Heat Transfer Characteristics Study on A Water – To – Water Heat Pipe Heat Exchanger using Effectiveness – NTU Method

Engineering

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ABSTRACT   *This paper presents the heat transfer characteristics of a water-to-water heat-pipe heat exchanger (W-W HPHE) experimentally. Methanol (CH3OH) is used as a working fluid. The analysis is based on the effectiveness ($\in$) –NTU (number of transfer units) approach to deduce its heat transfer characteristics. The experiment was carried out with various mass flow rate of water, inlet temperature of water in the evaporator section and heat input (Q) to the heat exchanger. The mass flow rate of water to the evaporator section varied from 30 lph to 60 lph, while in the condenser section it has been varied in the range of 10-60 lph. The mass flow rate of water in the condenser section 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. Several experiments were carried out under different operating conditions by varying the heat input to the heat exchanger from 1 kW to 4 kW. By varying the heat input to the heat exchanger, it is found that the inlet temperature of water to the evaporator section is varying in the range of 50-800C. In this study, the variation of overall effectiveness ($\in$) of W-W HPHE with heat capacity ratio (Ch/Cc) was presented and the effect of mass flow rate of water to the evaporator section and inlet temperature of water to the evaporator section were analyzed. The effect of mass flow rate of hot water to the evaporation section with respect to the overall heat transfer coefficient (U) also determined. It was shown that minimum effectiveness of W-W HPHE took place at Ch = Cc. Therefore equal value of mass flow rate of water in the evaporator and condenser section should be avoided. The optimum effectiveness is obtained when Ch = 2Cc for all heat inputs and mass flow rate of water to the evaporator section.*

INTRODUCTION

Heat exchangers with heat-pipes are smaller than conventional heat exchangers but this can handle high heat fluxes and transport more heat energy. Heat-pipes have made them more attractive for use as heat-pipe heat exchanger due to their special advantages, such as no moving parts, compactness, perfect separation between hot and cold fluid, light weight and high reliability reported by Dunn and Reay [1]. Due to this heat-pipe heat exchangers are widely used in many engineering industries as waste heat recovery systems reported by Amode and Feldman [2].

Expression of effectiveness for single heat pipe and for n rows of a heat pipe heat exchanger was reported by Krishman and Rao [3] and Chaudourne [4]. The effect of number of rows of co-axial heat pipes on thermal performance of heat exchanger is analysed theoretically by Azad and Moztarzadeh [5]. The variation of heat exchanger effectiveness with ratio of cold to hot flow-stream capacity rate for various rows of heat-pipes were analyzed theoretically by Azad and Gibbs [6]. However, most of the work reported earlier concentrated on theoretical studies and few experimental analyses only. Noie [7] investigated the effectiveness of an air-to-air thermosyphon versus the mass flow rate of water to evaporator section and heat inputs, based on ($\in$)-NTU method and compared the results with theoretical results. Hunag and Truei [8] used conductance model to analyse heat pipe heat exchanger performance and compared the predicted results to their experimental data, for which they reported good agreement. But their analysis requires more iterative procedure to a specified accuracy. Lee and Bedrossian [9] used conductance model to analyse the characteristics of counter flow heat exchanger using heat-pipes or two phase closed thermosyphon and compared experimentally. But this analysis also adopted more iterative procedure.

In this paper the thermal performance of a heat exchanger with three heat-pipes arranged in co-axial was investigated experimentally using methanol as working fluid. The effect of pa-

rameters such as mass flow rate of water and heat input to the evaporator section, were being considered in the analysis. An experimental set-up has been developed to allow for monitoring the performance of heat-pipe heat exchanger under various operating conditions.

In this study the ($\in$)-NTU method has been used to predict the performance of water-to-water heat-pipe heat exchanger as it consists of more accuracy and less calculations. This method is a successful alternative for predicting the performance of a heat pipe heat exchanger.

EXPERIMENTAL SETUP

To study the heat transfer characteristics of a water-to-water heat-pipe heat exchanger, an experimental setup was fabricated. Figure.1 depicts the schematic diagram of the experimental set-up. The physical parameters of constructed shell and heat-pipe are shown in Table 1.
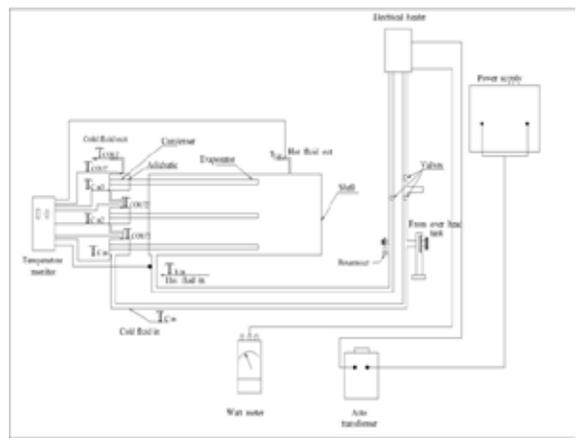

Fig.1: Experimental setup of heat pipe heat exchanger

TABLE-1 The Physical Parameters of the heat pipe heat exchanger

Physical Dimensions of the Shell	0.102 m (diameter) x 1 m (length)
Physical dimensions of each heat pipe	D_o = 0.019 m D_i = 0.017m L = 1m
Heat Pipe Arrangement	Staggered (co-axial) S_L = 0.03 m, S_T = 0.03 m
Total Number of heat – pipes	N = 3
Heat Pipe Material	Copper
Working Fluid	Methanol

It consists of three heat-pipes made up of copper with 1m long, and 19 mm outer diameter and 17 mm inner diameter. The heat-pipe consists of three sections namely evaporator section which is of length 700 mm, adiabatic section of length 150 mm and condenser section of length 150 mm. Methanol is used as working fluid. The evaporator section of heat-pipes are located inside the shell of length 1000 mm and diameter of 102 mm. The details of the constructed shell and heat-pipe and arrangement of tubes are shown in Figure 2.
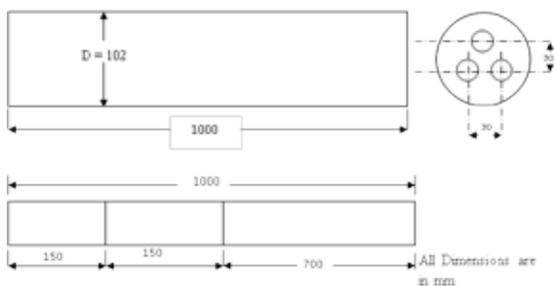

Fig. 2: Schematic of the shell and heat pipe and arrangements of tubes.

The stainless steel wick material were inserted inside the copper tubes of   heat-pipe is shown in figure 3.

Fig. 3: Heat-Pipe with Wick Structure

To measure the temperature, copper constantan thermocouples were provided in the following manner: two for hot water temperature, one for adiabatic temperature and six for cold water temperature. These thermocouples were connected to the digital temperature indicator for measuring the relative temperatures. Rotameters were used to regulate the flow of hot and cold water.

A vacuum pump was used to eliminate any non-condensable gases from the heat-pipe. Finally the heat-pipes were charged with the working fluid to make it ready for the experiment. The

entire length of shell is insulated properly using foam material and aluminium foil to minimize the heat losses to the surrounding.

During the first phase of experiments, the effect of mass flow rate water on the thermal performance of W-W HPHE with constant inlet temperature of hot water was investigated, while in the second phase of experiments the influence of inlet temperature of hot water with constant mass flow rate was studied. Experiments were carried out with increasing heat input into the evaporator section from 1 kW to 4 kW.

3. EXPERIMENTAL EFFECTIVENESS CALCULATION PROCEDURE

The effectiveness is defined as the ratio of actual heat transfer rate of heat exchanger to the maximum possible heat transfer rate between the water streams, considering the heat loss from the heat exchanger to the surroundings is negligible. Therefore,

$$\in = \frac{Q_{actual}}{Q_{max}} \tag{1}$$

The heat capacity rate is defined as the product of mass flow rate and specific heat of the fluid. Therefore,

$$C = \dot{m} c_p \tag{2}$$

If heat capacity rate of cold fluid is minimum i.e. $C_c = C_{min}$ then

$$C_c < C_h$$

$$\in = \frac{T_{c\,out} - T_{c\,in}}{T_{h\,in} - T_{c\,in}} \tag{3}$$

If heat capacity rate of hot fluid is minimum i.e. Ch = Cmin then

$$C_h < C_c$$

$$\in = \frac{T_{h\,in} - T_{h\,out}}{T_{h\,in} - T_{c\,in}} \tag{4}$$

RESULT AND DISCUSSION

The controlled parameters influencing in the thermal performance of water-to-water heat-pipe heat exchanger were working fluid as methanol (CH3OH), diameter of heat-pipe and shell are 19 mm and 102 mm respectively, stainless steel wick structure and material of heat-pipe is copper. The considering variable parameters were, inlet temperature (Th in) of water to the evaporator section (50-80 0C), inlet mass flow rate ($\dot{m}_{h\,in}$) of water to the evaporator section (30-60 lph), inlet mass flow rate ($\dot{m}_{cin}$) of water to the condenser section (10-60 lph) and heat input into the evaporator section (1kW to 4kW).

4.1 Effectiveness of the heat pipe heat exchanger:

A series of test were performed in order to investigate the thermal performance of the heat pipe heat exchanger. For each test, the inlet flow rate of water into the evaporator section was fixed and the mass flow rate of water into the condenser section was varied from 10 lph to 60 lph.

Figures 4 to 7 show the variations of overall effectiveness ($\in$) on heat capacity ratio $(\%)$ for different values of inlet mass flow rate of water in the evaporator section. The heat input into the evaporator varied between 1kW to 4kW. It has been found that the effectiveness increases with increasing the mass flow rate of water to the evaporator section. The overall effectiveness for all values of heat input and mass flow rate of hot water to the evaporator section has a minimum value at Ch = Cc. Hence to get better performance of the heat pipe heat exchanger, it is clearly observed that equal flow rate should be avoided in the condens-
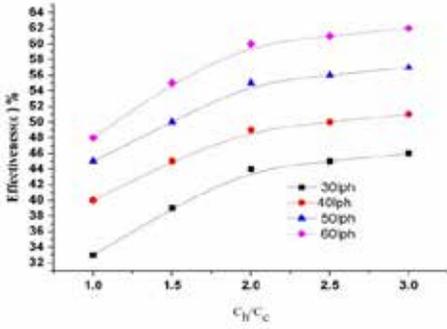
er and evaporator side.

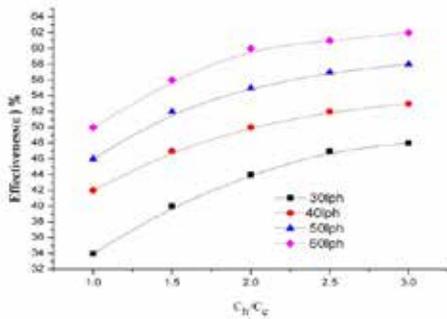**Fig. 4: Variation of overall effectiveness on Ch/Cc at Q = 1kW**

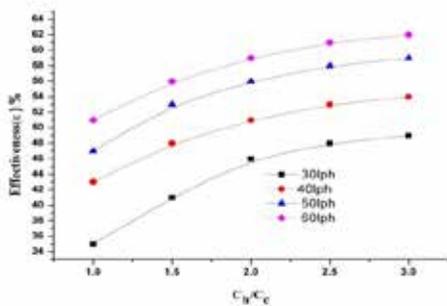**Fig. 5: Variation of overall effectiveness on Ch/Cc at Q = 2kW**

Fig. 6: Variation of overall effectiveness on Ch/Cc at Q = 3kW
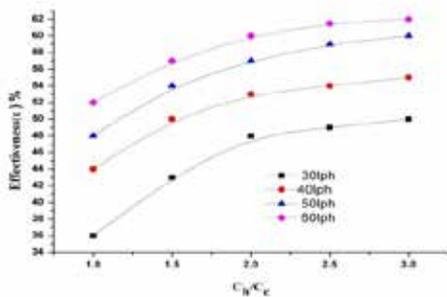

Fig. 7: Variation of overall effectiveness on Ch/Cc at Q = 4 kW

The investigation showed that the thermal performance of the heat-pipe heat exchanger can be increased up to 62% with in-

creasing the mass flow rate of water in the evaporator section. An increase in mass flow rate of hot water from 30 lph to 60 lph at = 2 and Q = 1kW, the effectiveness increased from 42% to 60%.

For various mass flow rate of water, the effect of inlet temperature of water in the evaporator section on overall effectiveness at the maximum heat input (4 kW) has been shown in Figure 8. As it expected, the effectiveness increases with increasing of inlet temperature of water in the evaporator.
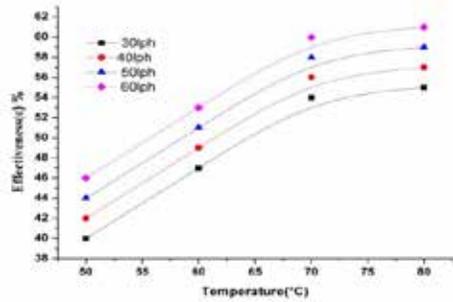

Fig. 8: Overall effectiveness with inlet temperature of water to the evaporator

Figure 9 represents the variation of overall heat transfer coefficient (U) and inlet temperature of hot water in the evaporator section. It is observed that overall heat transfer coefficient increases with increasing inlet temperature and mass flow rate of water to the evaporator.
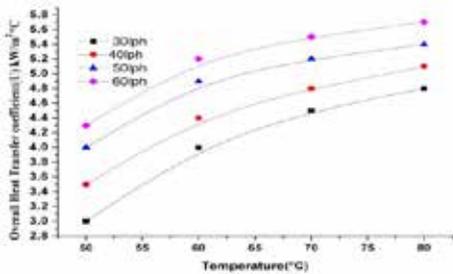

Figure 9: Effect of overall Heat transfer coefficient with Inlet temperature of water to the evaporator

CONCLUSION

Experimentally the effect of inlet temperature and mass flow rate of water in the evaporator on heat transfer characteristics of a heat pipe heat exchanger under normal operating condition was investigated. The hot water flow rate in the evaporator from 30 lph to 60 lph, inlet temperature of water to the evaporator section from 500C to 800C and the heat input into the evaporator section was varied between 1kW and 4 kW. The following conclusions were drawn from the present study.

1. The experimental results showed that in all operating conditions the minimum effectiveness of W-W HPHE took place at Ch = Cc. Therefore equal mass flow rate of water in evaporator and condenser should be avoided.

2. It is found that the optimum effectiveness of W-W HPHE is obtained when Ch = 2Cc. Therefore double the amount of hot water in the evaporator section than cold water in the condenser section should be preferred.

3. The overall experimental effectiveness of the heat pipe heat exchanger was over 35% for each of the conditions of all ex-

periments and reaches up to 62% with increasing of hot water flow rate to the evaporator section.

4. For constant mass flow rate of water the effectiveness of the heat pipe heat exchanger increased with increasing of hot water temperature of evaporator section.

5. The experimental results showed that the increasing of overall heat transfer coefficient increased with increase in inlet temperature of hot water to the evaporator section.

6. It is found that the optimum value of experimental overall effectiveness for 1 kW heat input is 59%, 2 kW is 60%, 3kW is 61% and 4kW is 62%. This shows that the effect of heat input from 1 kW to 4kW creates only a slight variation in overall effectiveness for various mass flow rate of water.

7. Effectiveness of heat-pipe heat exchanger is directly proportional to the mass flow rate and temperature of water.

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