Chapter 34
Heat Pipe Fabrication and Performance Evaluation for Different Coolants

Devendra Yadav, Simbal Pal, Saddam Quraishi and Mohammad Farhan

Abstract The heat pipe has higher thermal conductance, which prominent the thermal transport from one point to another point and makes it the most useful in the cooling applications. In this work, the heat pipe is designed and made to cool the electronic devices based on the case study on different parameters (pipe material, working fluid, length, angle, mesh size of wick). The pipe has a length of 30 cm, the internal diameter of 1 cm and a thickness 1 mm. Evaporator, adiabatic and condenser section lengths are 8.5 cm, 6.5 cm and 15 cm, respectively. The coolant filling ratio for water-based heat pipe is 85% of evaporator volume and for acetone-based is 100% by volume of evaporators. Annular fins (5×5 cm^2) of aluminium plates are used in the condenser section to enhance the heat transfer, and fin gap is 1.2 cm. The efficient cooling for heat pipes is observed at 60° of inclination and at a temperature of 60 °C. The maximum heat transfer capability of the wick is maximum at horizontal position.

Keywords Filling ratio · Adiabatic section · Fins · Mesh size · Inclination

Nomenclature

L	Length of the heat pipe
K_w	Permeability of wick
A_w	Cross-sectional area of wick
$\dot{m}$	Mass flow rate of vapour
r_c	Mean effective radius of wick
μ_l	Viscosity of liquid
ρ	Density of the fluid

D. Yadav (✉)
Department of Mechanical Engineering, Galgotias College of Engineering and Technology, Greater Noida, U.P., India

S. Pal · S. Quraishi · M. Farhan
Department of Mechanical Engineering, Axis Institute of Technology and Management, Kanpur, U.P., India

S. Yadav et al. (eds.), *Proceedings of International Conference in Mechanical and Energy Technology*, Smart Innovation, Systems and Technologies 174,
https://doi.org/10.1007/978-981-15-2647-3_34

q Heat flux

34.1 Introduction

The heat pipe is a high thermal conductance device which transfers heat by means of two-phase fluid flow. It transfers heat from a hot end (heat injection) to the cold end (heat exhaust) with minimum temperature differences inside a sealed vessel with the help of a backfilled working medium (or coolant) [1]. The vessel is to be evacuated in order to maintain vacuum inside the vessel. The working fluid flows inside the tube through capillary action with the help of wick. This device uses a combination of evaporation and condensation of the working fluid to transfer heat. It is based on the combination of conductive and convective heat transfer [2]. The basic components of heat pipe are evaporation, adiabatic and condensation regions and wick. The heat pipe picks up the heat from the evaporator [3]. The working fluid in the evaporator region is in the liquid phase which extracts the thermal energy as latent heat of vaporisation and its phase changes from liquid to saturated or superheated vapour. It is easier to change the liquid into a vapour phase under vacuum condition. As pressure increases, the vapour will flow towards the condenser section of heat pipe naturally using the pressure created by the minimum temperature difference travelling via adiabatic section [4]. The working fluid reaches to the condenser section and rejects the contained thermal energy as latent heat of condensation in the condenser section. The heat is dissipated using a heat sink. The working fluid changes its phase from vapour to a liquid state. It returns back towards the hotter section (evaporator section) of the heat pipe with the help of wick structure by utilising the capillary force [5].

The heat pipe used in many fields for the cooling purposes: in compact electronic enclosures, i.e., laptop and desktop computers, microprocessors, audio amplifier components, power supplies, etc., producing a highly efficient cooling effect with compact design due to miniaturisation [6]. The heat pipes are also used in aerospace technology for spacecraft cooling and temperature stabilisation and maintaining the isothermal structures. Its functionality is significant under the adverse solar heating in the field of aerospace due to its lightweight, reliability and no maintenance cost. They are also used for thermal control and heat distribution of satellites and spacecraft [7]. In passive thermal applications, in the field of medical devices in terms of less space required due to its miniaturisation with less environmental effects producing better cooling than pumped liquids and rejecting the heat from electrical and electronics computing hospital devices [8]. Some analysis has done on the effect of filling ratio of working fluid and angle of inclination for both thermosiphon and wick-assisted heat pipe [9, 10]. Some researchers Lips and Lefevre [11] and Carbajal et al. [12] have used thermal and hydrodynamic approaches to understand the variations of temperature, pressure and velocity distribution which is influenced by localised thermal fluxes under transient conditions. Derevyanko et al. [13] have used different wick structural configurations to ensure different heat transfer performance.

In this work, copper is used for making the heat pipe. The main challenging task in manufacturing of heat pipe is to evacuate the vessel to create a vacuum inside the heat pipe. For this, a new manual operated vacuum pump is developed at a very low cost. Using the disposal, working fluid is filled inside the vessel. Cu wire mesh wick structure is selected, and brazing is applied to seal the vessel. The experiments have performed for different coolants such as water and acetone. The performance analysis has done for various evaporator temperatures, heat transfer capability through the wick and a different angle of inclination of the heat pipe.

34.2 Governing Equations

In order to heat pipe function, maximum capillary pumping head must be able to overcome the total pressure drop of fluid in the heat pipe [14].

$$\Delta Pc_{\max} \geq \Delta P_{\mathrm{l}} + \Delta P_{\mathrm{v}} + \Delta P_{\mathrm{g}} \tag{34.1}$$

Liquid pressure drops through the homogeneous wick.

From Darcy's law:

$$\Delta P_{\mathrm{l}} = \frac{\mu_{\mathrm{l}} L_{\mathrm{eff}}}{K_{\mathrm{w(wick)}}} . \frac{\dot{m}}{\rho_{\mathrm{l}} \cdot A_{\mathrm{w}}} \tag{34.2}$$

The pressure drop of vapour

$$\Delta P_{\mathrm{v}} = \frac{128 \mu_{\mathrm{v}} \dot{m} L_{\mathrm{eff}}}{\rho_{\mathrm{v}} \pi D_{\mathrm{v}}^4} \tag{34.3}$$

Pressure difference due to a hydrostatic head

$$\Delta P_{\mathrm{g}} = \rho_{\mathrm{l}} g L \sin(\alpha) \tag{34.4}$$

Capillary pumping head

$$\Delta Pc = \frac{2\sigma_{\mathrm{l}} \cos(\theta)}{r_{\mathrm{c}}} \tag{34.5}$$

Normally, the vapour pressure drop is negligible compared to ΔP_{l}

$$\Delta Pc = \frac{\mu_{\mathrm{l}} L_{\mathrm{eff}}}{K_{\mathrm{w(wick)}}} . \frac{\dot{m}}{\rho_{\mathrm{l}} \cdot A_{\mathrm{w}}} + \rho_{\mathrm{l}} g L \sin(\alpha) \tag{34.6}$$

From the above equation

$$\dot{m} \cong \left(\frac{2\sigma_{\mathrm{l}}\cos(\theta)}{r_{\mathrm{c}}} - \rho_{\mathrm{l}} g L_{\mathrm{eff}} \sin(\alpha)\right) \times \frac{\rho_{\mathrm{l}} K_{\mathrm{w(wick)}} A_{\mathrm{w}}}{\mu_{\mathrm{l}} L_{\mathrm{eff}}} \tag{34.7}$$

Heat transport capability

$$Q = \dot{m} h_{\mathrm{fg}} \tag{34.8}$$

The maximum heat transport capability through wick is given by

$$Q_{\mathrm{max}} = \left(\frac{\sigma_{\mathrm{l}}\rho_{\mathrm{l}} h_{\mathrm{fg}}}{\mu_{\mathrm{l}}}\right)\left(\frac{A_{\mathrm{w}} K_{\mathrm{w}}}{L_{\mathrm{eff}}}\right)\left(\frac{2}{r_{\mathrm{c}}} - \frac{\rho_{\mathrm{l}} g L_{\mathrm{eff}} \sin(\alpha)}{\sigma_{\mathrm{l}}}\right) \tag{34.9}$$

34.3 Heat Pipe Fabrication

In present work, the copper pipe has a length of 30 cm which is calculated from the theoretical study. Its internal diameter and thickness are 1 and 0.1 cm, respectively. The length of the evaporator, adiabatic and condenser sections are 8.5, 6.5 and 15 cm, respectively. For the better condensation of vapour, 10 rectangular fins of area 6 × 6 cm^2 are attached in the condensation section. To seal one end of the copper tube, a copper piece with a rectangular shape is brazed. Now a copper plate of suitable size with a hole of 0.5 cm of diameter is used to seal the evaporation section. A copper tube of diameter 0.5 cm is brazed with this hole to introduce passage for filling coolant. Mazumder et al. [10] conducted experiment with varying filling ratios for different coolants, and estimated amount of coolant is to be filled inside the tube for achieving high heat transfer coefficient, reduced thermal resistance and minimum temperature difference between evaporator and condenser sections (the coolant filling ratio for water-based heat pipe is 85% of evaporator volume and for acetone-based is 100% by volume of evaporators). For creating the vacuum inside the tube, set-up is made which has a plastic T-joint connected to the externally attached pipe which is brazed previously to the side of the evaporator. One of the remaining two arms of T-joint which is perpendicular to the central axis of the heat pipe is connected to the vacuum gauge. And another end which is in the same direction of the central axis of the heat pipe is connected to a plastic pipe having a one-way non-returning valve inside the tube and is connected with disposal for creating the vacuum. From this set-up, perfect evacuation inside the heat pipe can be achieved. Cleanness is of prime importance to ensure that no incompatibilities exist in the heat pipe and also make the condition that the wick and wall will be wetted by the working fluid. Also, it checks the leaks. The welds on the heat pipe will be leakproof [15]. Ten aluminium fins are closely fitted and welded along with maintaining 1.2 cm gap between pair of fins in the 15 cm length of condensation section. Teflon is wrapped over the adiabatic section of 6.5 cm length present between the condensation and evaporation sections in order to insulate the adiabatic section. The vacuum-creating arrangement and fabricated heat pipe are shown in Figs. 34.1 and 34.2, and its specifications are listed in Table 34.1.

The evaporator section is made by dipping the evaporator section of the heat pipe into a container of water maintained at constant temperature by a digital temperature controller (W1209). Emulsion rod (2000 W) is used for heating the water. In order to maintain, regulate and indicate the temperature of the water contained in the vessel, there is a direct connection of emulsion rod negative terminal with the AC supply and positive terminal is connected between AC supply and thermoset. J-type thermocouples are connected at the different sections of the heat pipe. Three thermocouples are connected in condensation region for finding a variation of temperature. One thermocouple is connected at the middle of the adiabatic region and one at the middle of the evaporation region. One thermocouple is set free in order to find the temperatures of the tip of fins. All six thermocouples are connected to their respective positive terminals of the digital temperature indicator (DTI). And the negative terminal of the

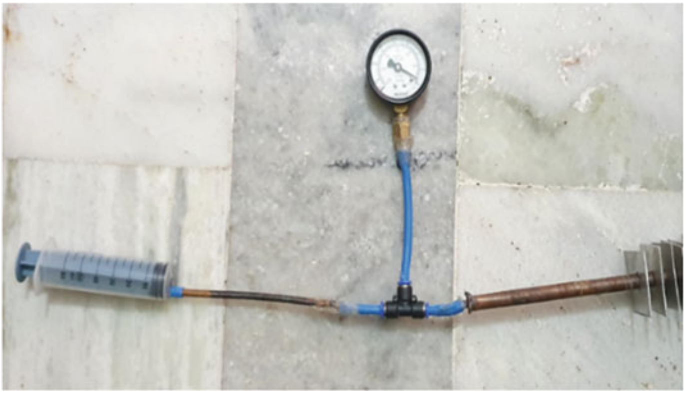

Fig. 34.1 Vacuum creation inside the pipe (by disposal system)

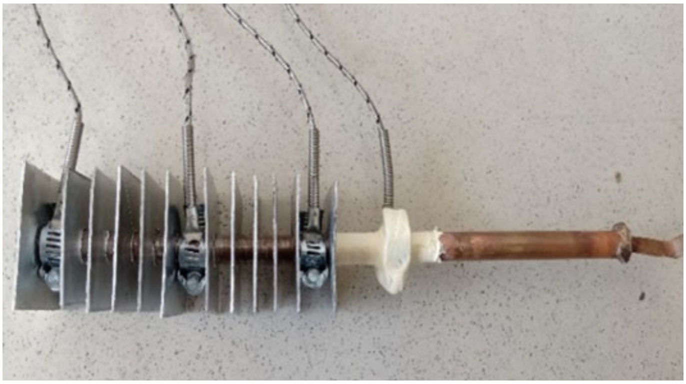

Fig. 34.2 Fabricated heat pipe

Table 34.1 Heat pipe material and design specification

Material	Specifications		
Heat pipe material	Cu	k = 385 W/m K	
Fin material	Al	k = 204.2 W/m K	
Length (cm)	Evaporator = 8.5 cm	Adiabatic section = 6.5 cm	Condenser = 15 cm
Coolant	Water (at 55 °C)	Volume = 5.6 ml	$\mu = 1.09 \times 10^2$ m Ns/m^2 (milli Newton second/metre square)
	Acetone (at 55 °C)	Volume = 6.5 ml	$\mu = 0.24$ m Ns/m^2 (milli Newton second/metre square)

DTI is connected to the AC supply. In this set-up, thermoset with A/D converter is used in place of turbulator for maintaining constant temperature at evaporator section inside water bath. The schematic of the experimental set-up is shown in Fig. 34.3. To

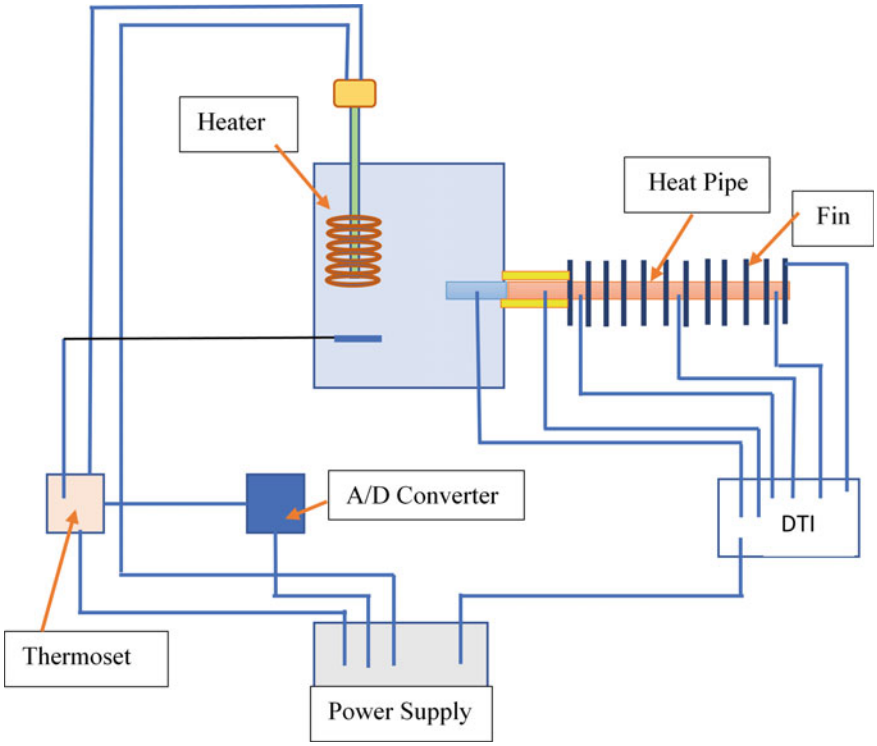

Fig. 34.3 Schematic diagram of the entire collaborated experimental set-up

analyse the effect of angular positions of the heat pipe along with the vessel, an angle measurement set-up was also collaborated in order to measure the angular positions of the heat pipe.

34.4 Results and Discussion

In order to perform the experiment, the evaporator section is kept in contact with a heat supplying zone (the evaporator section in the region which is required to be cooled). There are two approaches as per the principles of heat transfer to supply heat: (1) maintaining constant temperature and (2) supplying constant heat flux. In this work, the temperature of the evaporator section was kept constant. To accomplish this, a container of five litres of capacity filled with water has been taken. An electrical emulsion rod is used for heating water inside the container. And the constant temperature is maintained by using thermoset. Teflon is selected for insulating the adiabatic section due to its high insulating property. Thermosiphon performs better heat rejection in a vertical position due to the effect of gravity which assists in capillary effect. At varying inclinations, effect of gravity is reduced which produces lesser capillary effect. Thus, heat rejection is directly affected. But in case of heat pipes, the wick produces capillary effect. At varying inclinations, effect of gravity changes and the combined effect of wick and gravity at particular inclination decide the returning of the fluid to the evaporator section. Thus, heat rejection and performance of heat pipe varies at different tilt angles [9]. This set-up consists of a stationary arm which is fixed on a wooden base. Another arm is hinged at the other end of the stationary arm at which angle measuring tool is provided for measuring the different angular positions of the heat pipe. For performing the experiment, following components coupled together; (i) the heat pipe arrangement, a container or vessel with water (water bath) for the formulation of evaporator section. (ii) The arrangement which maintains a constant temperature inside the container or vessel. (iii) the temperature measuring and indicating devices. (iv) Angle measuring set-up for varying angular positions of the heat pipe. The container is thoroughly filled with water ensuring that the entire evaporator section is completely surrounded with water outside.

34.4.1 Experimental Analysis on Heat Pipe with Water

As per the theoretical concepts of thermosiphon, the temperature variation along the length of thermosiphon is maximum when it operates at a vertical position. But from the experiment on heat pipe at a different inclination angle of thermosiphon, 60° angle shows the best temperature variation across its length compared to other inclination angles 0°, 30°, 45° and 90°. For this observation, temperature variation across the length at 55 °C of evaporator temperature is shown in Fig. 34.4. So by

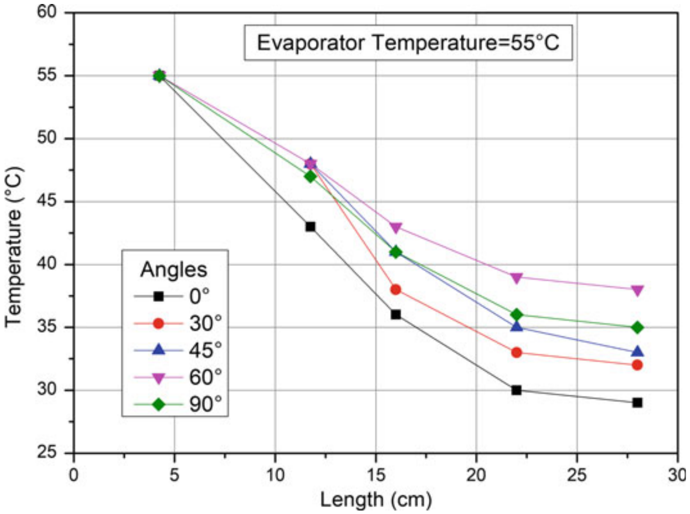

Fig. 34.4 Temperature variation at different heat pipe position (evaporator temperature = 55 °C)

this experimental result, we can say that the efficiency of heat rejection is more in thermosiphon at a 60° angle compared to other angles.

Another comparative analysis is conducted on different evaporator temperature of the thermosiphon (45, 50, 55 and 60 °C) at the vertical position (90° angle), and the temperature variation along the length of the thermosiphon is analysed (Fig. 34.5). The magnitude of temperature along the length is more for 60 °C of evaporator

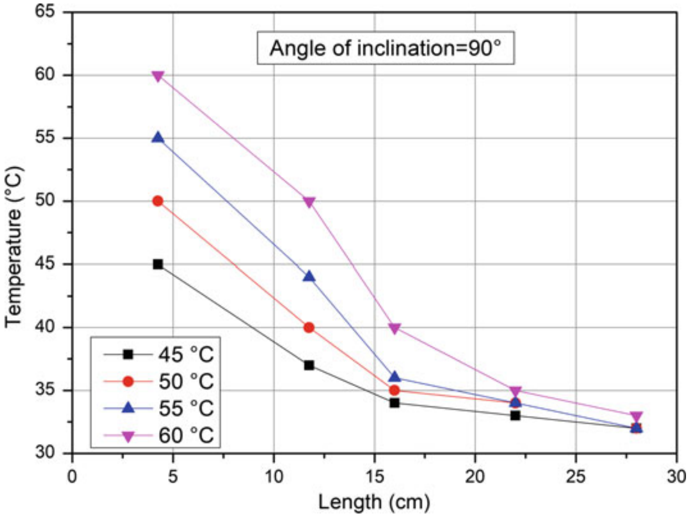

Fig. 34.5 Temperature variation along the length of the heat pipe at vertical position 90°

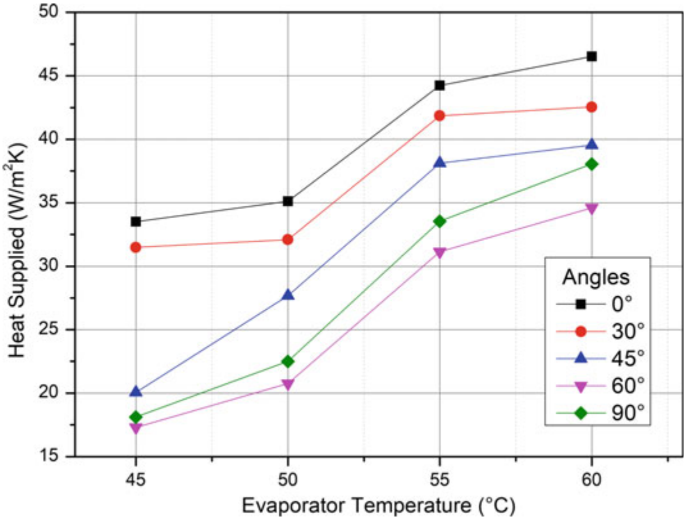

Fig. 34.6 Effect of angle of inclination on heat supplied to the evaporator

temperature. Therefore, heat rejection through the condenser section will be more at this temperature compared to another temperature. And the heat supplied to the evaporator is maximum at the horizontal position (Fig. 34.6).

34.4.2 Experimental Analysis on Heat Pipe with Acetone

As per the theoretical concept, heat pipe shows temperature variation across its length and maximum at horizontal position. From the experimental calculation at different angles of the heat pipe, the temperature variation across the length of the heat pipe at 55 °C of evaporator temperature, 45° angle of the heat pipe shows the maximum temperature difference across the length compared to another inclination angle of the heat pipe (Fig. 34.7). Another experiment is conducted at different evaporator temperature at the vertical position of the heat pipe across its length (Fig. 34.8). By performing different evaporator temperature (45, 50, 55 and 60 °C), the temperature variation is found maximum in 60 °C temperature of the evaporator. So, the heat transfer capability of the heat pipe is maximum at 60 °C temperature.

Using acetone as a working fluid, different experiments have been conducted on it. From the experiment data, the calculation is done on heat supplied to the evaporator section and we have compared this value to the different evaporator temperatures and different inclination angles of the heat pipe (Fig. 34.9). By comparison, heat supplied value in the evaporator section is maximum at 60° angle. The effect of angle and temperature of the evaporator section on maximum heat transfer capability through wick has been analysed by using Eq. 34.9. It is observed that the temperature of the

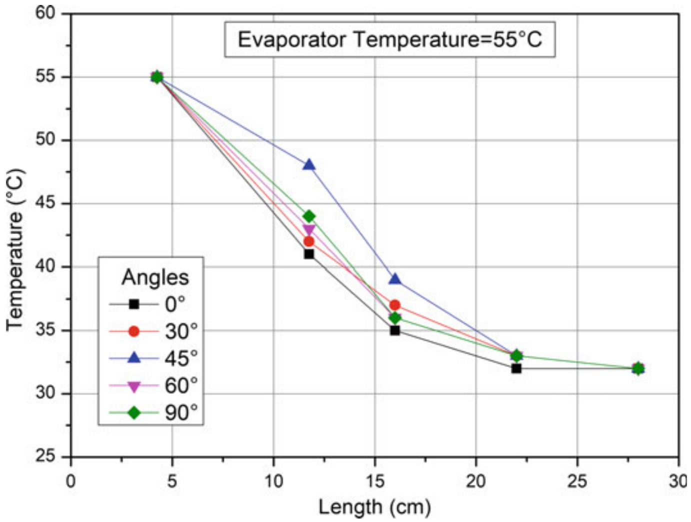

Fig. 34.7 Temperature variation at different heat pipe position (evaporator temperature = 55 °C)

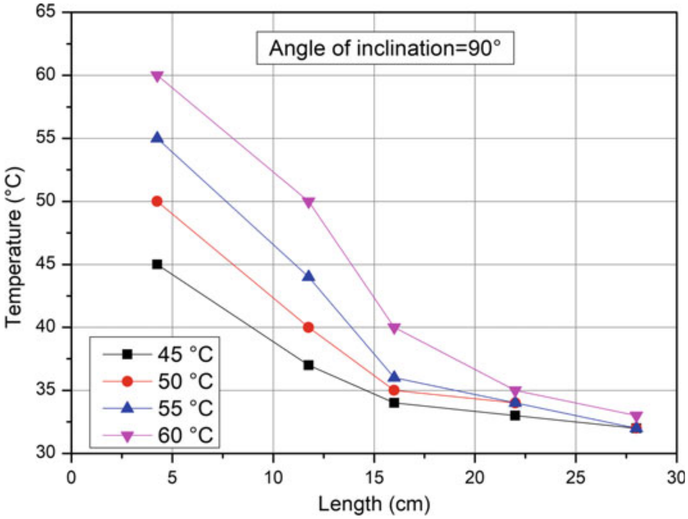

Fig. 34.8 Temperature variation along the length of the heat pipe at vertical position 90°

evaporator section does not affect the heat transfer capability, but the variation is observed for the different positions (angle) of heat pipe as shown in Fig. 34.10. At horizontal position, heat transfer capability is maximum and at vertical position it is minimum.

Normally, the thermal heat transfer capability of the heat pipe is greater than thermosiphon. But in case of our experimental analysis due to large wick diameter,

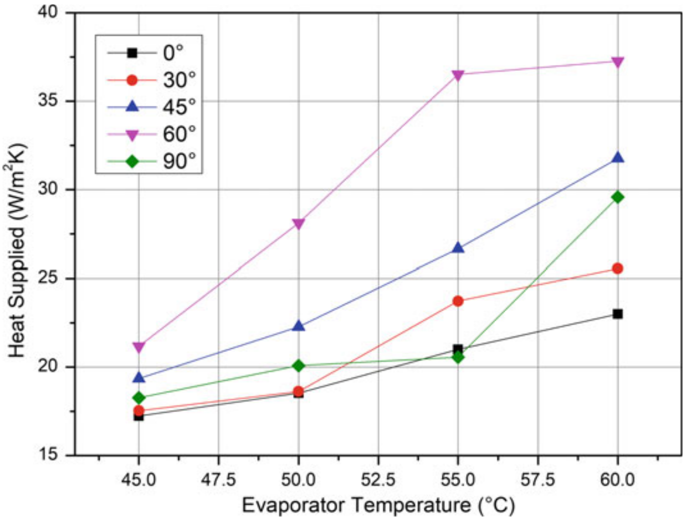

Fig. 34.9 Effect of angle of inclination on heat supplied to the evaporator

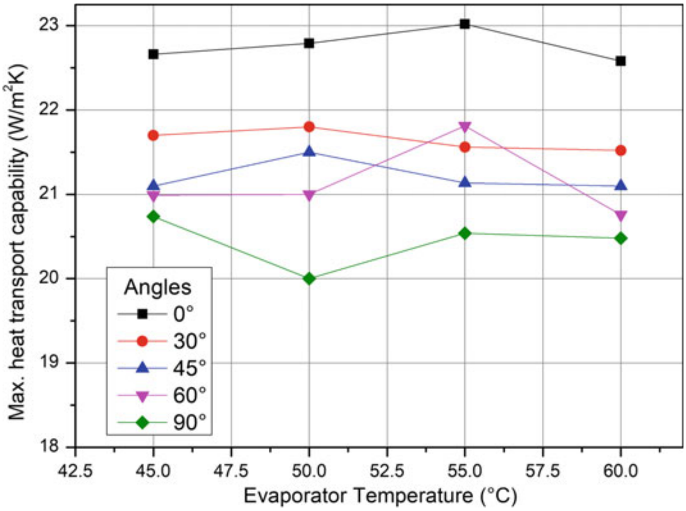

Fig. 34.10 Effect of angle of inclination of the heat pipe in heat transfer capability

there is the availability of smaller porous volume for travelling of working fluid (acetone). Thus, vapour travelling is blocked by wick structure which results as the reduced performance of heat pipe than thermosiphon with water as working fluid. The velocity of the fluid in the porous core must be greater than the velocity in wick configuration in order to resist blockage.

34.5 Conclusion

In this work, heat pipe and thermosiphon have been made at very low cost. A new manual operated vacuum pump is developed for the perfect evacuation of the heat pipe. The fabricated heat pipe performance is analysed for the different coolants, evaporator temperature and the angular positions. Water heat pipe (thermosiphon) has a better performance at 60°. For acetone heat pipe, its heat transfer capability is maximum at horizontal position. Due to the smaller cavity space for vapour transport in acetone heat pipe, it has lower heat transportation capability compared to the water thermosiphon.

References

1. Cotter, T.P.: Theory of Heat Pipes, 37th edn. DTIC Document, Los Alamos Scientific Laboratory, University of California (TID-4500) (1965)
2. Korn, F.: Heat Pipes and Its Applications. Project Report, MVK160 Heat and Mass Transport (May 07, 2008)
3. Panda, K.K., Basak, A., Dulera, I.V.: Design and development of high temperature heat pipes and thermosiphons for passive heat removal from compact high temperature reactor. In: Thorium Energy Conference (ThEC15), vol. 47, no. 25 (2015)
4. Deshpande, A., Patil, V., Patil, R.: Theoretical design of radiator using heat pipes. Int. J. Eng. Res. Technol. **5**(11), 17–23 (2016). ISSN: 2278-0181
5. Vanyasree, G., Ramana, P.V.: Experimental analysis on thermosyphon heat pipe to find heat transfer coefficient. Int. Res. J. Eng. Technol. (IRJET) **4**(8), 129–136 (2017). ISSN: 2395-0056
6. Grooten (Mart), M.H.M.: Towards an Optimal Design of Heat Pipe Equipped Heat Exchanger. Report No-WPC2007.01: 6-48 (2007)
7. Makhankov, A., Anisimov, A., Arakelov, A., Gekov, A., Jablokov, N., Yuditskiy, V., Kirillov, I., Komarov, V., Mazul, I., Ogorodnikov, A., Popov, A.: Liquid metal heat pipes for fusion application. Fusion Eng. Des. **42**(1–4), 373–379 (1998). https://doi.org/10.1016/S0920-3796(98)00216-6
8. Rashidian, B.: Modeling of the heat pipe heat exchangers for heat recovery. In: 2nd WSEAS International Conference on Engineering Mechanics, Structures and Engineering Geology, pp. 114–119 (2015). ISSN: 1790-2769
9. Khan, M.N., Gupta, U., Sinha, S., Singh, S.P., Pathak, S.: Parametric study of the performance of heat pipe—a review. Int. J. Mech. Eng. Technol. (IJMET) **4**(1), 173–184 (2013). ISSN 0976-6340
10. Mazumder, A.K., Akon, A.F., Chowdhury, M.S.H., Banik, S.C.: Performance of heat pipe for different working fluids and filling ratios. J. Mech. Eng. **41**(2), 96–102 (2010)
11. Lips, S., Lefevre, F.: A general analytical model for the design of conventional heat pipes. Int. J. Heat Mass Transf. **72**, 288–298 (2014). https://doi.org/10.1016/j.ijheatmasstransfer.2013.12.068
12. Carbajal, G., Sobhan, C.B., Peterson, C.P., Queheillalt, D.T., Wadley, H.N.G.: Thermal response of flat heat pipe sandwich structure to localized heat flux. Int. J. Heat Mass Transf. **49**, 4070–4081 (2006). https://doi.org/10.1016/j.ijheatmasstransfer.2006.03.035
13. Derevyanko, V., Nesterov, D., Suntsov, S.: Experimental investigation of flat heat pipes to remove high heat fluxes. In: 16th International Heat Pipe Conference, (16th IHPC), Lyon, France (2012)

14. Reay, D.A., Kew, P.A., Mc Glen, R.J.: Heat Pipes Theory, Design and Applications, 6th edn. Elsevier, Amsterdam (2014). https://doi.org/10.1016/C2011-0-08979-2
15. Harris, J.: Modeling, Designing, Fabricating and Testing of Channel Panel Flat Plate Heat Pipe. Report. Utah State University (2008)