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Experimental investigations on pulsating heat pipe

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Abstract

Thermal management of electronics is a contemporary issue in research field. Pulsating heat pipes are relatively new entrants to the family of heat pipes used for higher heat removal. Various experiments have been carried out in order to check the influence of filling ratio and input heat flux on the performance of the Closed Loop Pulsating Heat Pipe (CLPHP). The present paper deals with the experimental investigations on CLPHP. Water is used as working fluid. Inner diameter of the copper tube is 2.15mm. Heat transfer mechanism is a natural convection in condenser section. Experiments are conducted with filling ratio as 40%, 50% and 60%. Heat input is varied as 10W, 20W, 30W, 40W and 50W. The results indicated better system performance with lower level of filling ratio and at higher heat input.

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Keywords:Electonics;filling ratio; pulsating heat pipe;thermal management

1. Introduction

In pursuit to making our life better, comfortable and luxurious, electronic gadgets have found a permanent place from our house to our workplace. We want our miniature gadgets to perform faster. But what is left behind, we never concerned about that. With miniaturization, heat rejection from unit surface area has increased a lot. A two-phase phenomenon has proved to be better technique to solve such problems. PHP is one of the applications involving two-phase flow. Since its invention in 1990 by Akachi [1-2], PHP has been very popular for thermal management of electronics due to its compact and simple structure, faster thermal response and lower thermal resistance. PHPs have extended its applications in fuel cells [7], radiators [10], hybrid vehicles [5], chip cooling, air-conditioning, air to air heat exchanger, solar and waste heat recovery systems [12] and many more.

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NOMENCLATURE

L	Length (mm)	**Subscripts**	
D	Diameter (mm)	*crit*	Critical
T	Temperature (°C)	*liq*	Liquid
Q	Heat Input (W)	*vap*	Vapor
A	heat transfer area (m^2)	*i*	Inner
g	Gravitational acceleration (9.8 m/s^2)	*o*	Outer
Greek symbols		*a*	Adiabatic
ρ	Fluid density, kg/m^3	*c*	Condenser
σ	Surface tension (N/m)	*e*	Evaporator
Abbreviation			
CLPHP	Closed Loop Pulsating Heat Pipe	*PHP*	Pulsating Heat Pipe
FR	Filling Ratio		

PHP is a passive device working on the principle of liquid evaporation which increases the heat removal rate compared to other cooling techniques [3]. The working fluid gets heated in evaporator and rejects heat in condenser. The boiling point temperature of the fluid keeps lower through evacuation of PHP. Due to capillary dimension of the tubes, working liquid distributes randomly within the system. The surface tension force is to be ensured to dominate over gravity force (though Eq. 1) [9] which makes liquid bubbles to bridge the whole loop.

$$D_{crit} < 2\sqrt{\left(\sigma/\left(\rho_{liq} - \rho_{vap}\right)\right)} \tag{1}$$

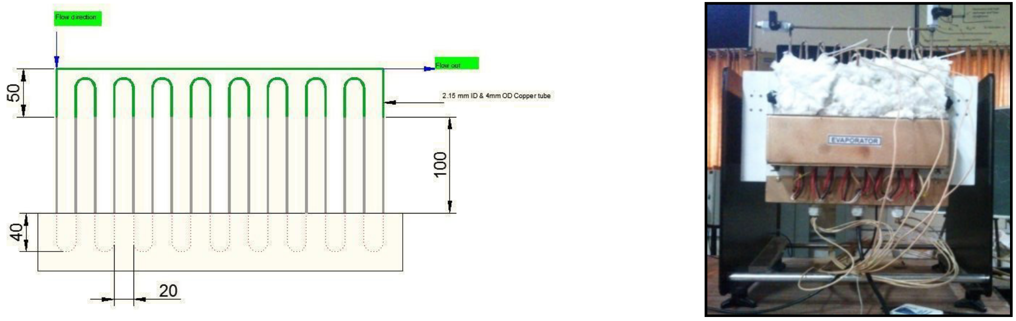
Table 1: Literature Survey

Di (mm)	Mode Of cooling	FR (%)	Pressure	Working Fluid	References
2	Forced air & water cooling	Vary	<10e-4 mbar	DI water, ethanol, R123	Khandekar [9]
1.651	Forced air cooling	30-70	0.12 to 0.1333 bar	acetone, methanol & DI water	Clement, Wang [7]
Square	Forced air cooling	0-50	73.25 mbar	1-butanol,1-pentanol, water	Fumoto et al. [8]
2.2	Forced water cooling	40 & 70	NA	Distilled water & ferro fluid	Mohammadi et al. [11]
Square	Forced water cooling	40,50,60,70	NA	DI water	Chien et al. [6]
2	Forced water cooling	20,40,60,80,100	NA	methanol, ethanol, acetone, water	Baitule, Pachghare [4]
1.8	Forced water cooling	30,40,50,70,80	0.001 mbar	Water & Ethanol	Shafii et al. [13]

The literature survey clearly suggests that among all above experiments, investigations based on natural convection have not been carried out yet. As the system works on natural convection/cooling method, device complexity reduces. Also vacuum inside the system was lowest possible as compared to others. In view of the numerous applications of CLPHP, the present paper is aimed to investigate the following objectives: (1) the effect of Filling Ratio (FR) on the performance of CLPHP (2) the effect of input heat flux on the performance of CLPHP.

2. Experimental Setup

The experimental setup is developed with 2.15 mm internal diameter copper tube with 9 turns and shown in Fig. 1(b). Evaporator section is fabricated with the help of cartridge heaters (Ø10.0×40mm) of 100 W. Copper tubes were inserted in the heater block. The adiabatic section is developed by wrapping glass wool on copper tubes.



(a) (b)

Fig. 1 (a) schematic diagram (b) experimental setup

The glass wool is wrapped firmly to reduce the heat loss from this section. In condenser section, copper tubes with bends are kept open in atmosphere to dump the heat into the atmosphere. Schematic diagram with geometrical dimensions are shown in Fig. 1(a). Data acquisition system is used to scan and record the data on computer in each 2 seconds. A carbon dimmer is used to adjust input voltage and subsequently heat fluxes. K-type thermocouples are used at different locations in evaporator (total 09 numbers) and condenser section (total 04 numbers) for temperature measurement. Vacuum pump is used to evacuate the system up to 9×10^{-5} mbar.

The system is first flushed with the help of pressurized air followed by evacuating the system with the help of vacuum pump. Desired quantity of fluid is admitted to the system with the help of a syringe & filling valve. Now close the valve & set system for heating. Heat input is controlled with the help of dimmer. Data logging is started immediately with heating & thermal performance of CLPHP is monitored as well as calculated.

3. Results & Discussion

The experimental analysis is presented in this section. The system performance is measured in terms of thermal resistance (R_{th}). Thermal resistance of a system is the measurement of a body's ability to prevent heat from flowing through it and calculated from Eq. (2).

$$R_{th} = \left(T_e - T_c\right)/Q \tag{2}$$

T_e and T_c are average steady-state evaporator and condenser temperatures respectively and Q is the heat input in the evaporator. The influence of Filling Ratio (FR) and input heat flux is discussed in the following sections.

3.1 Effect of Filling Ratio

Filling ratio represents the amount of liquid present in the system by its volume percentage. 0% FR means there is no working liquid in the system and 100% FR mean the system is full of liquid. If FR=0%, the system acts as conduction mode of heat transfer which shows very high value of thermal resistance. If FR=100%, the system acts as thermosyphon. The actual value of FR lies in the range of 20%-80% [9]. In order to study the influence of FR, experiments are conducted with varying FR as 40%, 50% and 60% and shown in Figs. 2-3.

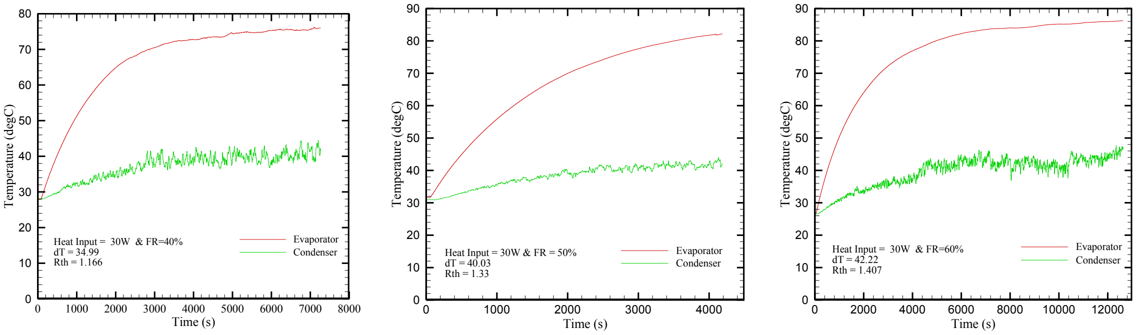


Fig. 2 Effect of FR at 30W heat input

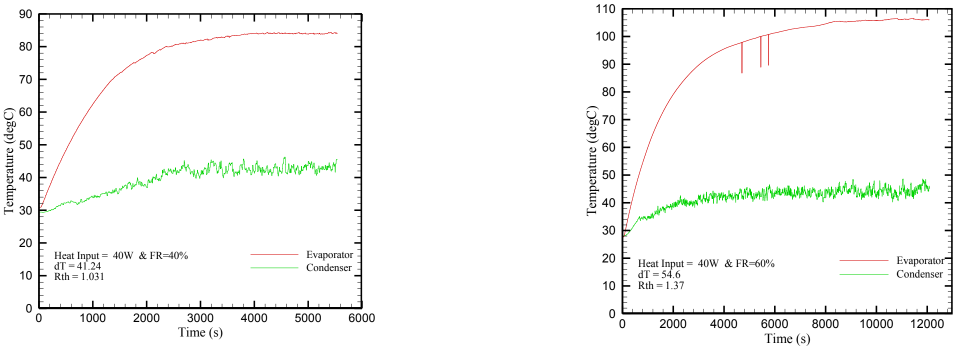


Fig. 3 Effect of FR at 40W heat input

As shown in Fig. 2, different temperature variation is observed for evaporator and condenser sections when heat flux is kept constant at 30W and FR is varied as 40%, 50% and 60%. It is observed that increase in FR increases the system thermal resistance for the same heat input. The similar effect is observed for heat flux of 40 W and FR of 40% and 60% as shown in Fig. 3. For FR=60%, larger volume of the system is occupied by the working fluid. Hence fewer bubbles would be formed in the system. So, bubble pumping action is reduced and system performance lowers. Contrary for FR=40%, bubble would find it easier to move in the system as compared to FR=60%. More bubbles would generate in the system which leads to better pumping action. Hence, improve the performance of the system. For all heating conditions and FR=40%, the system performs better as compared to that of 50% and 60%. This is because of the bubble dynamics as well as latent heat advantage coupled with sensible heat transport through liquid plug is sufficient to get pulsating mode advantage. Also for the same heat input and varying FR, it is observed that system takes longer time to come to a steady state. At lower level of heat input and FR=50%, CLPHP performs better. With increase in heat input for FR=40% turned out to be better.

3.2 Effect of input heat flux

Input heat-flux is the driving force for pulses in the CLPHP. In real-life situation, PHP may be used to various heat load conditions. For very smaller heat flux values, there may be situation in which pulsation even don't start. For very high heat flux, there may be dry-out. To investigate the influence of various heat fluxes on the performance of CLPHP, experiments are carried out for input heat fluxes ranging from 10W to 50W at different FR. The effect of heat flux at FR=40% is shown in Fig. 4 while the same effect observed for FR=60% is shown in Fig. 5. It is seen that the thermal resistance of the system decreases with increase in heat flux.

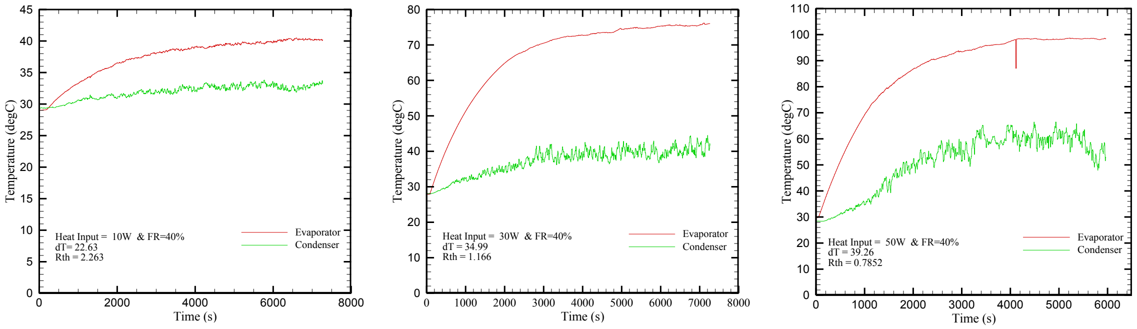


Fig. 4 Effect of input heat flux for FR=40%

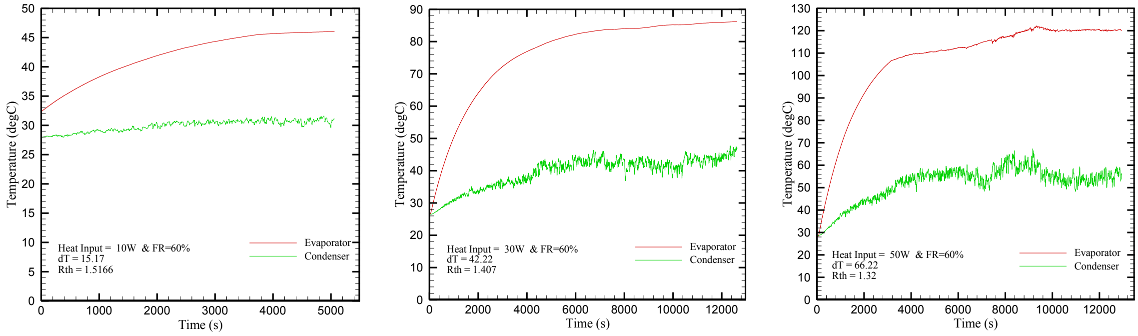


Fig. 5 Effect of input heat flux for 60% FR

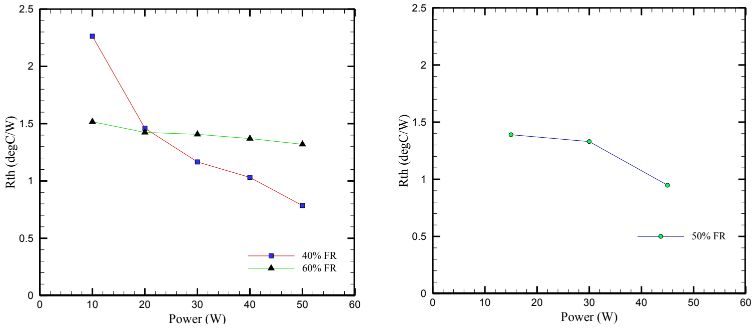


Fig. 6 Effect of input heat flux on thermal resistance for different FR

Steady state evaporator temperature and steady state condenser temperature difference also increases with increase in input heat flux. Moreover with increase in heat input values, the randomness of the condenser temperature increases. At 10W this randomness was observed less. As the heat input is increased, temperature fluctuates violently. The influence of input heat flux on thermal resistance of the system at different FR is shown in Fig. 6. Thermal resistance is observed higher for FR=40% compared to FR of 50% and 60% at lower value of heat input. It starts to decrease with increase in input heat flux at all FR as expected and mentioned in the foregoing discussion.

5. Conclusion

The present paper is an attempt to investigate the performance of the CLPHP. The conclusions drawn from the present research paper is as follows:

1. The system performs better with lower FR for the same input heat flux.
2. Steady state evaporator temperature T_e is observed to increase with increase in FR for the same heat input values.
3. Difference between steady state evaporator temperature T_e and steady state condenser temperature T_c increased with increase in both FR and input heat flux.
4. As the heat input increases, R_{th} decreases due to the chaotic fluid movement.
5. For FR=40%, chaotic fluid movement is observed with T_c values. As the heat input is increased with same FR, larger fluctuations are observed. This trend is also observed for FR=60% but the amplitude is lower as compared to 40% and 50% FR.
6. Difference between steady state evaporator temperature T_e and steady state condenser temperature T_c increased with increase in input heat flux. For the same heat input values, system took longer time to reach steady state with increase in FR.

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