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OPERATIONAL AND PRESSURE CHARACTERISTICS OF A THERMOLOOP DEVICE

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ABSTRACT

Thermoloop, a particular kind of two phase pulsated thermosyphon (PTPT) is passive cooling device which can meet high heat flux dissipation requirements. This paper gives emphasis on the analysis of working phenomena and operational characteristics of this device. The PTPT comprises of three components; evaporator, condenser and reservoir connected by flexible tubing. Experiments were carried out for different working fluids and thermal loads for a specific geometry of the device. During each experiment the temperature of the components at different points and pressure at evaporator were measured at steady state condition. Neither mechanical pump nor gravity force is used to assist the flow. Only natural convection was allowed for condensation. It is realized that, the variation of pressure drives the working fluid through the system components. Development of vacuum pressure due to condensation plays key role to refill the evaporator with fresh liquid at the end of each cycle. For a particular working fluid the cycle duration decreases with thermal load but, the $\Delta T_{sat,}$ maximum evaporator wall temperature, and maximum cycle pressure increases. The condensate return temperature and maximum vacuum pressure increases slightly with thermal load. The operating cycle can be described by three regions viz. constant volume heat addition, vapor transfer and condensate return region.

Keywords: Thermoloop, Evaporator Pressure Drop, Cycle Time.

1. INTRODUCTION

Pulsated two phase thermosyphons (PTPT) can meet the demand in electronics industry for its compact size and faster technology to dissipate heat. It is a very effective means of cooling for many purposes. To develop this idea many research works are done. As a result of these series works, conventional heat pipes (capillary driven) were developed by Peterson [1], Faghri [2], Khrustalev et al. [3] which are capable of working against gravity. After heat pipes have been invented, Meidanik et al. [4] and Ku [5] developed loop heat pipe, LHP and capillary pumped loops, CPL, as a part of the research above. In the last few years, Akachi et al. [6], Dobson et al. [7] and Groll et al. [8] have proposed and developed oscillating heat pipes or pulsating heat pipes (OHPs or PHPs), wickless devices able to operate against gravity . But oscillation of temperature occurred in the evaporator section with high frequency [7-8] In 2001, Fillipschi [9] developed an initial idea of implementing PTPT device in electronic and micro-electronic equipments. In 2003, Fillipschi et al. [10] proposed a device for electronic equipment cooling with FC72. That was the first miniature experimental apparatus based on PTPT. In 2005, Fillipschi [11] also carried out a study to find out the influence of main parameters on thermal behavior and developed a mathematical model to analyze the parameters.

Alam [12], first came with the idea of Thermoloop, made it as a patent and performed few experimental tests identifying the key performance parameters. Later Rahman et al. [13], in May 2008, has conducted some experiment on Thermoloop device in the heat transfer laboratory of Bangladesh University of Engineering and Technology keeping reservoir open to atmosphere and described the effect of evaporator fill ratio and condenser convection condition on evaporator temperature. More recently, Islam et al. [16] completed a research project on PTPT device and extensive data are collected by combining different geometry and sizes of evaporator and condenser for different working fluids. In the project and other recent studies, the system pressure was measured by an indirect means as there was no direct pressure measuring device. Therefore, operating characteristics of the PTPT device is not clearly understood hitherto.

This present study conducted experiments to measure system pressure correctly using a pressure transducer and understood operating characteristics of the thermoloop device more comprehensively. By collecting these experimental data, in this study a description of the pressure characteristics is offered.

And some characteristics curves are also presented here to describe the working principle.

2. EXPERIMENTAL SET-UP

2.1 Arrangement

The device comprised of three components; an evaporator E(made of copper) with internal volume of 3 cc, a natural cooling copper tube condenser C(4 turns, 25 cc) & a flexible reservoir R, shown in figure 1, placed at a same level to avoid the influence of gravity. The components above were connected by forward lines, FL (7mm) return lines, RL (7mm). These lines are transparent tubes to facilitate flow visualization.

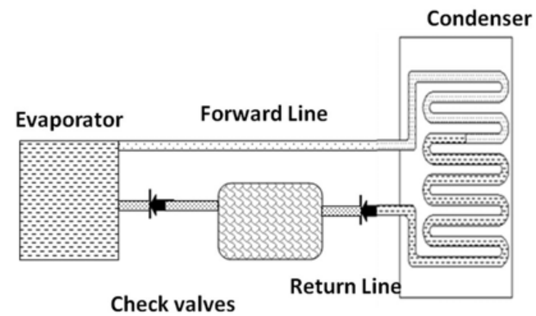

Fig 1. Simple schematic diagram of Thermoloop

Two check valves were placed at the both ends of the reservoir to make the flow unidirectional. The temperature of evaporator wall, fluid (in evaporator) and condensate temperatures were measured by K-type thermocouple. Fluid pressure in evaporator was measured by a pressure transducer. The temperatures and pressure were recorded by a data logger (Pico TC-08). Two cylindrical AC heaters, each of 200 watts were connected in parallel, pressed into a closed flat copper box to apply thermal load to the evaporator. A thermal material coating was applied between the mating surfaces evaporator and heater body to reduce thermal resistance due to air gap.

2.2 Experimental Procedure

The study was conducted with three different working fluid viz. Methanol, Ethanol and Water for thermal loads 50W, 75W and 100W. Initially all the components of the thermoloop were filled by a suction pump with working fluid and residual air bubbles were bleed out. Then the setup was checked for any possible leakage. All the tests were performed by placing the whole setup horizontally. Then the power connection to the heater was switched on and the desired heat input was ensured by setting the variac to the required level and taking consequent ampere reading. The temperature of the evaporator wall and condenser outlet and pressure inside the evaporator were recorded for certain periods. The total time required for completion of every heat transport cycle was recorded for all the tests performed, along with readings of wall temperature of the evaporator, inlet and outlet temperature of the condenser and voltage of the voltmeter connected with pressure transducer. Almost all the experiments were carried out for about 500 seconds.

3. RESULTS AND DISCUSSION

3.1 Single Heat Transport Cycle Analysis

The Thermoloop device works in a periodic fashion. The cycle starts with constant volume heat addition of subcooled liquid in the evaporator and when the condensate returns to the evaporator from the reservoir, the cycle is completed. Temperature evolutions for 6 consecutive heat transfer cycles of water for thermal load of 50 W is shown in figure 2.

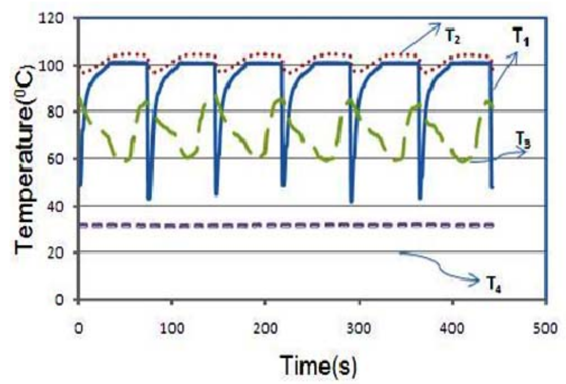

Fig 2. Temperature evolutions of water for 6 consecutive cycles for thermal load of 50 W

The operation of a sample cycle (Methanol, 75W) analyzed here and time expressed in terms of percentage of total cycle duration. The whole cycle can be described through three distinguished regions. These are –

A. Constant volume heat addition region
B. Vapor transfer region
C. Condensate return region

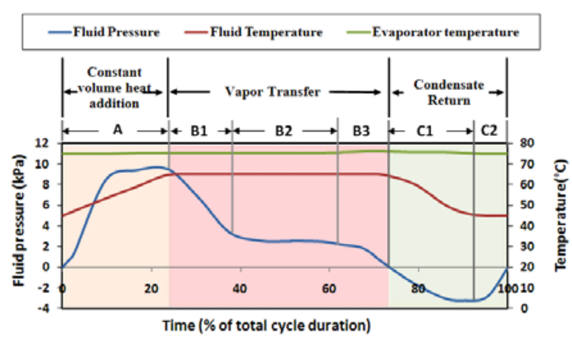

Fig 3. Operating cycle of a Two Phase Pulsated Thermoloop

A. Constant volume heat addition region

This region last for 25% of the cycle. At the beginning of this region the evaporator is fully filled with subcooled liquid and the pressure is atmospheric. The temperature of the evaporator wall is higher than the saturation temperature of liquid. The liquid near the evaporator wall first receive heat and free convection current is responsible for rising temperature of the subcooled liquid. Bubbles begin to form near the wall, dissipated in the liquid and pressure in the evaporator gradually increases. Pressure difference required to initiate flow from evaporator which is

$$\Delta P = 32 L \mu u_m / D^2 \qquad (1)\ [15]$$

The developed pressure in the evaporator is not enough to make flow and the liquid get heated in a constant volume manner. At end of this region liquid temperature rises to saturation temperature and pressure builds up to maximum in the cycle. The evaporator wall temperature is increases a little.

B. Vapor transfer region

This region is characterized by removing heat by boiling of liquid and transfer of vapor form evaporator. It lasts for 50% of the cycle. The region can be best described by three sub-regions viz. B1, B2 and B3:

In region B1, the saturated liquid starts to vaporize. The generated vapor moves towards the condenser via forward tube. The vapor carries some liquid causing a mixed flow of liquid and vapor. The pressure in the evaporator drops as the mixed flow poses less viscosity than the liquid flow. The percentage of liquid in mixed flow gradually decreases with time and approaches to zero at the end of sub-region.

Fully vapor flow established in sub-region B2 and pressure in the evaporator is enough to maintain the vapor flow. The check valves direct the vapor towards the condenser and after condensation it returns to flexible reservoir. The generation and transportation of vapor maintains an equilibrium which keeps the evaporator pressure almost constant.

In sub-region B3, evaporator pressure drops back to atmospheric pressure. As only a fixed volume of the liquid is transported into the evaporator in each cycle, when most of the liquid vaporizes the equilibrium of sub-region B2 cannot be maintained. For slower vapor generation rate, pressure drops and descends to atmospheric.

Throughout the Vapor transfer region evaporator wall temperature gradually increases.

C. Condensate return region

This is remaining 25% time when the evaporator is refilled by fresh subcooled liquid. The system pressure drops due to condensation of vapor, a vacuum creates which sucks a bulk of fresh subcooled liquid from reservoir, then pass through return line, evaporator, forward line and reaches up to condenser inlet. The flexible reservoir collapses during suction to maintain atmospheric pressure. The region briefly analyzed through sub-regions C1& C2.

In region C1, as soon as fresh subcooled liquid comes in contact with superheated evaporator wall, some of the liquid momentarily vaporizes and rest of the liquid carry out heat by heating sensibly. It leads to immediate drop in evaporator body temperature.

At region C2, both the liquid and evaporator temperature holds steady and that seems to be an establishment of thermal equilibrium. The heat removed by flow of fresh subcooled liquid under vacuum pressure is equal to heat rejected by evaporator.

As liquid fills the vacuum created by condensation of vapor the pressure of system recovered to atmospheric again and a new cycle starts.

3.2 Variation of Performance Parameters under Different Thermal load and Working Fluid

This study proposes the experimental investigation of thermoloop device to determine the variation of functional parameters on the performance of the thermoloop.

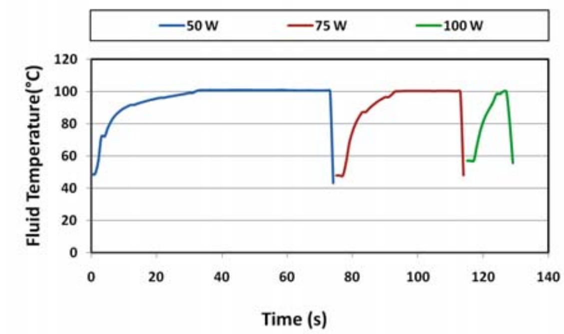

Fig 4. Comparison of cycle times for thermal load of 50W (a), 75W (b), 100W (c)

The figure 4 presents a comparative description of a single cycle for different thermal load. For all working fluid the cycle duration decreases with heat input. For higher thermal load it takes less time to complete the heat transport cycle. because a fixed volume of liquid in the evaporator boils faster. In case of water, for 50 W it takes around 75 seconds, where for 75 W it is 40 seconds and for 100 W it is only 13 seconds. Water exhibits maximum cycle duration for its highest value of latent heat of vaporization and methanol exhibits the minimum for a certain thermal load.

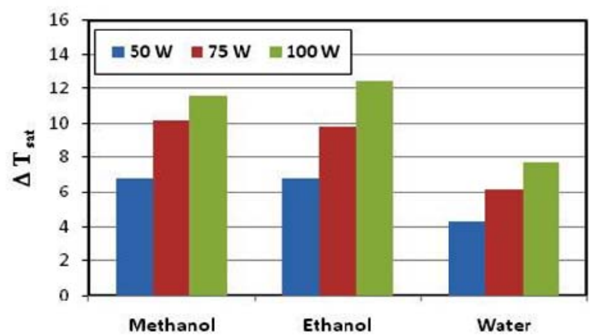

Fig 5. Variation of ΔT_{sat} with Thermal Load.

Figure 5 presents the variation of ΔT_{sat} with Thermal Load**.** The simple law of heat transfer for boiling is heat flux $q \propto h\,\Delta T_{sat}$ and the $\Delta T_{sat} > 0$. An increment on thermal load increases the heat flux which in terms increases both the ΔT_{sat} and h. Water has a maximum enthalpy of vaporization which poses maximum value of h and for the same reason ethanol exhibits minimum value of h. So ΔT_{sat} is minimum for water and maximum for ethanol for a certain thermal load.

Figure 6 shows the variation of Maximum Fluctuation of Evaporator wall temperature with Thermal Load. The temperature of evaporator drops in condensate return region when sub-cooled liquid passes through the evaporator and rises during constant volume heat addition and vapor transfer region.

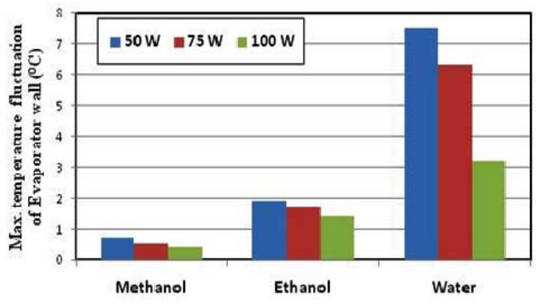

Fig 6. Variation of Maximum Fluctuation of Evaporator wall temperature with Thermal Load

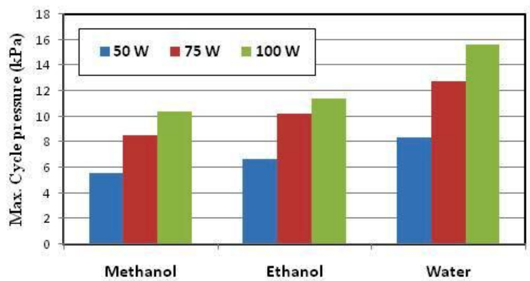

Fig 7. Variation of Maximum Cycle Pressure with Thermal Load

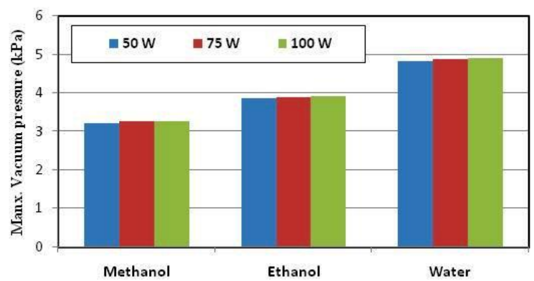

Fig 8. Variation of Maximum Cycle Vacuum Pressure with Thermal Load

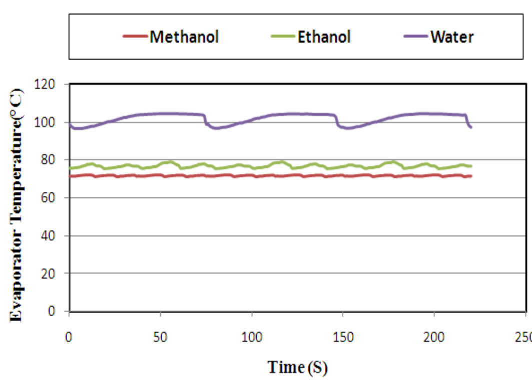

Fig 9. Comparison of evaporator temperature for different working fluid

The temperature drops mostly depends on specific heat C_p of sub-cooled liquid. As water has the highest value of C_p, the temperature drops most and the minimum value of C_p of methanol causes to drop least.

Figure 7 presents comparison of Maximum Cycle Pressure with different Thermal Load. The maximum pressure increases with thermal load. The maximum cycle pressure develops in sensible heating region which depends on the viscosity of the fluid. The pressure is also depends on change in specific volume due to phase change in some degree and its influence is not realized fully yet. From the observation, water shows maximum pressure and methanol shows the minimum temperature for different working fluid.

Figure 8 shows the variation of Maximum Cycle Vacuum Pressure with Thermal Load. The vacuum pressure develops for condensation of saturated vapor to liquid in the condenser so it depends on the change in specific volume due condensation. Methanol has least change in specific volume for condensation and vacuum creates the minimum among other fluid. The water shows maximum drop in pressure. The maximum vacuum pressure increases with thermal load.

Figure 9 shows a comparative description on cooling process between water and methanol . Methanol boiling point is lower than the boiling point of water. And methanol keeps the evaporator at a lower temperature than that of water. So it is useful to use a working fluid with lower boiling point.

4. CONCLUSION

Periodic two phase thermosyphon (PTPTs) is a special type of unsteady state heat transfer device for high end electronics cooling, capable of operating without gravity support. The maximum thermal load handled were 100W under natural convection. The operational characteristics and influence of various functional parameters on the performance of the thermoloop may be summarized to make following conclusions:

1. The variation of pressure drives the working fluid through the system components. Development of vacuum pressure due to condensation plays key role to refill the evaporator with fresh liquid at the end of each cycle.
2. For a particular working fluid the cycle duration decreases with thermal load but, the $\Delta T_{sat,}$ maximum evaporator wall temperature, maximum cycle pressure, and condensate return temperature and maximum vacuum pressure increases.
3. Fluid of low boiling temperature (like Methanol 67°C) performs better in cooling purposes and build less thermal stress for the thermoloop device.

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6. NOMENCLATURE

Symbol	Meaning	Unit
E	Evaporator	
C	Condenser	
R	Reservoir	
RL	Return Line	
FL	Forward Line	
L	Line Length	m
D	Line Diameter	m
P_E	Evaporator Pressure	Pa
ΔP	Pressure difference	Pa
μ	Viscosity	Ns/m^2
u_m	Fluid Velocity	m/s
q	Heat Flux	Wm^{-2}
h	Heat transfer coefficient	W/m^2K
t	Cycle Time	sec
T_1	Temperature of Evaporator Liquid	^0C
T_2	Temperature of Evaporator Body	^0C
T_3	Temperature at condenser Inlet	^0C
T_4	Temperature at condenser Outlet	^0C
ΔT_{sat}	Temperature difference between evaporator wall and saturation temperature of liquid.	^0C
C_p	Coefficient of heat transfer	J/kg^0C

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