Proceedings of MARTEC 2010
The International Conference on Marine Technology
11-12 December 2010, BUET, Dhaka, Bangladesh

AN EXPERIMENTAL STUDY OF TWO-PHASE LOOPED THERMOSYPHON

A. K. Azad[1], S. K. Sarkar[2], C. M. Feroz[3] and M. M. Alam[4]

[1,2]Department of Mechanical Engineering
Bangladesh University of Engineering and Technology
BUET, Dhaka-1000, Bangladesh
E-mail: azad_sgfl@yahoo.com

[3,4]Professor, Department of Mechanical Engineering
Bangladesh University of Engineering and Technology
BUET, Dhaka-1000, Bangladesh
E-mail: mmalam@me.buet.ac.bd

ABSTRACT

The present experimental work investigates the heat transfer performance of Miniature Looped Parallel Thermosyphon (MLPT) which consists of two single tube thermosyphon connected by two U tubes of same diameter at the top and bottom ends. For this purpose, the copper tube of 5.78 mm ID used with ethanol, methanol, acetone and water as the working fluids. Heat transfer characteristics are determined experimentally, based on the principle of phase change at different heat flux and different coolant flow rates. An analysis of the experimental data gives that the axial wall temperature of both condenser and evaporator sections decreases with the increase of coolant flow rate. The wall temperature increases with increase of heat flux. The thermal resistance decreases with the increase of both coolant flow rate and thermal load. Overall heat transfer coefficient increases with the increase of both coolant flow rate and heat flux.

Keywords: *Heat flux; overall heat transfer coefficient; Working fluid; Thermosyphone; Phase change;*

1. INTRODUCTION

Thermosyphon or heat pipe is a device of very high thermal conductance. Among other cooling technique heat pipe emerged as the most appropriate technology and cost effective thermal design due to its excellent heat transfer capacity, high efficiency and structural simplicity [1-5]. The heat pipe can, even in its simplest form, provide a unique medium for the study of several aspects of fluid dynamics and heat transfer, and it is growing in significance as a tool for use by the practicing engineer or physicist in applications ranging from heat recovery to precise control of laboratory experiments [2, 6-9].

The idea of looped parallel thermosyphon (1) (2) is developed to minimize several insufficient performances of single tube thermosyphon such as low maximum heat transfer rate and non-uniform wall temperature in an evaporator section. In LPT, two single type thermosyphons are joined by two U-tubes at the top and bottom ends and thus total heat transfer area is increased. A small quantity of fluid is placed in the tube from which the air is evacuated and the tube sealed. The lower end of the tube (evaporator section) is heated causing the liquid to vaporize. After that, the vapor moves to the cold end of the tube (condenser section) where it is condensed. The condensate is returned to the hot end by gravity. Since the latent of evaporation is large, considerable quantities of heat can be transported [9-11].

Thermal designers have widely accepted the miniature looped parallel thermosyphon (MLPT) for their thermal design solution and the area of application increases day by day. Normally MLPTs have 3 to 6 mm diameter and less than 400 mm length. Most preferable length is 150 mm. MLPT is relatively a new technology; relevant data, information is quite scarce (3). So, a thorough investigation of heat transfer capability of MLPT is indispensable for further development and improvement of performance. The purposes of this study are to show heat transfer characteristics in evaporator and condenser sections in miniature looped parallel thermosyphon (MLPT) and experimentally examined the maximum heat transfer rate, wall temperature profile and thermal resistance in the test sections [7,11].

2. MINIATURE LOOPED THERMOSYPHON

The schematic diagram of experimental apparatus is shown in the Fig. 2. The test loop consists of a pair of evaporator, adiabatic, condenser and U tube sections and is vertically oriented. Detailed dimensions of the MLPT are shown in the Fig. 1. Two evaporator and two condenser sections are located at bottom and top of the loop, respectively. All sections are made of 5.78 mm ID copper tube. The length of the evaporator, adiabatic, and condenser sections are 50 mm, 30 mm, and 70 mm, respectively. The both tubes are connected by U tubes with the same inside diameter at top and the bottom. The U tube is a half of a circular ring with 31.72 mm inner radius.

Two single tube thermosyphon consists of three sections as shown in Fig. 1.

a. Evaporator section
b. Adiabatic section
c. Condenser section

The detail dimensions of looped thermosyphon used in the experiment are summarized in Table-1.

Evaporator section: It is bottom part of thermosyphon. Heat is added to the thermosyphon through evaporator section.

Condenser section: It is upper most part of the thermosyphon. Heat is removed from the thermosyphon through condenser section.

Adiabatic section: Adiabatic section is located between the evaporator and condenser sections. This section is actually kept with heat pipe to distinguish evaporator section and condenser section. Adiabatic section is thermally insulated.

Table 1: The detail dimensions of thermosyphon

Parameters	**Dimension** (mm)
Outside diameter of pipe, d_0	6.48
Inside diameter of pipe, d_i	5.78
Length of evaporator, L_e	50
Length of adiabatic section, L_a	30
Length of condenser, L_c	70

3. WORKING FLUIDS

The working fluids used in this study are Methanol (CH_3OH), Ethanol (C_2H_5OH), Acetone (CH_3COCH_3) and Water (H_2O). Some important properties of these four working fluids are mentioned below.

Methanol: Methanol or Methyl alcohol is a colorless, flame-able liquid. Pure methanol boils at 327.85 K at atmospheric pressure and molecular weight is 32.00.

Ethanol: Ethanol or Ethyl alcohol is a colorless, flame-able liquid. It boils at 351.3 K at atmospheric pressure

Acetone: Acetone is a flame-able, colorless liquid. It is the simplest of the organic chemical called ketones. It is completely soluble in water. It has a mild pleasant odor. It boils at 329 K at atmospheric pressure.

Water: Water is a colorless liquid. It boils at 373 K at atmospheric pressure.

4. EXPERIMENTAL PROCEDURE

The Ni-Cr thermic wires are wound around the wall of the evaporator at a constant interval of 1.5 mm. The heat added to the two evaporator sections of MLPT is processed in the electrical method by using the two separate DC power supply. The evaporator sections are covered with glass fiber to minimize heat loss. The adiabatic and the condenser sections are also covered with the insulator.

The condenser sections are cooled by a constant temperature water coolant, circulating in an annular space between the copper tube and jacket. The water coolant is supplied from an elevated water tank and the flow is controlled by the flow meters. Nine calibrated thermocouples of T type are attached at each side at the wall of the MLPT to measure the wall temperature. Five units in the each evaporator section, two units at the each adiabatic section, and two units are at the each condenser section. The inlet and outlet coolant temperatures are also measured. The thermocouples are attached at the wall surface using adhesive. Temperatures are measured by the digital thermometers.

The input power to the heater in the each evaporator section is increased stepwise. The measurements are made under a steady state condition at each input power. Ethanol, methanol, acetone and water are used as the working fluids.

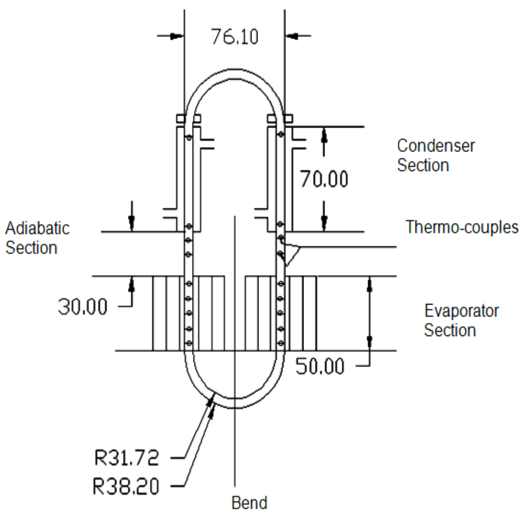
In the present study, the performance of MLPT is evaluated by measuring the thermal resistance, *R* (^{0}C/W), which is defined in Equation (1)

$$R = \frac{T_e - T_c}{Q} \tag{1}$$

The overall heat transfer coefficient, U_t (kW/m^2 ^{0}C) is obtained from Equation (2) as follows

$$U_t = \frac{Q}{A_e(T_e - T_c)} \tag{2}$$

4.1 SCHEMATIC DIAGRAM



(All dimensions are in mm)

Fig. 1: Dimensions of thermosyphon

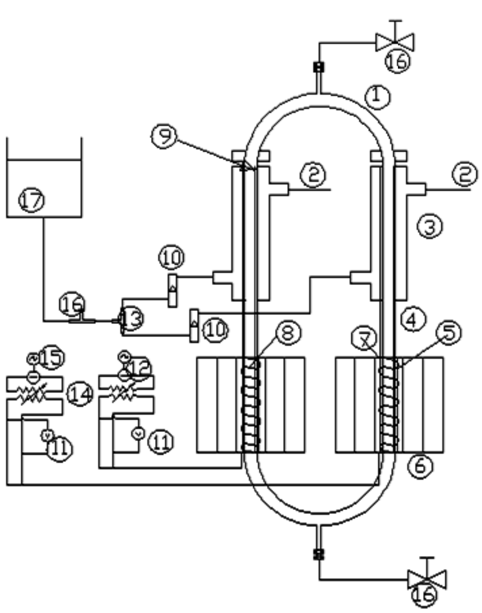


Fig. 2: Experimental apparatus

1. U-Tube, 2. Water out, 3. Condenser, 4. Adiabatic section, 5. Evaporator section, 6. Insulator, 7. Mica sheet, 8. Heater, 9. Insulating tape, 10. Flow meter, 11. Volt meter, 12. D.C. power source, 13. T-joint, 14. Volt slider, 15. A.C. power source, 16. Gate valve, 17. Water tank

5. RESULTS AND DISCUSSION

For better understanding the heat transfer characteristics of thermosyphon as well as the wall temperature at different points of the two phase looped thermosyphon are measured. From these measured data the temperature profiles are plotted against the axial distances. By using equations (1) and (2) thermal resistance, R and overall heat transfer coefficient, U_t are determined. Each of these properties are compared and explained in detail on the following section with graphs.

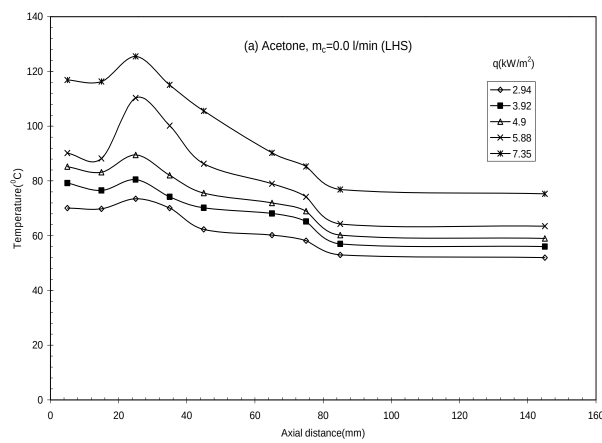


Fig. 3: Temperature distribution for various heat fluxes

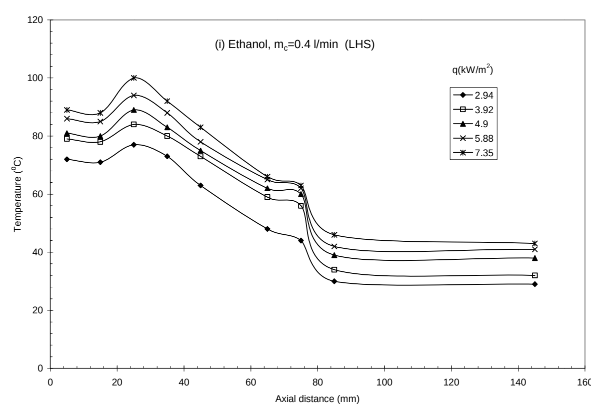


Fig. 4: Temperature distribution for various heat fluxes

Figures 3 and 4 show the wall temperature profiles along the axial length from the bottom of thermosyphon having 5.78 mm ID for acetone and ethanol working fluids respectively. The wall temperature increases with increasing heat flux. It also found in the figures that both condenser and evaporator wall temperature decreases with the increase in coolant flow rate (i.e. 0.01-0.40 L/min).

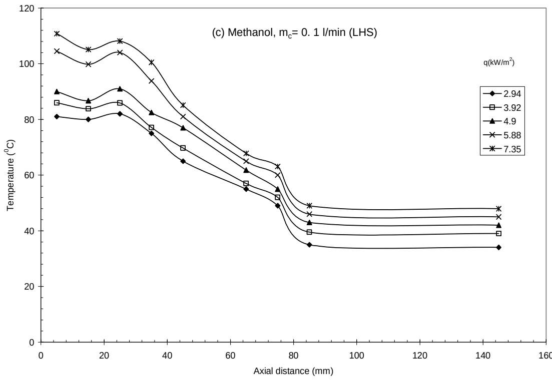


Fig.5: Temperature distribution for various heat fluxs

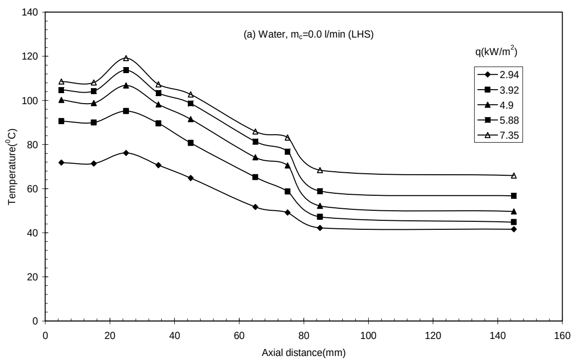


Fig. 6: Temperature distribution for various heat fluxs

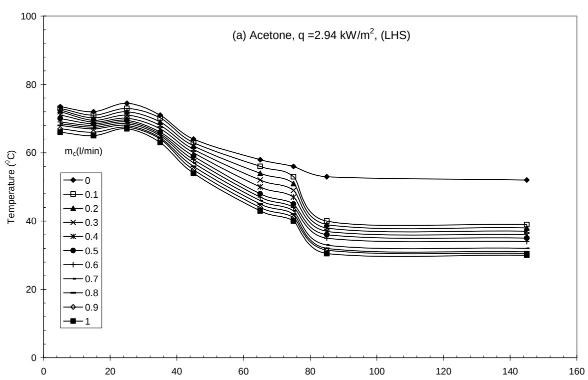


Fig. 7: Temperature distribution for various coolant flow rate

Figures 5 to 7 show the wall temperature profiles along the axial length from the bottom of thermosyphon having 5.78 mm ID for methanol, water and acetone working fluids. Figures indicate the similar result as found for ethanol and acetone. The wall temperature increases with increasing heat flux at all elevation.

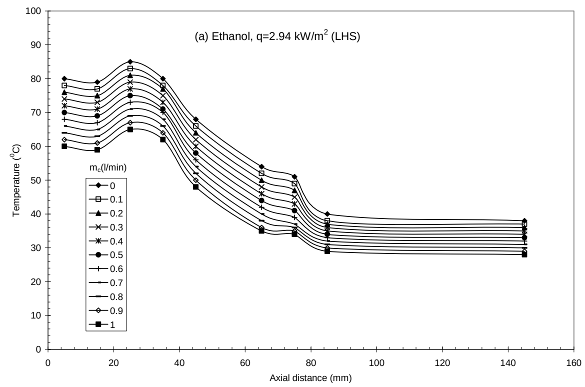


Fig. 8: Temperature distribution for various coolant flow rate

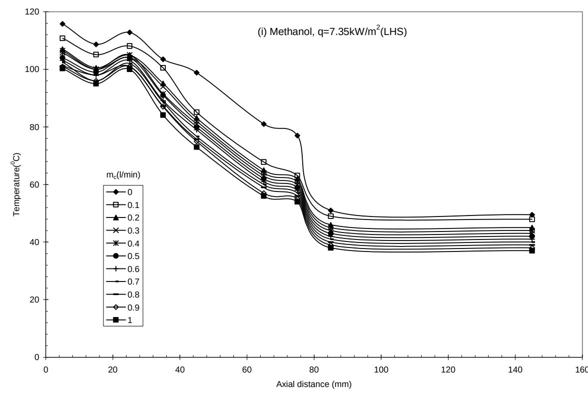


Fig. 9: Temperature distribution for various coolant flow rate

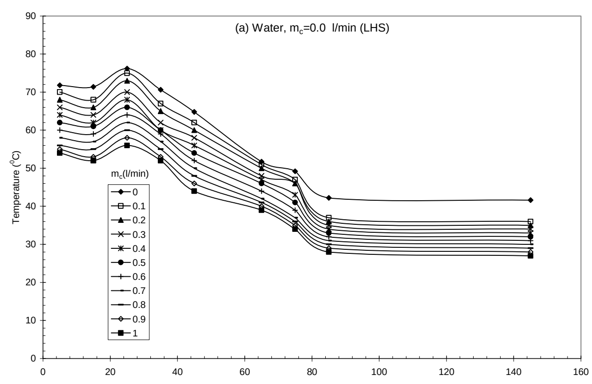


Fig. 10: Temperature distribution for various coolant flow rate

Figures 8 to 10 show the axial wall temperature distribution of the thermosyphon at various coolant flow rate for Ethanol, methanol and water working fluids. At a lower coolant flow rate wall temperature in the condenser section is found very irregular. This irregularity decreases with the increase of coolant flow rate. The evaporator wall temperature also decreases with the increasing coolant flow rate. It also shows the axial wall temperature distribution of the thermosyphon at various coolant flow rate for water working fluid. It is found in the figures that both condenser and evaporator wall temperature decreases with the increase in coolant flow rate.

6. CONCLUSIONS

The results of the performance test for the thermosyphon having 5.78 mm ID and length of 150 mm give the following conclusions:

[1] The axial wall temperature distribution of both condenser and evaporator decreases with the increase in coolant flow rate and it can be seen that the wall temperature increases with increase in heat flux. There is no significant variation between left and right side heat pipes of thermosyphon.

[2] The thermal resistance decreases with the increase of coolant flow rate but there is no significant change after a flow rate of 0.2 l/min.

[3] Thermal resistance of the thermosyphon also decreases with the increase in thermal load.

[4] Overall heat transfer coefficient of the thermosyphon increases with the increase of both heat flux and coolant flow rate. At higher heat flux condition of 7.35 kW/m^2, the overall heat transfer coefficient of methanol is 0.126 kW/m^2 ^{0}C, the overall heat transfer coefficient of acetone is 0.2 kW/m^2 ^{0}C, the overall heat transfer coefficient of ethanol is 0.17 kW/m^2 ^{0}C the overall heat transfer coefficient of water is 0.16 kW/m^2 ^{0}C. There is no significant variation of thermal resistance and Overall heat transfer coefficient between left and right side thermosyphon.

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NOMENCLATURE

Symbol	Meaning	Unit
d_o	Outside diameter of pipe	mm
d_i	Inside diameter of pipe	mm
L_e	Length of evaporator	mm
L_c	Length of condenser	mm
L_a	Length of adiabatic section	mm
T_e	Evaporator Temperature	^{0}C
T_c	Condenser Temperature	^{0}C
Q	Fluid Flow rate	L/min
A_e	Area	m^2
R	Thermal resistance	^{0}C/W
U_t	overall heat transfer coefficient	kW/m^2 ^{0}C