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Enhanced heat transfer by thermosyphon method in electronic devices

K. Gopi Kannan[1*], R. Kamatchi[1], T. Venkatajalapathi[2], A.S. Krishnan[3]

[1] School of Mechanical Engineering, Vellore Institute of Technology, Vellore 632 014, India
[2] Department of Mechanical Engineering, SNS College of Technology, Coimbatore 641 049, India
[3] Department of Mechanical Engineering, Coimbatore Institute of Technology, Coimbatore 641 014, India

Corresponding Author Email: gopimetier@gmail.com

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ABSTRACT

In the present work, the heat dissipation rate and thermal resistance of electronic cooling system is investigated with different coolants by two-phase closed loop thermosyphon method for both steady and unsteady state conditions. The coolants used in this study are acetone, alcohol and petrol respectively and are poured in the created test facility. A square heater of size 35 × 35 mm is fixed in the primary tank and used as a heat source. The heat input is given to the system varies from 10 to 60 W. The temperature of the experimental setup is measured by seven K-type thermocouples which are attached at various locations. Results indicate that (i) the convective heat transfer coefficient increases and thermal resistance decreases with increasing of heat input for all the coolants (ii) the acetone has high heat removal rate of 65.4 % at 60 W due to low boiling point, high latent heat of evaporation and less effect on subcooling, which directly helps in phase change process and heat extraction rate (iii) a maximum reduction in thermal resistance of about 0.523 ^{0}C/W for acetone in comparison with alcohol and petrol by virtue of its high superheat which accelerates to nucleate boiling.

1. INTRODUCTION

The advancement in design, fast response and compact of the electronic systems generates huge amount of heat during its operation and hence, cooling of these system is the difficult task for the heat transfer engineers in the recent years. Though the liquid cooling driven by a pump is efficient for high heat dissipation rate, there is a chance of leakage during its operation, which leads to unstable operation of the electronic devices. As a result, two-phase closed loop thermosyphon with evaporative technique is known to be the efficient method that circulates the coolants without the use of any external aid and electrical power [1, 2]. The working fluid again comes back into the secondary tank due to buoyancy effect is the advantage of this technique. Moreover, the thermal exchange by natural convection and buoyancy induced heat transfer leads to better performance [3, 4].

In general, the coolant used in electronic cooling system should have (i) excellent thermo physical properties (ii) good thermal and chemical stability (iii) non-corrosive, non-toxic and biodegradable in nature (iv) high heat storing ability [5, 6]. Palm et al. [7] studied two-phase thermosyphon system for cooling the electronic devices by considering the various parameters involved for selection of working fluid. They concluded the increased pressure level leads to lower temperature difference. Further, it is suggested that there are no ideal working fluids for electronic cooling systems.

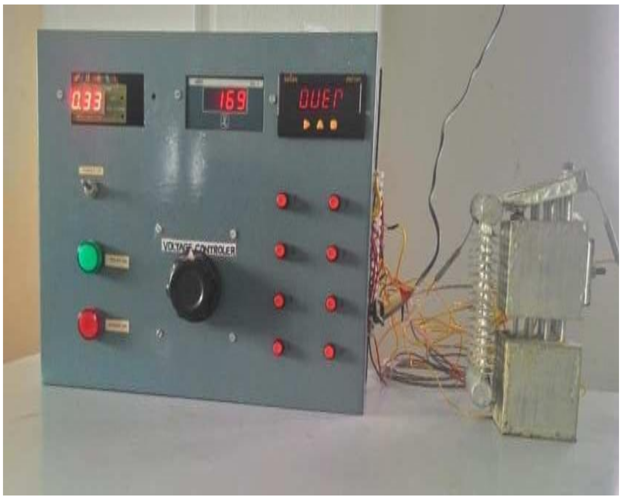
Zhang et al [8] suggested that two-phase thermosyphon is an effective method, heat transfer rate can be increased by grooved evaporation ability and boiling heat transfer. Chang et al. [9] found that the increase of heat input leads to lower thermal resistance. The effect of various parameters such as heat input, rate of condensation and evaporation under cyclic steady conditions for an electronic device are studied by Kandasamy et al. [10]. To increase the heat transfer performance, fins made of high thermal conductive material are fixed in heat sink [11, 12]. The ability of portable electronic devices having plate fins of different volumetric fractions have studied by baby et al. [13]. They identified that the heat sinks with fins are best convective heat transfer medium and this can prolong the operation of the electronic devices.

Casano et al. [14] pointed out the internal heat removal from electronic devices are foremost problem or else it leads to immediate failure. Naik et al. [15] explained the removal of heat would require convectional metallic heat sinks for electronic devices including microprocessors and higher end power converters. They also pointed out the closed loop pulsating heat pipe is a better device for enhancing the heat transfer that helps to electronic cabinet cooling. Kyan et al. [16] investigated the heat transfer performance of a thermosyphon device. They concluded the required amount of coolant and suitable dimensions of the condenser are the major factors for the enhanced performance.

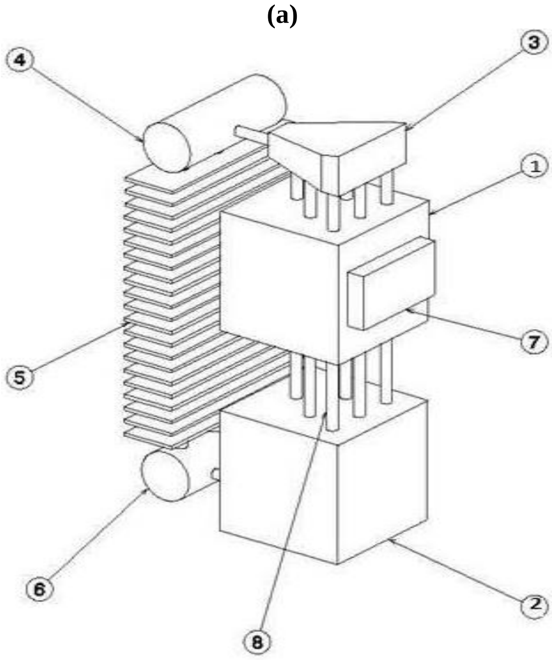
Therefore, an evaporative method of two-phase closed loop thermosyphon using acetone, alcohol and petrol for electronic devices to extract the heat and maintaining optimum temperature for stable operation are investigated. Further, the performance characteristics of heat flux rate and thermal resistance of the electronic device with various working fluids are analysed and compared.

2. EXPERIMENTAL SETUP

An experimental setup (Figure 1) is developed to explore the heat extraction rate from electronic components. Figure 1 (a) consists of a primary and secondary tank, fins, heater, thermocouple, voltage regulator, triangular and cylindrical manifold.



(a)



(b)

Figure 1. Experimental Setup: **(a)** Photographic View **(b)** Schematic View: 1.Secondary tank 2.Primary tank 3.Triangular manifold 4.Upper cylindrical manifold 5.Fins 6.Lower cylindrical manifold 7.Heater 8.Tubes carrying coolant

The primary tank is in contact with the heat producing electronic device, whereas the secondary tank is intended to maximize the heat transfer rate which holds specially engineered copper tubes that extends up to the primary tank. The triangular manifold is used to facilitate the free flow of the working fluid, in which space is being provided for the evaporation and circulation. There are two cylindrical manifolds placed one at the top and other is at the bottom. In order to enhance the heat transfer rate from the working fluid to the ambient, a maximum of 16 fins are provided, as shown in figure 1(b). The gap between the two successive fins is 8 mm. The dimensions of the fins are 75 × 20 × 1 mm and fixed to the copper tubes by brazing. A size of 35 × 35 mm heater [12 Ω, 3 kW] is attached in the primary tank and used as a heat source. A total of seven K-type thermocouple are inserted at different locations with sensitivity of 41μV/^{0}C.

The working of the above setup is based on phase change liquid evaporation method. The primary and secondary tank is filled with water and different coolants respectively. The heat input is given to the setup various from 10 to 60 W. Once the wall of the primary tank gets heated up, it transfers the heat to the primary coolant (water). Since the water is in contact with 10 copper tubes, it again transfers heat to the working fluid. Also the working fluid becomes vapour and rises to the top, which are stored in triangular and cylindrical manifold. When the vapour passes through the fins, it rejects the heat and becomes liquid due to increase of density. The working fluid again comes back into the secondary tank due to capillary effect and remains constantly in the tubes. Thus, the process occurs in a cyclic manner without the use of electricity.

The total heat carried away by secondary coolant is described by the following expression:

$$Q_{tot} = Q_i - (\Sigma Q_p Q_s Q_f Q_{ct} Q_{cb} Q_t Q_{bc}) \tag{1}$$

There is different convective heat losses occur in various components. The primary tank is in contact with the heat producing electronic device in which convective heat loss will be more and it can be calculated by considering three vertical sides, top and bottom surface of the primary tank.

The convective heat loss in the primary tank is given by

$$Q_p = (\Sigma 3h_v h_t h_b) A_p (T_p - T_\alpha) \tag{2}$$

Convective heat loss in secondary tank surface

$$Q_s = (\Sigma 4h_v h_t h_b) A_s (T_s - T_\alpha) \tag{3}$$

Convective heat loss through fins

$$Q_f = \eta A_f h_f (T_f - T_\alpha) \tag{4}$$

Convective heat loss at top of the cylinder

$$Q_{ct} = h_{ct} A_{ct} (T_{ct} - T_\alpha) \tag{5}$$

Convective heat loss at bottom of the cylinder

$$Q_{cb} = h_{cb} A_{cb} (T_{cb} - T_\alpha) \tag{6}$$

Convective heat loss in triangular manifold

$$Q_t = h_t A_t (T_t - T_\alpha) \tag{7}$$

Convective heat losses in back cover temperature

$$Q_{bc} = h_{bc} A_{bc} (T_{bc} - T_\alpha) \tag{8}$$

The heat transfer coefficient for vertical, top and bottom are calculated by following equations:

$$h_v = \frac{0.59(GrPr)^{0.25} k_p}{L} \quad (9)$$

$$h_t = \frac{0.54(GrPr)^{0.25} k_p}{\left(\frac{L}{4}\right)} \quad (10)$$

$$h_b = \frac{h_t}{2} \quad (11)$$

The heat flux and convective heat transfer coefficient can be calculated by following equation:

$$q = \frac{VI}{A} \quad (12)$$

$$h_e = \frac{q}{(T_w - T_\alpha)} = \frac{q}{\Delta T} \quad (13)$$

The accuracy of the instrument used for measuring the voltage and current are 0.01% and 0.25% respectively. The error in measuring the temperature by K-type thermocouple is 1.5ºC. The following equations (14, 15) are used to find the uncertainity in measuring the heat flux and convective heat transfer coefficient [17]. The maximum uncertainity is found as $\pm$2.54% and $\pm$4.28% respectively.

$$\left(\frac{\Delta q}{q}\right)^2 = \left(\frac{\Delta V}{V}\right)^2 + \left(\frac{\Delta I}{I}\right)^2 + \left(\frac{\Delta A}{A}\right)^2 \quad (14)$$

$$\left(\frac{\Delta h_e}{h_e}\right)^2 = \left(\frac{\Delta q}{q}\right)^2 + \left(\frac{\Delta(\Delta T)}{\Delta T}\right)^2 \quad (15)$$

3. RESULT AND DISCUSSION

The heat flux rate and thermal resistance of electronic device are investigated using acetone, alcohol and petrol in this work.

3.1 Effect of heat input on rate of heat removal

Figure 2 illustrates the rate of heat removal in percentage for different heat input. The heat input various from 10 to 60 W for different coolant. The heat removal rate increases with the heat input for all the coolants used in this study. As seen from figure 2, the acetone has the maximum heat carrying capacity of about 65.4% at 60 W, while the percentage heat removal with alcohol and petrol are 53.9% and 51.4% respectively. Naik et al. [15] suggested that the amount of vapour enters into the condenser is high which leads to less effect on subcooing of acetone. This may also be the reason for the obtainted results. Szymanski et al. [18] investigated that the pressure rise at evaporator of capillar pumped loop using pure acetone as working fluid. They reported that the acetone has low boiling point which induced to high evaportaion rate. This is due to the fact that the acetone has high latent heat of vaporization in comparison with alcohol and petrol.

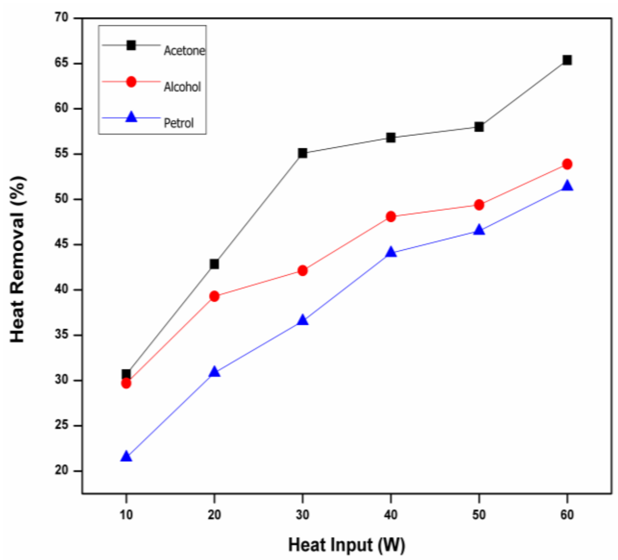


Figure 2. Rate of heat removal for different coolants

3.2 Effect of heat input on heat transfer coefficient

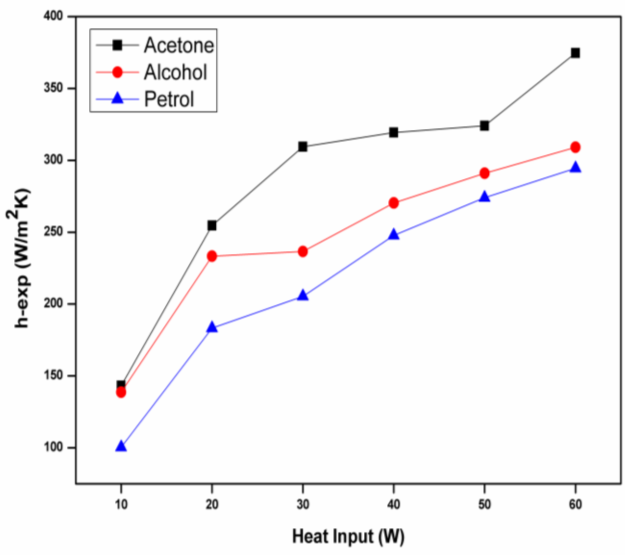


Figure 3. Heat input on heat transfer coefficient for various coolants

Figure 3, shows heat transfer coefficient for different heat inputs. As observed from the figure 3, the convective heat transfer coefficient increases with the increase of heat input for acetone, alcohol and petrol respectively. The maximum of 374.59 W/m^2K is found for acetone whereas the alcohol and petrol has 309.07 and 294.5 W/m^2K respectively. In general, the heat transfer coefficient depends on geometric shape of the device and rate of fluid flow.

The high heat transfer coefficient for acetone is mainly because of the high specific heat and low viscosity [18, 19]. Also, the system reaches steady state much more faster than for alcohol and petrol [15].

3.3 Effect of heat input on thermal resistance

In the evaporative liquid cooling method, the thermal resistance due to evaporation and condensation has a important role for high heat transfer enhancement. It is known that the heat input is always inversely proportional to the thermal resistance.

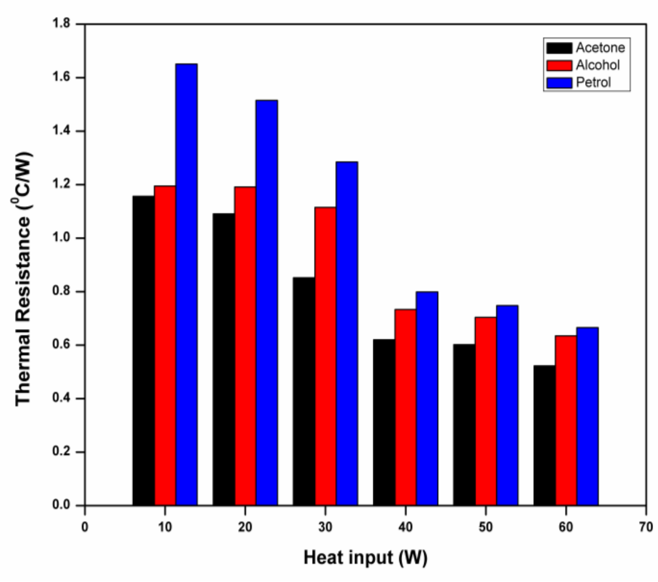


Figure 4. Thermal resistance with various heat inputs for coolants

Also, the thermal resistance of the electronic device depends on the cooling capacity of the working fluid, likewise the calculations are made using the following Equation 16,

$$R_{th} = \sum R_e R_c R_{cov} \tag{16}$$

The thermal resistance with various heat inputs for acetone, alcohol and petrol is evaluated and are shown in figure 4.The maximum reduction in thermal resistance of about 0.523 ^{0}C/W is found for acetone at 60 W. At high flow rate, by increasing the heat input from 10 to 60 W, the vapour is compressed, thus the pressure and velocity of working fluid in the copper tube increases, which further causes decrease in thermal resistance. Han et al [19] studied that the increase in heat input reduces the viscosity of working fluid. Further, they reported the specific heat and latent heat of evaporation increases with heat input which caused for the reduction in thermal resistance. At high heat input, superheat will be more which leads to nucleate boiling consequently thermal resistance is low [15].

4. CONCLUSION

The heat transfer enhancement of electronic cooling is carried out using two-phase closed loop thermosyphon method. The effect of heat input on various parameters such as rate of heat removal, heat transfer coefficient and thermal resistance are studied with acetone, alcohol and petrol respectively. The following observations are made during this experimental study:

(i) A maximum heat removal rate of about 65.4 % at 60 W is carried away by acetone in comparison with alcohol and petrol. This mainly because of low boiling point and high latent heat of evaporation.

(ii) At 60 W, the observed heat transfer coefficient values are 374.59, 309.07 and 294.5 W/m^{2}K for acetone, alcohol and petrol respectively. It is seen that acetone has higher value due to its low viscosity at maximum heat input.

(iii) The effect of heat input on thermal resistance exhibits a maximum reduction of about 0.523 ^{0}C/W at 60 W for acetone. It is suggested that the superheat is more which leads to nucleate boiling resulting low thermal resistance at 60 W.

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NOMENCLATURE

A	Area of the surface, m^2
Gr	Grashof number
h_e	Heat transfer coefficient by experiment, W/m^2K
I	current, A
k	Thermal conductivity, W/m-K
L	Length, m
Pr	Prandtl number
q	heat flux, W/m^2
Q	Heat carried by coolant, W
Q_i	Heat input, W
R_c	Thermal resistance by condensation, $^0C/W$
R_{cov}	Thermal resistance by convection, $^0C/W$
R_e	Thermal resistance by evaporation, $^0C/W$
R_{th}	Overall thermal resistance, $^0C/W$
T	Temperature, ^0C
T_α	Fluid temperature, ^0C
V	Voltage, Volts

Greek symbols

Δ	Increment
η	Efficiency

Subscripts

b	Bottom side
bc	Back cover surface
cb	Cylinder at bottom
ct	Cylinder at top
f	Fin surface
p	Primary tank
s	Secondary tank
t	Triangular manifold
tot	Total heat carried away by coolant
v	Vertical side