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Preliminary Experimental Performance of a Loop Thermosyphon

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Abstract

A loop wickless heat pipe (or loop thermosyphon) consists of two vertical and two horizontal pipes connected together in a rectangular manner. The unit is vacuumed and filled with a working fluid. A rectangular shaped loop thermosyphon was fabricated using a 9 mm diameter copper pipe filled with R410A. This paper reports on an experimental investigation to determine its thermal performance. Two modes of heat input were attempted. In the vertical mode, heat was provided at one of the vertical pipe (evaporator section) with electric wire wound around the pipe. In the horizontal mode, the device was rotated through 90 degrees with the heated section on the bottom. A water jacket provided cooling at the condenser section. Fill volume is defined as the ratio of liquid fill/height of vertical limb. Experiments were conducted with power inputs from 50W to 140W, water coolant temperatures of 5°C and 20°C and fill volume ratio of 0.5 and 0.75. The results showed that the vertically-heated unit performed better than the horizontally-heated one. Better performance was obtained with a high fill volume.

Highlight

a) Thermal performance of a R410A-filled loop thermosyphon investigated experimentally.

b) Evaporator and condenser wall temperatures and thermal resistances determined.

c) High fill volume > 0.75 recommended.

d) Vertical heating performed better than horizontal heating.

Keywords: Loop thermosyphon; R410A; Horizontal heating; Vertical heating; Thermal resistance

Introduction

Heat pipes (HPs) are highly effective heat transfer devices that are capable of transferring huge amounts of heat effectively. A wickless HP is known as a two-phase closed thermosyphon (TPCT). A TPCT consists of a sealed metal pipe vacuumed and filled with a working fluid as shown in Figure 1. Heat provided at the evaporator section evaporates the working fluid which rises up to the condenser section where it condenses and loses its heat of vaporization. The condensate then flows back to the evaporator section via gravity. The process of evaporation and condensation continues as long as heat is provided at the evaporator section and removed from the condenser section.

The thermal performance of a TPCT is dependent upon factors such as type of fill fluid, fill volume, condenser or coolant temperature, heat load and physical dimensions of the device. The heat transfer press is very complex. Texts on heat pipes are available in Faghri [1], Peterson [2], Reay and Kew [3] and Zohuri [4]. A TPCT could be employed in various applications, especially to cool down the high heat flux electronic components [5-7]. A review on the development, testing and analysis of the LT has been made [8-11]. Jafari [12] wrote a review of the LT in solar application.

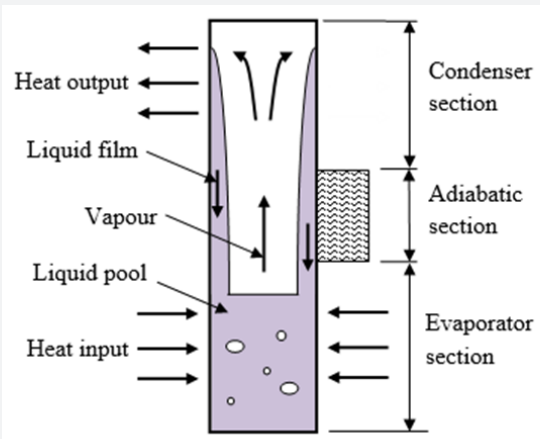

Figure 1: Vertical two-phase closed thermosyphon.

Louahlia et al. [13] investigated the performance of a TPCT with water as working fluid. They showed that micro-porous layers at the evaporator eliminated the thermal resistance by 75% and enhanced the evaporator heat transfer surface. Zhu et al. [14] established a mathematical model of the LHP with a heat load of 30W to 110W. They concluded that the driving force of the TPCT is due to the capillary pressure head and pressure during evaporation. Ong et al. [15] studied the performance of LT with R410A as working fluid. They carried out experiments on various inclination angles in order to obtain the thermal resistance. A thermal resistance network model was developed.

Zhou et al. [16] investigate the two-phase flow characteristics of a LT. The maximum heat load was 550W with water under forced convection cooling at 25°C and with evaporator temperature at 91.2°C. The thermal resistance was 0.068C/W at 500W. When heat load is at 550W, partial dry out occurs at the evaporator. In order to overcome dry out problem, Setyawan et al. [17] designed a modified LHP with added diaphragm pump to increase the fluid flowing through. This prevented dry out and decreased the evaporator temperature.

Lataoui et al. [18] carried out experiments to show that the thermal behavior of the TPCT. From their experiment, dry out occurred at the bottom part of the evaporator. Stable thermal behavior was obtained with overfilling. Xu et al. [19] visualizated boiling press in the thermosyphon with two aspect ratios of inclination and surface wettability. From their results obtained, they showed that the surface wettability affected significantly the overall thermal performance of the thermosyphon.

Sukchana et al. [20] investigated on how bending and tilting of the adiabatic section influenced the thermal performance of TPCT. They claimed that bending at the upper end of the flexible hose showed poorer performance than bending at the lower end. Besides, bending at both ends of the flexible hose resulted in lowest temperature of the thermosyphon. Jafari et al. [21] performed an experimental investigation on the heat transfer characteristics. They described the sensitivity of evaporation heat transfer correlation on the heat flux and fill ratio. Naresh et al. [22] carried out experiments on an internally finned vertical thermosyphon. Based on the results obtained, the optimum fill ratio is 50%. In conclusion, the thermal performance increased when the internal finned increase.

A two-phase loop thermosyphon (LT) consists of four pipes connected together in the shape of a rectangular loop as shown in Figure 2. In the horizontal heating mode, Figure 2a, heat is supplied at the bottom horizontal evaporator section and removed from the top condenser section. In the vertical heating mode, Figure 2b shows heat being supplied to one of the vertical limb and removed from the other. There is no previous investigation on comparison of vertically and horizontally heated LT with various fill volumes.The objective of the present investigation is to determine the performance of a R410A-filled LT with horizontal and vertical heating modes. The performance of the device would be affected by fill ratio, heat input at the evaporator section and condenser section temperature.

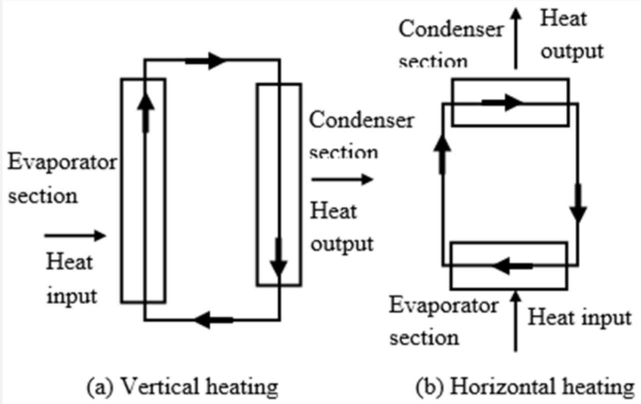

Figure 2: Loop Thermosyphon.

Experimental Investigation

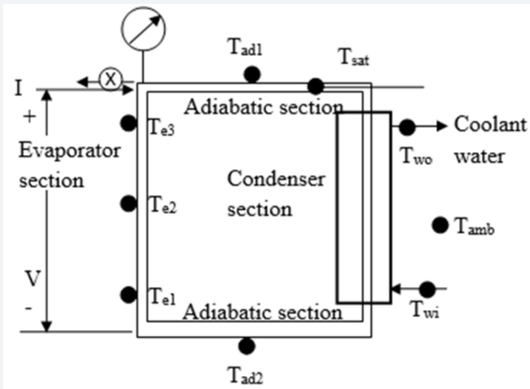

Figure 3: Experimental loop thermosyphon (vertical heating) showing location of thermocouples.

The experimental rectangle-shaped LT is fabricated by brazing together four 11mm O/D x 9.53mm I/D copper tubes as shown in Figure 3. The evaporator and condenser sections are each 50mm long while the connecting adiabatic sections are 10mm long. The condenser consisted of a 40mm long concentric pipe copper water-jacket. Inlet coolant water was cooled with a cold temperature water bath under forced convection. Coolant water temperatures were controlled at 5°C and 20°C. Water flow rate not controlled and set at maximum in order to provide uniform condenser wall temperature. A cross-piece was provided at the top to provide connections to a vacuum pump, vacuum gauge and thermocouple. Fill liquid was refrigerant R410A. Fill volume (FV) is defined as the height of liquid fill/height of vertical limb. Fill volumes FV=0.50 and 0.75 were attempted. Insulation was provided all around the LT. Heat input was provided with electrical heating element wound entirely around the evaporator section. AC power input was measured with laboratory standard voltmeter and ammeter (±3%). Experiments were performed with power inputs (P_{EHs}) from 50W to 140W. Type T (copper-

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constanten) thermocouples (±0.5°Caccuracy) were employed to measure the wall temperatures at the evaporator section (Te1-Te3), adiabatic section (T_{ad1}-T_{ad2}) and condenser inlet and outlet water (T_{wi}-T_{wo}). Saturation temperature (T_{sat}) was measured with a thermocouple inserted into the thermosyphon. The environment was not controlled and room conditions varied by about ±1.0°C. The LT was first oriented for horizontal heating and then for vertical heating. All thermocouple readings were recorded on a Graphtec multi-point data logger. Locations of these thermocouples with vertical heating mode are shown in Figure 3. Steady-state could be achieved in about 30 minute. Experimental results are tabulated in Table 1.

Table 1: Summary of experiments conducted on loop heat pipe with R410a.

Fill Volume FV	Orientation H/V	Coolant Water Tw (°C)	Input Power P (W)	T_e(°C)	Tc (°C)	R_t(K/W)
0.5	H	20	50	33.7	20.6	0.26
			70	39	20.8	0.26
			90	43.6	20.9	0.25
			100	45.1	20.8	0.24
			120	50.7	21.2	0.25
			140	57.4	21.4	0.26
		5	50	28.8	5.6	0.46
			70	33.8	5.8	0.4
			90	39.8	5.9	0.38
			100	40.4	5.7	0.35
			120	46.4	6.1	0.34
			140	51.3	6.4	0.32
	V	20	50	29.3	20.3	0.18
			70	31.1	20.7	0.15
			90	33.5	20.8	0.14
			100	39.4	20.9	0.19
			120	43.8	21	0.19
			140	48.5	21.3	0.19
		5	50	25.8	6.1	0.39
			70	28.7	5.5	0.33
			90	31.4	5.8	0.28
			100	36.3	5.7	0.31
			120	40.7	6	0.29
			140	43.4	5.9	0.27
0.75	H	20	50	33.1	21	0.24
			100	37.6	21.9	0.16
			140	43.4	22.6	0.15
		5	50	28.4	5.6	0.46
			100	30	6	0.24
			140	30.9	6.2	0.18
	V	20	50	30.5	21.4	0.18
			100	33.9	22.1	0.12
			140	39.4	23.4	0.11
		5	50	26.5	7	0.39
			100	32.9	8.5	0.24
			140	34.4	9.9	0.17

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Experimental Results

Steady state temperature distribution

Typical steady state wall temperature distribution with horizontal heating showing the effects of power input and FVs with 20°C coolant water temperature is shown in Figure 4. The results show that temperatures increase with power input as expected. Evaporator wall temperature is highest followed by saturation and the condenser water temperatures. The outlet coolant water temperature (T_{wo}) is only about 0.5-1.0°Chigher than the inlet temperature (T_{wi}) because of the high water flow rate employed.The temperature distribution in the evaporator (T_{e1-e3}) section depends on the power input. At low power of 50W and FV=0.5, the distribution is quite uniform. With FV=0.5 at higher input power and also with all the results for FV=0.75, the middle portion of the evaporator exhibited a lower temperature than the end portions. From an accompanying ongoing visualization project, it was observed that the fill liquid oscillated up and down in the adiabatic pipes. Figure 4 show that the adiabatic temperatures are lower than the evaporator temperatures. This observed temperature variation would indicate that the liquid in the adiabatic section tended to occupy the upper and lower limbs of the loop. The results for fill volume of 0.50 show higher wall and saturation temperatures compared to those for 0.75. For example, for FV=0.5, mean evaporator temperature is about 57°C at 140W compared to 33°Cand for FV=0.75, mean evaporator temperature was 35°C compared to 25°C. A higher evaporator wall temperature indicates less efficient cooling. Hence the device performs better at high FV. A fill volume of at least 0.75 is recommended.

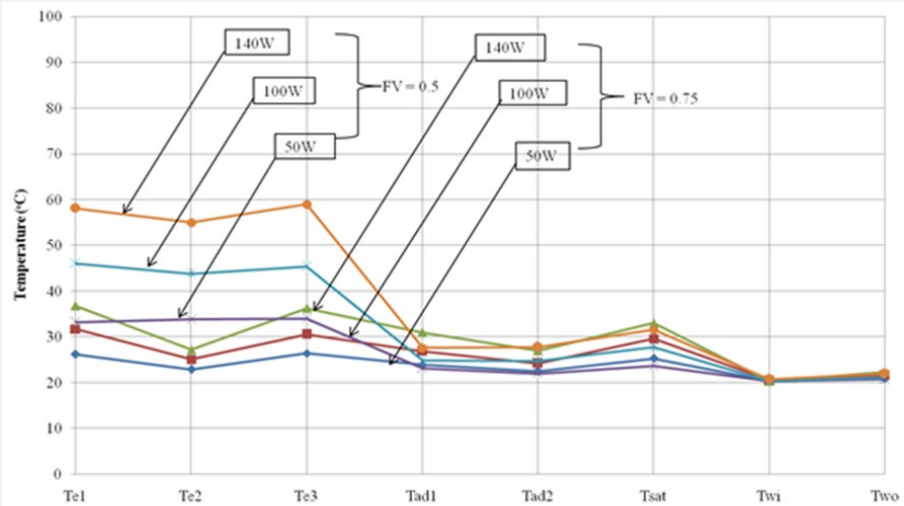

Figure 4: Typical study state temperature distribution with horizontal heating showing effect of power and FV with 20 ^{0}C coolant water temperature.

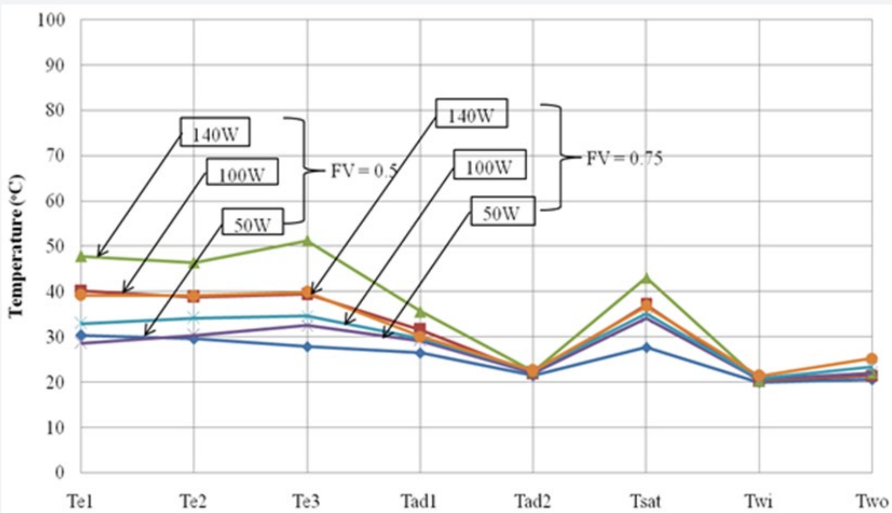

Figure 5: Typical study state temperature distribution with vertical heating showing effect of power and FV with 20 ^{0}C coolant water temperature.

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For vertical heating, a minimum fill volume is required in order to avoid dry-out in the evaporator section. The minimum FV specified is 0. The entire length of the evaporator section is wrapped with heating wire and heated up. Typical steady state temperature distribution with vertical heating is shown in Figure 5. At the low value of FV=0.5, a rise in temperature in the lower portion of the evaporator section would seem to indicate dry-out occurring there. This effect is not observed with FR=0.75 because of more fill liquid. In particular, the vertical heating mode shows better performance in terms of lower evaporator wall temperature. For example, at 140W, mean evaporator temperature is about 48°Cwith FV=0.5 compared to 40°Cwith FV=0.75.

Typical steady state temperature distribution with horizontal heating showing the effects of coolant water temperature with FV=0.5 is shown in Figure 6 and with vertical heating in Figure 7. The results show that the lower coolant water temperature of 5°Cresults in lower evaporator wall temperatures. For example, for the vertical heating case at 140W, mean evaporator wall temperature is about 50°C for FV=0.5 with coolant water at 20°Ccompared to about 42°C with 5°C coolant. A lower coolant flowing in the condenser results in lower device temperature.

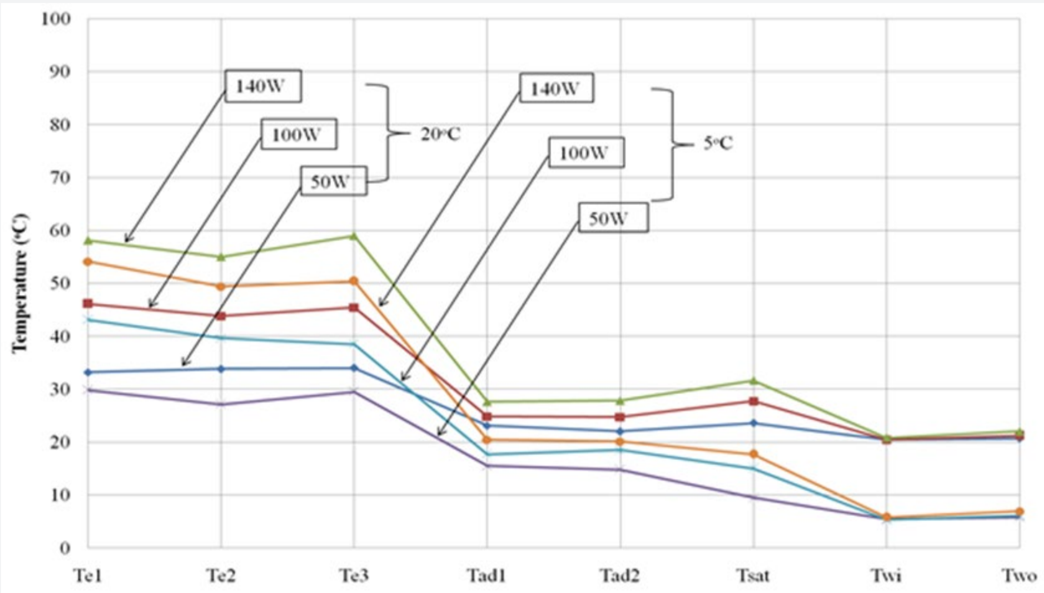

Figure 6: Typical study state temperature distribution with horizontal heating showing effect of coolant water temperature with FV=0.5.

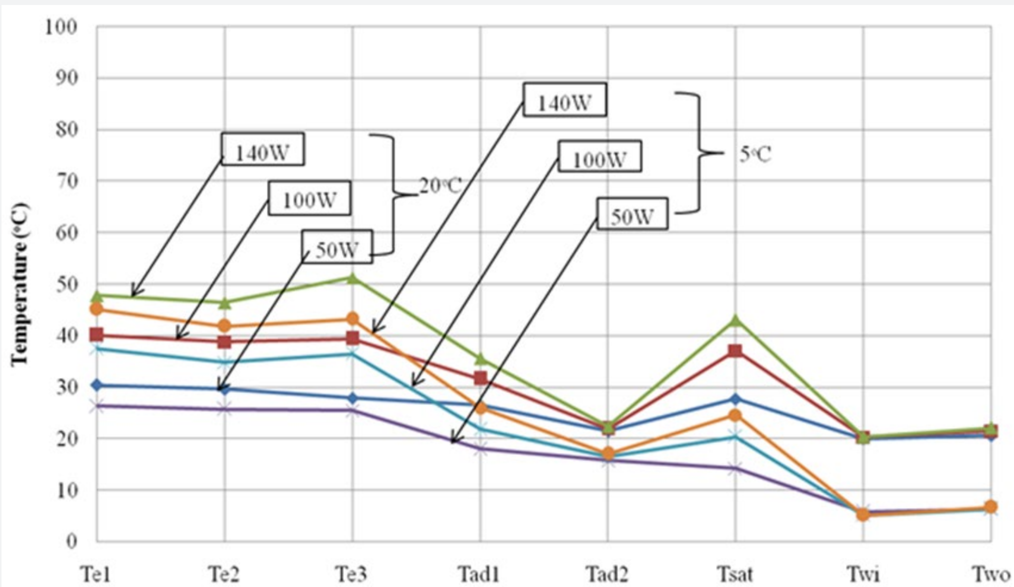

Figure 7: Typical study state temperature distribution with vertical heating showing effect of coolant water temperature with FV=0.5.

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Thermal resistance

Evaporator and condenser sections thermal resistances could be calculated from:

$$R_{evap} = \frac{(T_e - T_{sat})}{P_{EH}} \quad (1)$$

$$R_{cond} = \frac{(T_{sat} - T_c)}{P_{EH}} \quad (2)$$

The total LT heat transfer resistance is

$$R_t = R_{evap} + R_{cond} \quad (3)$$

In the present study, condenser wall temperature is assumed to be equal to the mean condenser cooling water temperature [=0.5 (Two + Twi)]. Total heat transfer resistance values are tabulated in Table 1. Figure 8 shows the total thermal resistance plotted against input power for FV=0.5 at the water coolant temperatures of 5°C and 20°C and Figure 9 for FV=0.75. The results show that thermal resistance decreases initially as power increases and then tending to be constant at high powers. Also, vertical heating performed better as the total thermal resistance is lower. For example, for FV=0.5, the highest evaporator thermal resistance was about 0.46K/W at coolant temperature of 5°C compared to 0.39K/W.

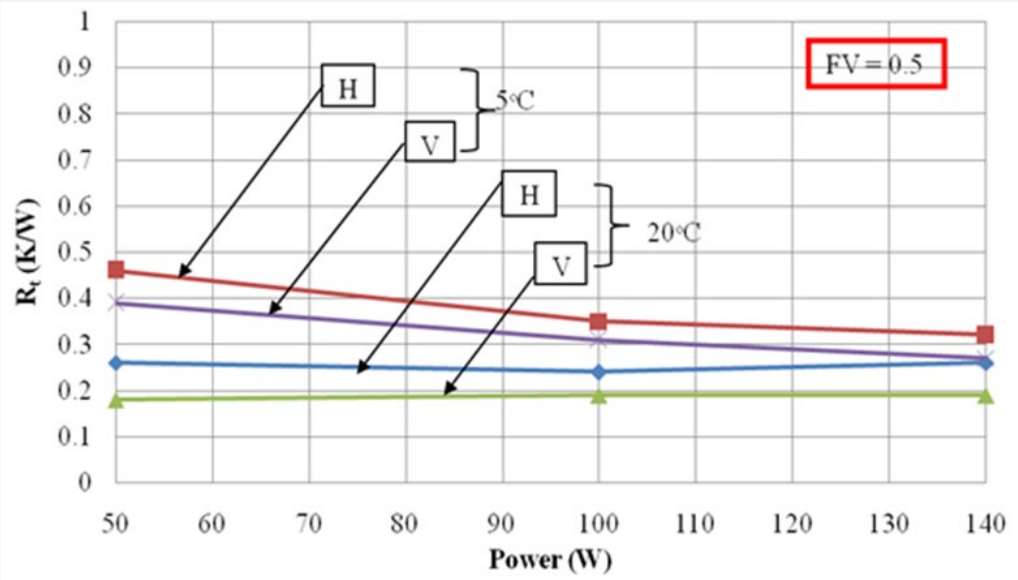

Figure 8: Total thermal resistance for FV=0.5.

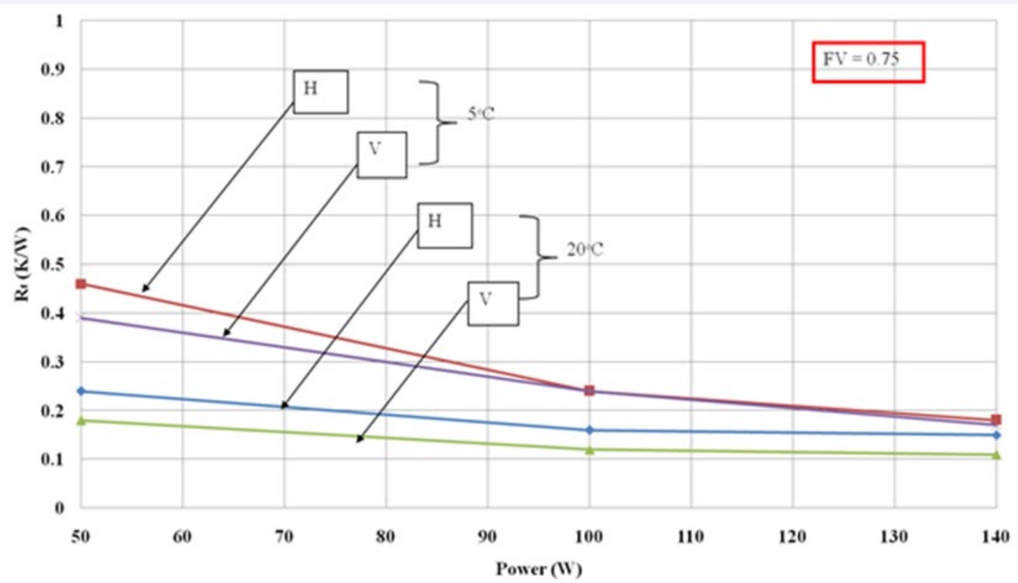

Figure 9: Total thermal resistance for FV= 0.75.

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The LT performs better at high FVs. For example, for vertical heating at 140W, thermal resistance is 0.27K/W for FV=0.5 compared to 0.11K/W for FV=0.75. Hence fill volume of the LT should be kept above 0.75.

Conclusion

The performance of a R410A-filled loop thermosyphon operated as a heat pipe heat exchanger was investigated experimentally. Heating was supplied with electrical heating element and cooling with a water jacket under forced convection. The following conclusions could be made:

a. All temperatures increase with power input.

b. A high fill volume of at least 0.75 is recommended.

c. The vertical heating mode shows better performance.

d. A lower coolant water temperature results in lower evaporator temperature.

e. Thermal resistance tends to be constant at high powers.

f. The highest evaporator thermal resistance was about 0.46K/W at coolant temperature of 5°Ccompared to 0.39K/W for the vertical heating.

g. For vertical heating at 140W, thermal resistance is 0.27K/W for FV=0.5 compared to 0.11K/W for FV=0.75.

Acknowledgement

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Nomenclature

PEH	Input power (W)
Rcond	Thermal resistance of condenser (K/W)
Revap	Thermal resistance of evaporator (K/W)
Rt	Total thermal resistance (K/W)
Tamb	Ambient temperature (°C)
Tc	Condenser temperature (°C)
Te	Evaporator temperature (°C)
Tad	Adiabatic temperature (°C)
Tsat	Saturation temperature (°C)
Twi	Condenser water inlet (°C)
Two	Condenser water outlet temperature (°C).

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