowest permissible degree of superheat will occur at maximum temperature

$$\Delta T \leq \left(\frac{3.06 \sigma l T_{sat}}{\rho_v L \delta} \right) \tag{3}$$

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Table 3: Sonic Limit Heat Flux

Water	9.000 K
Methanol	0.717 K
Acetone	0.690 K

The calculated values of degree of superheat for the three choices of working fluid are given in table 3. Preference must be given to those fluids that have the highest degree of superheat since the chances of boiling in the wick will be reduced. In our case water gets the first preference as the working fluid followed by methanol and acetone.

D. Entrainment Limit

The entrainment limit is evaluated at maximum temperature of operation and is given by (4)

$$q_{ent} = \pi r v^2 \sqrt{\frac{2\pi \rho v \sigma r}{L z}} \tag{4}$$

Table 4: Entrainment limit

Water	15786.20 W
Methanol	10917.34 W
Acetone	7401.33 W

The heat pipe has a circular cross section and is required to transport 300 W. Comparison with the entrainment limitations as given in table 4; we can see that the limit is not going to be reached for the fluids.

E. Capillary Limit

The performance of the working fluids can be evaluated by the Merit Number. The formula for evaluating merit number is given by (5). The Merit number for different fluids are shown the figure below

$$\rho l \left(\frac{\sigma}{\mu} \frac{1}{L} \right) \tag{5}$$

Capillary limit is only a comparative criterion that can be used to select the working fluid. Capillary limit plays a very significant role when the heat pipe is operated in orientations other than the vertical

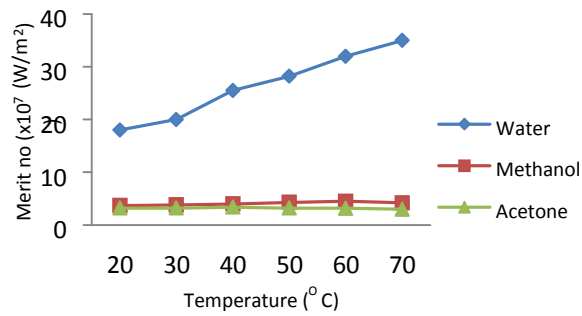


Figure 4: Chart displaying the merit number of different working fluids

Figure 5 shows the experimental setup of the heat pipe. The adiabatic section and the protruding ends of condenser and evaporator section are insulated by means of glass wool. Figure 6 shows the front view of the heat pipe setup and Figure 7(a) shows the close up view of evaporator section, Figure 7(b) adiabatic section and Figure 7(c) the condenser section.



Figure 5: Experimental setup



Figure 6: Front view of the heat pipe setup



Figure 7(a): Evaporator, Figure 7(b): Adiabatic, Figure 7(c): Condenser

Three thermocouple wires are connected to the heat pipe, one for each region, and the other end to a multipoint scanner for temperature measurement. The voltage is controlled by means of a voltmeter to provide a supply power of 18W. Three sets of temperature readings were taken and the average of them is tabulated in table 5.

Table 5: Experimental results

Evaporator temperature	Adiabatic temperature	Condenser temperature	Ambient temperature
65°C	45°C	42°C	40°C



Figure 8: Installed heat pipe system

III. CFD ANALYSIS OF HEAT PIPE

In order to verify the accuracy of the results, CFD analysis was performed and the results were compared. All the analysis was carried out in ANSYS Fluent R16.0. Transient Multiphase modeling with two Eulerian phases in the Volume of Fluid (VOF) approach was used. In order to reproduce results more accurately, appropriate source terms were coined and included in the mass and energy transfer equations. A five layered 1, 73,718 noded quad4 element mesh was used. PISO scheme for pressure- velocity coupling and second order upwind scheme for momentum and energy are used with a time step of 1e-6. The number of iterations was limited to 7.

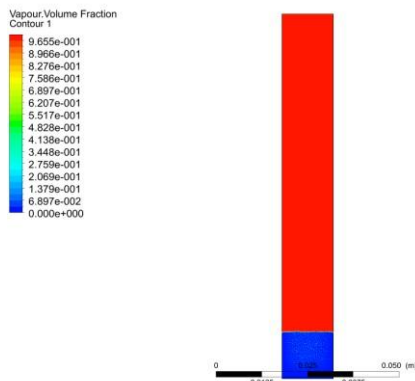


Figure 9: Contour of volume fraction at t= 2s

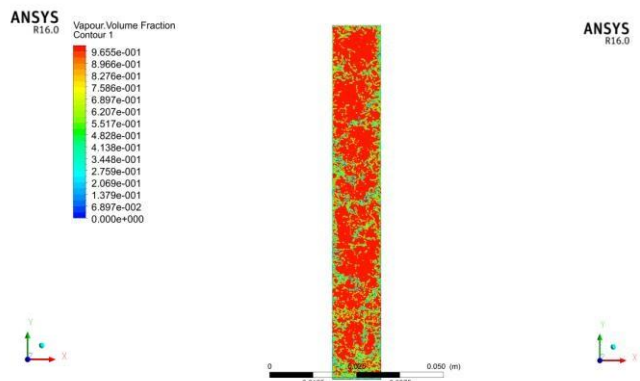


Figure 12: Contour of volume fraction at t=64 s

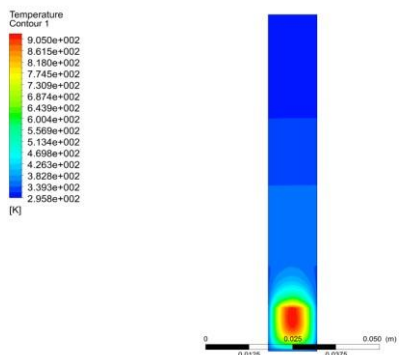


Figure 10: Contour of temperature at t= 2s

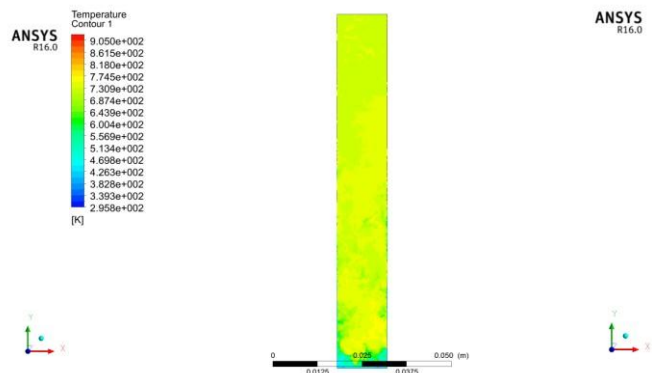


Figure 13: Contour of temperature at t= 64 s

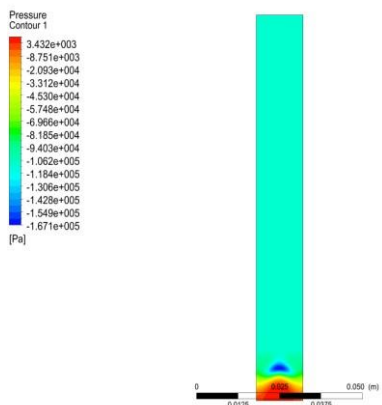


Figure 11: Contour of pressure at t= 2s

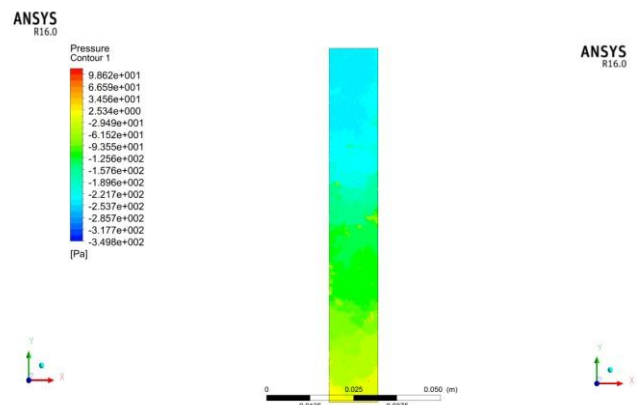


Figure 14: Contour of pressure at t= 64 s

Table 6: CFD Results

Evaporator temperature	Adiabatic section temperature	Condenser temperature
60°C	53°C	40°C

Table 7: Comparison between experimental and CFD results

Section	Position	T _{EXP} (°C)	T _{CFD} (°C)	R _E (%)
Evaporator	T _e	65	60	8.33
Adiabatic	T _a	45	53	17.77
Condenser	T _c	42	40	5.00

The convergence criteria of the scaled residuals were in the order of 10^{-4} . The entire simulation took two months to be completed due to the excessive computational effort that is required. Steady state was reached around 1.067 minutes. The volume fraction of vapor phase, the temperature and pressure at the beginning and the end of simulation are displayed above. Three thermocouple wires were connected in the car, one to measure the ambient temperature, one to measure the temperature of the car cabin and the other to measure the temperature of the heat pipe. Fig. 8 shows the installed heat pipe on the car. As it can be seen, the evaporator is located below the roof of the car while the condenser is located above the roof of the car.

Table 8: Results after installing heat pipe

Before heat pipes		After heat pipes	
Peak inside temperature	40°C	Peak inside temperature	43°C
Ambient temperature	19°C	Ambient temperature	38°C
ΔT	19°C	ΔT	5°C

VI. CONCLUSION

The following conclusions are drawn from the studies conducted.

1. The heat pipe system, its materials and fabrication were easily and commercially available at a low cost.
2. The total temperature drop of the heat pipe was 6°C
3. The heat pipe system reached steady state around 64 s
4. The final temperature drop inside the car cabin was 5°C
5. Distilled water was found to be excellent working fluid for copper heat pipes.
6. The presence of mesh inside the heat pipe ensured sufficient capillary pressure for the return of working fluid under inclined orientation.
7. Thus, heat pipes were found to be efficient heat transfer devices for car cabin cooling system.

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