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Thermal Behaviour Analysis of Baffled Multi Heat pipe Induced Heat Exchanger

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Abstract*: Thermal behaviour of a multi-heat pipe induced in compact heat exchanger has been analysed with the influence of baffles. The heat transfer fluid and working fluid used for the investigation are water and acetone. In this investigation, baffles are used to improve performance. In this research, different parameters like temperature range of hot and cold water were 50ºC, 60ºC, 70ºC and 32ºC throughout the analysis. The mass flow rates of hot and cold water ranges as 40 LPH to 120 LPH and 20 LPH to 60 LPH with an increase of 20 LPH and 10 LPH. The result shows that for an optimum revealed conditions of an angle of 0º with 60ºC and 100 LPH there is an increase in effectiveness occurs as 82.05% while comparing to without baffled conditions.

***Keywords* : Heat pipe, Heat exchanger, Mass flow rate, Effectiveness, Baffles.**

I. INTRODUCTION

In several processing plant, heat recovery systems, space applications heat transfer performance in widely achieved using heat pipe. The performance of the heat pipe is analysed with different working fluids and fill ratios for space applications [1-2]. The heat pipe is analysed with gravitational effect shows superior in results with flat heat pipe [3-4]. Joudi and Witwit [5] analysed the wickless heat pipe with tilt angle effect, which shows improvement in performance. Hossain *et al*. [6] analysed the performance which depends upon various angles and different heat input does not depend on coolant flow rate. The study shows that for the similar input of heat and angle with acetone for micro heat pipe shows improved performance. Influence of working fluid for heat pipe was studied with several tested were stated in [7 -8]. Luis Diego Fonseca *et al*. [9] reveals with varying the working fluid with different fill ratios within 20% to 90%, the optimal performance at a fluid ratio were 69.68%. Shabgard *et al.* [10] applied a model on thermal network to characterize the thermal study in a high temperature latent heat thermal energy storage system.

The heat pipe with different materials and tilt angles were analysed with the wick of the heat pipe were reported [11-12]. Heat pipe with various working fluids and filling ratios were investigated for various applications revealed in [13–14]. Vivek [15] fabricated a heat pipe using ammonia and methanol. The investigation were made on satellite applications and performance is analysed.

In the work of several researchers, their research was done with minimum geometrical constraints on heat pipe heat exchanger. The constraints includes were geometrical parameters, working fluids, fill ratios and heat transfer fluids in heat pipe. To rectify the above-stated constraints in this research, the multi-heat pipes are designed and analysed with a shell assisted heat exchanger. Influence of triangular baffles were analysed and performance are studied. The inlet parameters of the heat transfer fluids are measured with various mass flow rates and temperature inputs.

II. FABRICATION AND WORKING PROCESS

A. Fabrication of setup

To study the heat transfer characteristics of a MHPIHE is designed by without and with baffles and given in Figure 1&2. In this work, MHPIHE is fabricated with three heat pipe in which copper as a heat pipe material and Galvanized Iron as shell material for heat exchanger with a diameter of 102 mm and length of 850mm at evaporator zone. Heat pipe inner and outer diameter as 19 and 17 mm and total length as 1000mm. Condenser diameter of 35mm, length as 150mm and without adiabatic length. Nine numbers of triangular baffles were used with the size of 60 x 60 x 10mm were shown in figure 2a.

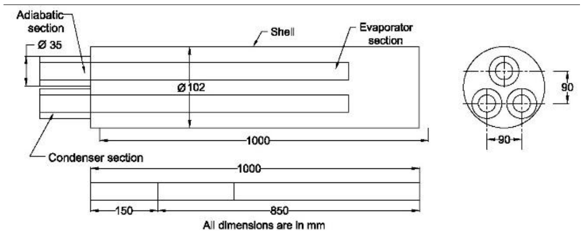

Fig 1. Schematic diagram of a Multi Heat-pipe Heat exchanger without Baffles

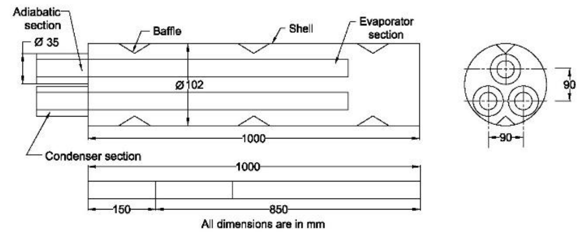

Fig 2. Schematic diagram of a Multi Heat-pipe Heat exchanger with Baffles

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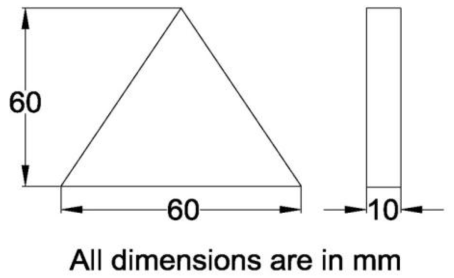

Fig 2 a. Schematic diagram of a Triangular Baffles

The two water tanks, for hot and cold water with a capacity of five liters. Which contains one coiled immersion electric heater with two Kilowatts and a temperature controller to regulate the temperatures of hot water. The rotameters with a range of three Liter per minute are used to regulate the flow rates of both hot and cold water. Two thermocouples observe the external surface temperatures of the evaporator and condenser regions to measure the temperature interface with the environment. The experimental setup is designed for both without and with baffles are given in figure 3&4.

Table 1. Thermo-physical properties of Acetone

Properties	Acetone
Boiling point	56.08°C
Melting point	-94.9 °C
Latent heat of evaporation (λ)	534 kJ/kg
Density of liquid (ρ_l)	784.5kg/m³

B. Working Process

At primary test, heat pipes are induced in the heat exchanger without baffles and the secondary test is carried out with nine numbers of triangular baffles. In both the test Acetone is used as working fluid and charged with fill ratios of one hundred percentage, the thermo-physical properties of working fluid are shown in Table 1. The heat transfer fluid is chosen as water for the analysis.

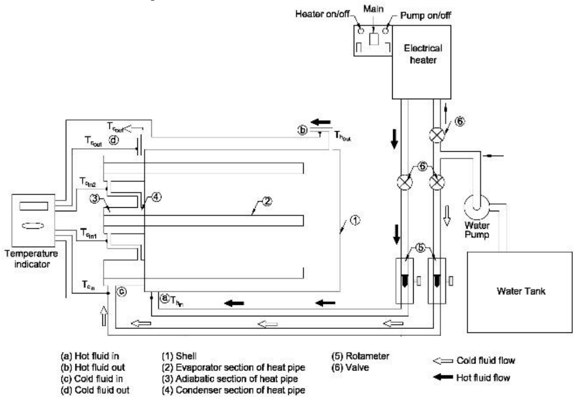

Fig 3. Schematic diagram of an Experimental setup of MHPIHE without Baffles

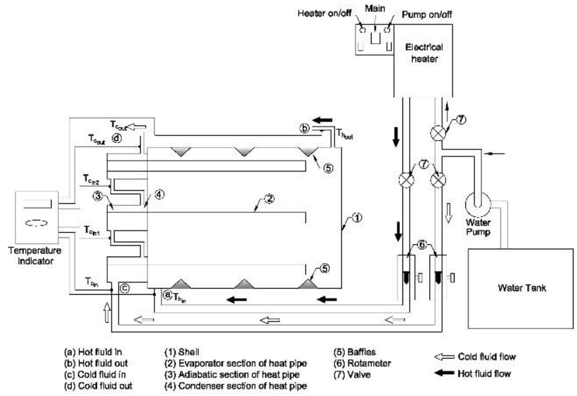

Fig 4. Schematic diagram of an Experimental setup of MHPIHE with Triangular Baffles

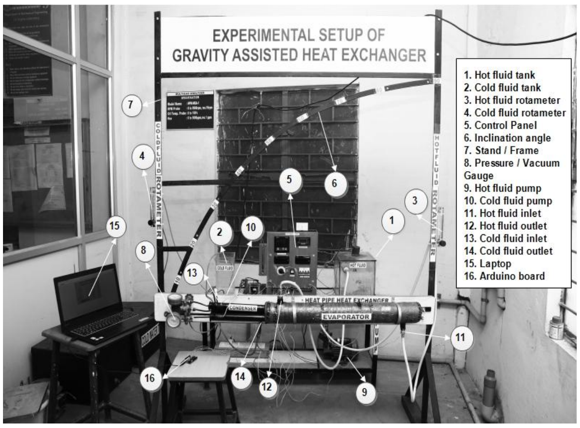

Fig 5. Fabricated experimental setup of the Multi-Heat pipe heat exchanger

At primary stage, MHPIHE is kept at a 0º tilt angle (horizontal axis) and the WF as acetone and water as HTF as shown in figure 5. In initial stage MHPIHE is fabricated by without baffles. The Hot water mass flow rate and inlet temperature are fixed as 40 LPH and 50 ºC. The mass flow rate of cold water and inlet temperature as 20 LPH and 32 ºC as the ambient temperature condition for the analysis. At the evaporator zone of a heat exchanger, hot water exchanges the heat to the acetone in the heat pipe. Thus WF absorbs the heat and latent heat of phase change have occurred. The hot and cold zones mass flow rates are given in LPH such as 60, 80, 100, 120 and 30, 40, 50, 60. Temperatures at an inlet of hot and cold zones are 60 ºC, 70 ºC and 32 ºC. The above similar conditions are repeated for second test rig with the influence of triangular baffles and experimentation is done.

III RESULTS AND DISCUSSION

To investigate the fabricated MHPIHE. The figure 6 predicts the mass flow rate of hot water on effectiveness for both without and with baffles condition. This graph predicts that by using water as HTF and Acetone as WF for the first test is carried out by without baffles condition. The inlet temperatures of the hot water as 50°C to 70°C and for varying m_{hi} from 40 LPH to 120 LPH and ψ as 0°. The maximum effectiveness observed is 39% at 100 LPH, ψ as 0° and 60°C. When the mass flow rate increases by 120 LPH the achieved effectiveness is 32% for same condition. In the second test, the triangular baffle are used with similar stated condition. In 100 LPH the observed effectiveness is

71% for 0^o. At 120 LPH the achieved effectiveness is 57% for 0^o. In this investigation also similar trends of graphs are predicted for 100 LPH and 120 LPH. This shows that both tests of without and with baffles conditions the 100 LPH, 60°C shows superior results than other temperature and mass flow rate. Similarly while improving the m_{hi} from 100 LPH to 120 LPH the same decrement in effectiveness is achieved for both test rigs. This decrement in effectiveness is due to the minimum heat absorption and release capability of the hot and cold fluid at both zones of the heat pipe. The influence of triangular baffles shows increase in effectiveness due to the increase in surface area inside the shell. This increase in surface area leads to the increase in contact area of the heat transfer fluid with the working fluid inside the heat pipe. Thus maximum phase transformation is accrued in the WF. In this analysis above 60°C there is maximum heat evolved in the shell so, no phase transformation is occurred inside the heat pipe at the evaporator zone so performance gets reduced when the temperature of HTF increases above the optimum condition. This leads to the improvement in effectiveness is calculated by the equation (1)

$$\in = \frac{T_{c_o} - T_{c_i}}{T_{h_i} - T_{c_i}} \quad (1)$$

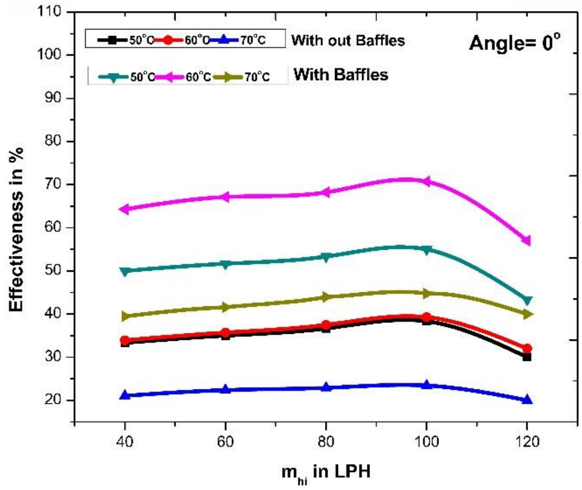

Fig 6 Mass flow rate of hot fluid on Effectiveness

Figure 7 inferred the mass flow rate on heat transfer rate for without and with baffles conditions. The conditions for the observation are T_{hi} as 50°C to 70°C, m_{hi} ranges from 40LPH to 120 LPH and the inclination angle of 0^o. In the first test, Acetone is used as WF and Water as HTF for without baffle condition. The heat transfer rate (Q) shows increment for 40 LPH to 100 LPH at the range of 209W to 576W for ψ as 0^o and 60°C. Similarly, for 120 LPH, the Q value is 544W for ψ as 0^o and 60°C. This plots reveals that 100 LPH shows highest heat transfer rate in the system. In the second test, for with triangular baffle condition. The similar type of trends are achieved. The heat transfer rate (Q) shows increment for 40 LPH to 100 LPH at the range of 419W to 1151W for ψ as 0^o and 60°C. Similarly, for 120 LPH, the Q value is 1116W for ψ as 0^o and 60°C. This observation also reveals the same results at 100 LPH maximum (Q) values are achieved than 120 LPH. In both the investigations at 100 LPH, ψ as 0^o and 60°C has highest results, but by comparing both the conditions of with and without baffles, with baffles shows superior result. This increase in heat transfer rate is achieved by the maximum absorption of heat energy by the cold fluid at the condenser zone. When the hot fluid inlet temperature at 60°C there is maximum heat transfer happens between HTF and working fluids at the evaporator zone. Hence, the heat transfer rate is calculated using below formula (2) and (3)

$$Q_h = \dot{m}_h \, c_{ph}(T_{hi} - T_{ho}) \quad (2)$$

$$Q_c = \dot{m}_c \, c_{pc}(T_{co} - T_{ci}) \quad (3)$$

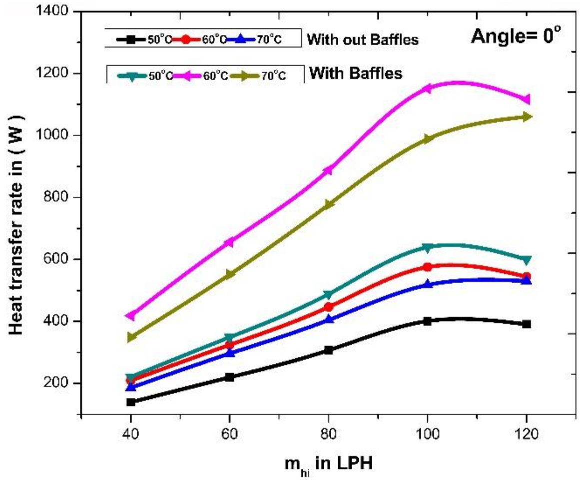

Fig 7 Mass flow rate on Heat transfer rate

Figure 8 shows that mass flow rate on heat transfer coefficient with water as HTF for both without and with baffles conditions. The conditions for observation are T_{hi} as 50°C to 70°C, m_{hi} from 40LPH to 120 LPH, inclination angle of 0^o and without baffle condition. The observed heat transfer coefficient (h) at 40 LPH to 100 LPH for ψ as 0^o and 60°C is 320 W/m^2 °C to 989 W/m^2 °C. At 120 LPH, ψ as 0^o and 60°C the observed value is 899 W/m^2 °C. In with triangular baffles the similar value of trends is observed. At 40 LPH to 100 LPH the observed (h) value ranges as 845 W/m^2 °C to 2594 W/m^2 °C for ψ as 0^o and 60°C. Similarly for 120 LPH the observed (h) as 2105 W/m^2 °C for ψ as 0^o and 60°C. In both with and without baffles shows similar trends in the investigation at 100 LPH highest value of (h) is achieved than 120 LPH. While considering the both tests with baffles shows highest heat transfer coefficient. Using the below equation the convective heat transfer coefficient of cold fluid on MHPIHE is analysed by the equation (4)

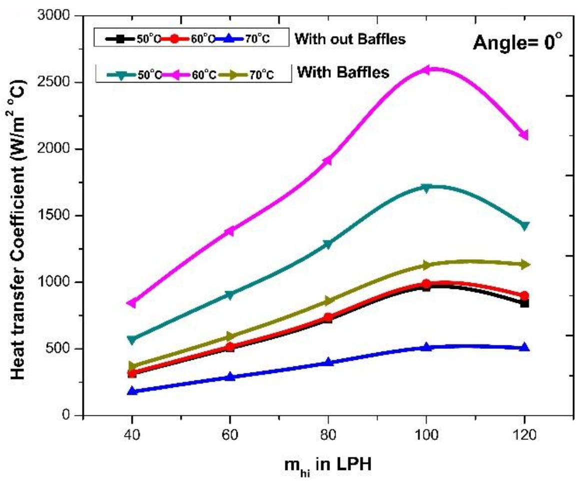

Fig 8 Mass flow rate on heat transfer coefficient

$$h = \frac{Qc}{A * (\Delta T)_{lm}} \qquad (4)$$

In comparing the both test rigs. This predicts the higher heat transfer coefficient at hot fluid for 100 LPH and 60°C with the 0° inclination angle for acetone as WF. This is due to the higher release of sensible heat to the cold fluid, by the working fluids which lead to maximum heat transfer along the system.

IV CONCLUSION

- It is inferred that optimum conditions observed from the investigation are hot fluid mass flow rates (m_{hi}) as 100 LPH and cold fluid (m_{ci}) as 50 LPH, hot fluid at an inlet temperature (T_{hi}) as 60ºC, the inclination angle (ψ) as 0º (Horizontal axis) for with triangular baffles.
- While comparing both conditions of with and without baffles for above-revealed conditions, with triangular baffles shows maximum results when comparing to without baffles. There is an increment in results of 82.05% for effectiveness, 98.92% for heat transfer rate, 162.28% for heat transfer coefficient are achieved.
- This investigation reveals that Multi heat pipe induced in the heat exchanger with triangular baffles shows superior in results, while comparing to without baffles in all the observed conditions of the investigation.

APPENDIX

Nomenclature

A - Area of heat transfer (m^2)
C - Heat capacity rate (kW/K)
C_p - Specific heat of the fluid (kJ/ kg K)
D - Diameter (m)
h - Heat transfer coefficient (W/m^2 °C)
L - Length (mm)
m - Mass flow rate of fluid (LPH)
Q - Heat transfer rate (W)

Abbreviations

MHPIHE - Multi Heat Pipe Induced Heat exchanger
HTF - Heat Transfer Fluid
LPM - Liter Per Minute
WF - Working Fluid

Greek Letters

$(\Delta T)_{lm}$ - Log mean temperature difference, (°C)
∈ - Effectiveness, (%)
ψ - Tilt angle / Inclination angle, (◦)

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