Experimental investigation of Gravity Assisted Heat pipe Heat Exchanger using D.I. Water

R. Rajmohan[1], B. Sivaraman[2], S. Vijayaraj[3] , P. Raveendiran[4]
1,3 Department of Mechanical Engineering, AVC College of Engineering, Mayiladuthurai.
2,4. Department of Mechanical Engineering, Annamalai University, Annamalainagar – 608 002, Tamilnadu.

Abstract : Experimental research has been carried out to investigate the thermal performance of a water-to-DI water heat-pipe heat exchanger. DI Water has been used as a working fluid in the heat pipe. The analysis is based on the effectiveness $(\epsilon) -$ NTU approach to determine the thermal performance of heat exchanger. Many factors influences the thermal performance of heat-pipe heat exchangers such as temperature of water in the inlet of evaporator section, mass flow rate of water and inclination angle of the heat exchanger. The mass flow rate of evaporator section has been varied from 20 lph to 100 lph, while the condenser section flow rate has been altered in the ratio of 1:1, 1:1.5, 1:2, 1:2.5 and 1:3 as that of evaporator section. Many experiments were conducted under different operating conditions by varying the inclination angle of heat pipe from 0° to 60° in order to investigate their effect on the thermal performance of a heat-pipe heat exchanger.

In this study, the effect of mass flow rate of water to the evaporator section, mass flow rate of water to the condenser section and inlet temperature of water to the evaporator section were analyzed. The effect of gravity assistance to the condenser section with respect to the effectiveness also determined. It was found that, for all operating conditions the effectiveness of GAHPHX has increased with increase in mass flow rate of water to the evaporator section and maximum value at 80 lph. The optimum effectiveness of GAHPHX has been obtained when $C_h = 2\ C_c$ for all operating conditions.

***Keywords*:** Heat pipe, inclination angle, effectiveness, NTU

NOMENCLATURE

A	-	Total Heat Transfer Area m^2
m	-	Mass Flow Rate, kg/s
NTU	-	Number of Heat Transfer Units
T	-	Temperature, □C
HPHX	-	Heat Pipe Heat Exchanger
GAHPHX	-	Gravity Assisted Heat Pipe Heat Exchanger
D	-	Diameter, m
L	-	Length, m

SUBSCRIPTS

in	-	inlet
h	-	hot fluid
c_o	-	cold fluid outlet
c_i	-	cold fluid inlet
h_i	-	hot fluid inlet
o	-	outer
i	-	inner

GREEK LETTERS

$\in$	-	effectiveness, %
ψ	-	inclination angle, deg.

I. INTRODUCTION

The heat pipes have made them more attractive for use as heat-pipe heat exchangers. Heat pipe is a heat transfer device which transports large quantities of heat with minimum temperature gradient without any additional power. It consists of three different sections namely evaporator, adiabatic and condenser sections. Heat exchanger with heat pipes possess many advantages such as perfect separation between hot and cold fluid, light weight, high heat recovery effectiveness, no moving parts, no external power and high reliability reported by Dunn and Reay [1]. This type of heat exchangers have been used and studied extensively in heat transfer application and in most of those investigation, the axial heat pipes had been used as waste heat recovery systems [2-4]. Due to the high transport capacity to a considerable distance, heat exchanger with heat pipes are used in handling high heat flux. Chaudourne [5] Krishman and Rao [6] have investigated the expression of effectiveness with single and n rows of heat pipe heat exchanger. Experimental and theoretical investigation of thermal performance of air-to-air thermosyphon at various mass flow rate and inlet temperature of hot water to evaporator section have been reported by Noie [7]. Air-to-air thermosyphon heat exchanger using water as the working fluid with 12 kW of input heat to the evaporator section, operating below 300 °C was investigated by Dube *et al.* [8]. Gravity-assisted heat pipes do have a capillary structure in order to protect the liquid against the shear stress exerted by counter flowing vapour Busse *et al.*, Rice *et al*. [9-10]. The working flow used in heat-pipes having low surface tension but due to gravity-assistance, the heat-pipes can achieve relatively high rate of heat transfer Kemmer, Abhat *et al*. [11-12]. Based on the above brief review, it has been proposed to design a heat pipe heat exchanger to investigate the thermal performance of heat exchanger for the effect of different inclination angles of heat-pipes using DI water has working fluid in heat pipe. In this study $\in -NTU$ method has been used to predict the thermal performance HPHX due to its accuracy. Three heat-pipes have been arranged co-axially and the effect of various parameters such as mass flow rate of hot water, temperature of hot water and the thermal performance of the heat exchanger as a function of inclination angle (gravity-assistance) of heat-pipe along with shell of heat exchanger have been investigated. The details about shell, heat-pipe, and inclination angle of heat-pipe have been tabulated in Table. 1.

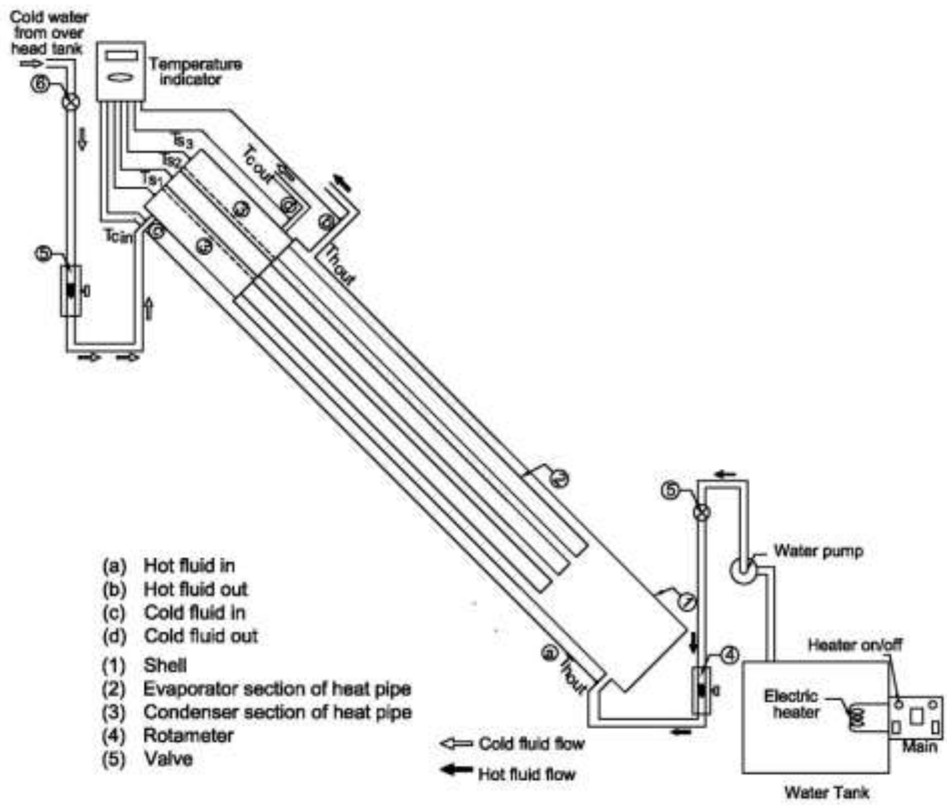

Fig. 1 Experimental setup of gravity-assisted heat pipe heat exchanger.

Table 1. Details of heat pipe, shell and wick materials

Sl. No.	Description	Materials	Size	Number
1.	Shell	GI	102 mm x 800 mm	1
2.	Heat pipe	Copper	D_o-19 mm D_i-17 mm L = 1000 mm	3
3.	Condenser	GI	D = 35 mm	3
4.	Wick	Stainless steel	Mesh no. 2000	2 layer
5.	Working fluid	DI water	-	-
6.	Inclination angle	-	15°, 30°, 45° & 60°	-

To investigate the thermal performance of HPHX an experimental set-up was fabricated and arranged with gravity assistance. Figure 1 shows the schematic diagram of experimental set-up of GAHPHX. It consists of three number of heat-pipes, electrical heater with water pump, four numbers of thermocouple, temperature monitor and temperature indicator. In order to measure and control the flow rate of hot and cold water to the heat exchanger, rotameters were used. A water tank of 40 liters capacity with two number of electrical heaters (each 2 kW capacity) with temperature monitor has been used to heat the flowing fluid of the shell side of heat exchanger. The temperature of both hot and cold water has been measured with a digital temperature indicator. Four numbers of RTD have been provided to measure the temperature of hot and cold water. The heat-pipes were charged with DI water which has been used as working fluid in GAHPHX.

The condenser section of heat pipe along with shell has been kept inclined so that the gravitational effect has its impact on heat pipes. Initially the inclination angle has been set at 15° and then it has been changed to 30 45 and 60 to investigate its effect on different operating condition by considering various parameters to analyze the thermal performance of GAHPHX.

In the first set of experiments, the effect of mass flow rate of water on the thermal performance of GAHPHX with constant inlet temperature of hot water was investigated. It was followed by a second set of experiment to investigate influence of inlet temperature of hot water with constant mass flow rate of hot water. Both trials were carried out at different inclination angle of heat-pipe (i.e., as 15, 30, 45, 60°). In all operating condition the flow pattern will be laminar and the effectiveness of GAHPX has been calculated using the following expression.

$$\epsilon = \frac{T_{co} - T_{ci}}{T_{hi} - T_{ci}} \qquad \rightarrow (1)$$

II. RESULTS AND DISCUSSION

The results reported in the paper have been obtained on Gravity Assisted heat-pipe heat exchanger having the following variable parameters.

Variable Parameters

Inlet mass flow rate of hot water ($T_{h\ in}$)	: 20 lph – 100 lph
Inlet mass flow rate cold water (T_{ci})	: 10 lph – 50 lph
Inlet temperature of water to the evaporator section	: 50C – 70 C
Inclination angle (ψ)	: 15°– 60°

In order to investigate the thermal performance of heat-pipe heat exchanger, number of tests were conducted. In every test, the mass flow rate of hot water at the inlet of evaporator section was fixed and varying the mass flow rate of cold water in the ratio of 1:1, 1:1.5, 1:2, 1:2.5 and 1:3.

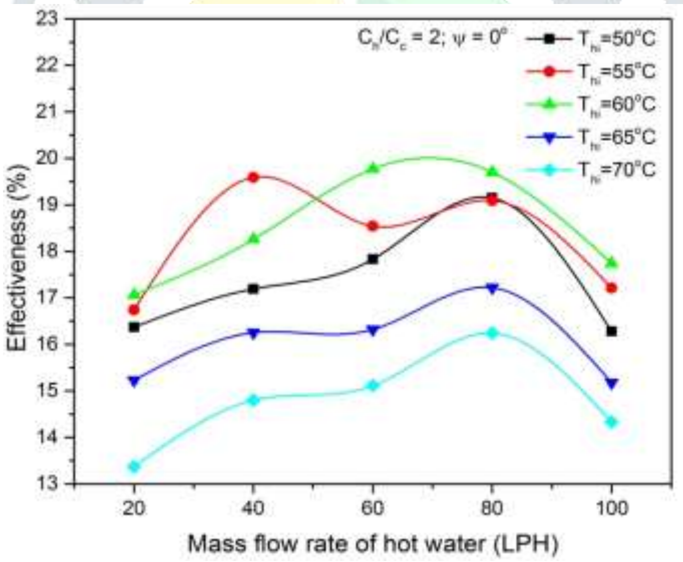

Fig. 2

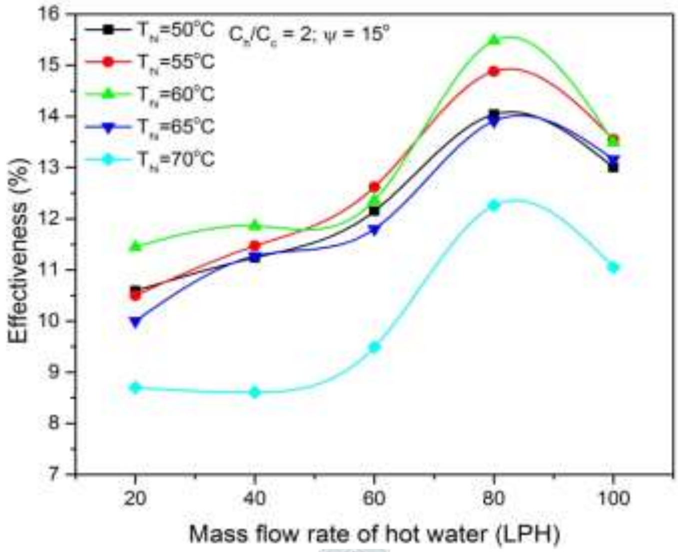

Fig. 3

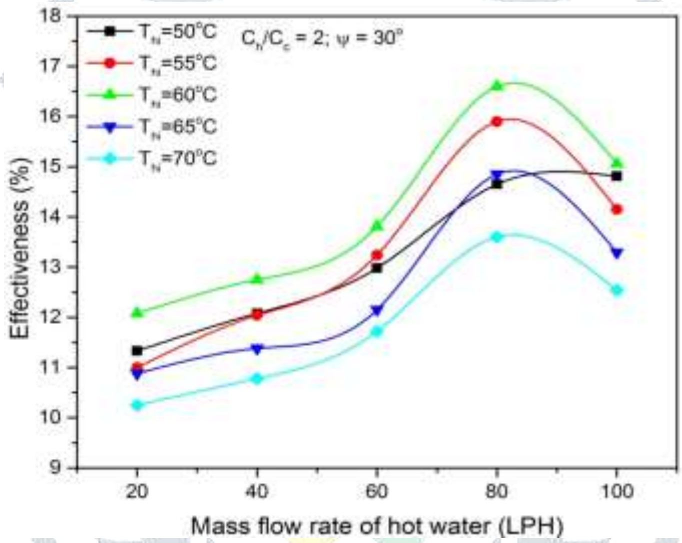

Fig. 4

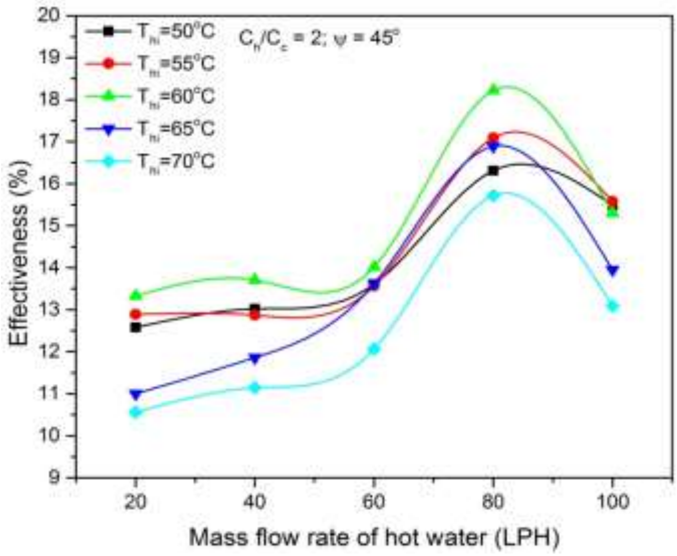

Fig. 5

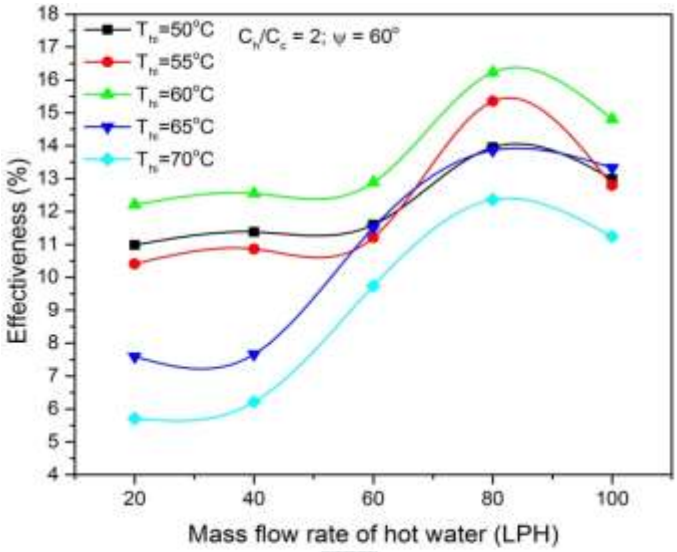

Fig 6

Figure 2 to 6 show the variation of effectiveness (∈) on mass flow rate of water to the evaporator section ($m_{h\ in}$) for different inclination of heat pipe. The heat pipe inclination varied between 0° to 60°. In all set of operating conditions the heat capacity ratio as (C_h/C_c) 2. It has been found that the effectiveness increases with increasing the mass flow rate water to the evaporator section, the heat exchanger has minimum value of effectiveness at $m_h = m_c$ ie., equal heat capacity ratio. Hence to get better performance of the heat pipe heat exchanger, it is clearly observed that equal flow rate of water should be avoided in the condenser and evaporator section.

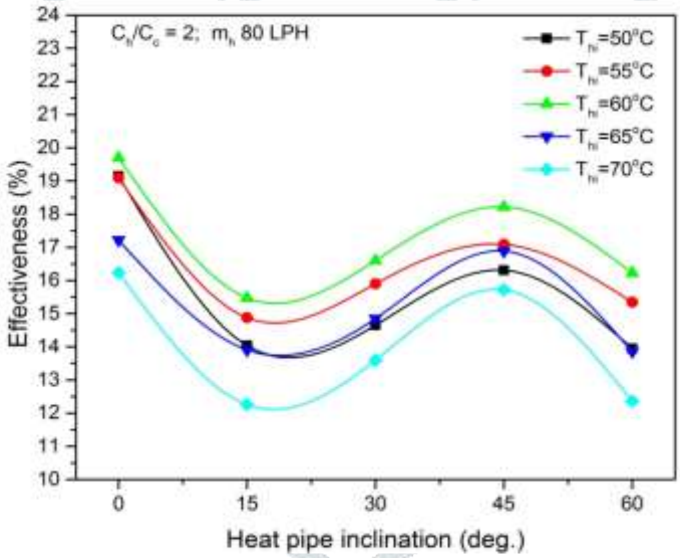

Fig. 7

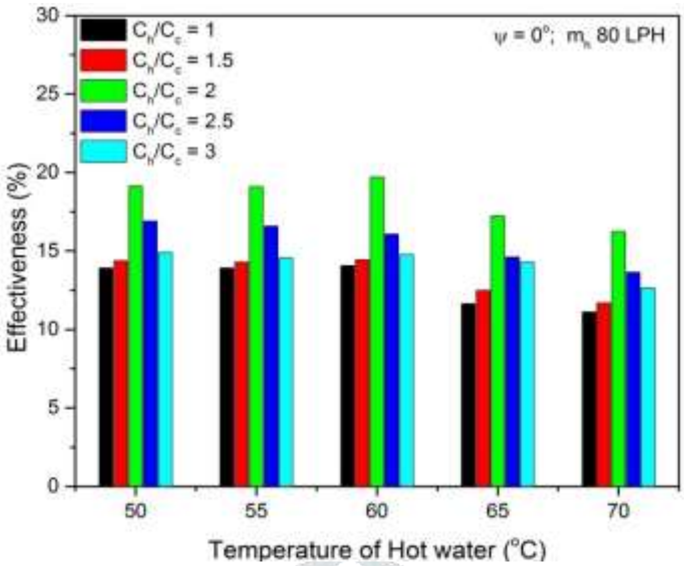

Fig 8

Figure 7 shows the effect of inclination angle over effectiveness of heat-pipe heat exchanger for different inlet temperature of hot water. It is clear from the plot that in an inclined position, the maximum effectiveness of heat exchanger occur at 45° inclination of heat pipe in all operating conditions. It has been inferred from the above analysis that the optimum effectiveness of GAHPHX has been obtained at 45° inclination and 80 lph of mass flow rate of hot water.

Figure 8 shows the effect of inlet temperature of hot water over effectiveness of heat pipe heat exchanger for different values of heat capacity ratio at 0° inclination and mass flow rate of hot water at 80 LPH. It is clear from the plot that the maximum effectiveness of heat exchanger occur at 60°C and $C_h/C_c = 2$ in all operating conditions.

III. CONCLUSION

Based on experimental study, this paper presents the effect of mass flow rate of water, inlet temperature of water and inclination angle of heat-pipe on effectiveness of a GAHPHX. From this analysis it has been found that the mass flow of hot water having significant effect on effectiveness of heat exchanger.

In all operating conditions, minimum effectiveness of GAHPHX took place at lowest mass flow rate and inlet temperature of hot water to the evaporator section. For all the values of C_h it has been found that optimum effectiveness of GAHPHX has been obtained when $m_h = 80$ lph $T_{hi} = 60$□C and $\psi = 45$□. The overall optimum experimental effectiveness of the gravity-assisted heat pipe heat exchanger was 18.5 % for all operating conditions.

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