Heat transfer Augmentation of Gravity Assisted Multi Heat pipe Induced Heat Exchanger

P. Ram Kumar, M. Sivasu bramanian, P.RajeshKanna, P.Raveendiran

Abstract: ***Heat transfer augmentation of a heat exchanger with a multi-heat pipe has been investigated with the influence of gravity assistance. The working fluids used to analyse the performance are methanol and acetone. Water is used as a heat transfer fluid. In which, the analysis is carried out with the gravity-assisted angles of 0º, 45º and 90º. In this work, various parameters such as temperatures of hot water ranges 50ºC, 60ºC, 70ºC, and cold water temperature are observed as 32.5ºC throughout the investigation. Hot water mass flow rates as 40 LPH to 120 LPH with an increase of 20 LPH, cold water as 20 LPH to 60 LPH with an increase of 10 LPH. The result reveals that increase in effectiveness occurs at an angle of 0º for Acetone with 60ºC and 100 LPH is 71.5% of an increase in effectiveness is achieved than methanol for optimum said conditions.***

Keywords **:** ***Heat pipe, heat exchanger, Gravity-assisted angles, Mass flow rate, Effectiveness.***

I. INTRODUCTION

In many processing plant, heat recovery systems, space applications heat transfer performance in widely achieved using heat pipe. The gravitational influence shows improvement in performance was analysed by segments of the heat pipe [1 -2]. The heat pipe used for various applications was analysed with numerical and experimental studies were stated in [3-4]. Esarte and Domiguez [5] experimented the flat heat pipes working against gravitational influence. In which thermal resistance was less and the coefficient of performance have twice the value than theoretical prediction. Luis Diego Fonseca *et al.* [6] analysis reveals with varying the working fluid with different fill ratios within 20% to 90%, the optimal thermal performance at a fluid ratio was 69.68%.

Shabgard *et al.* [7] applied a model on a thermal network to characterize the thermal behaviour in a high-temperature latent heat thermal energy storage system. Hossain *et al.* [8] observed result shows that performance depends upon different tilt angles and various heat input does not depend on the coolant flow rate. The study shows that for the similar input of heat and tilt angle with acetone for a micro heat pipe shows improved performance.

Influence of nanofluids as working fluid for heat pipe was studied with several tested were stated in [9 -10]. 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]. Işık *et al* [15] fabricated a heat pipe using ammonia. The investigation was made on space applications and burst test in the heat pipe.

In the research by vast investigators, 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 investigation, the multi-heat pipes are designed and analysed with a shell assisted heat exchanger under the influence of gravitational effect. In further analysis is carried out with different tilt angles and working fluids. 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 GAMHPIHE, an experimental setup is designed and given in Figure 1. In this work, GAMHPIHE 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 700mm at evaporator zone. Heat pipe inner and outer diameter as 19 and 17 mm and total length as 1000mm. Condenser diameter as 35mm and length of 200mm and adiabatic length of 100 mm.

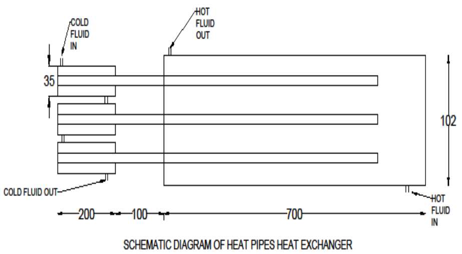

Figure 1. Schematic diagram of a Multi Heat-pipe Heat exchanger

The two water tanks, for hot and cold water with a capacity of five liters.

Revised Manuscript Received on December 5, 2019

* Correspondence Author

P. RamKumar *, Department of Mechanical Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, Virudhunagar, 626126, Tamil Nadu, India. Email: rkmailmech@gmail.com

M.Sivasubramanian, Department of Automobile Engineering, Kalasalingam Academy of Research and Education, Krishnankoil, Virudhunagar, 626126, Tamil Nadu, India. Email: m.sivasubramanian@klu.ac.in

P.RajeshKanna, Department of Mechanical Engineering, Al Ghurair University, Dubai, United Arab Emirates. Email: prkanna@gmail.com

P.Raveendiran, Department of Mechanical Engineering, Alagappa Chettiar Government College of Engineering and Technology, Alagappa University, Karaikudi – 630003, Tamil Nadu, India. Email: praveendiran@gmail.com

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.

Table 1. Thermo-physical properties of working fluids

Properties	Methanol	Acetone
Boiling point	64^oC	56.08^oC
Melting point	$-97.9\ ^oC$	$-94.9\ ^oC$
Latent heat of evaporation (λ)	1055 kJ/kg	534 kJ/kg
Density of liquid (ρ_l)	746.2 kg/m^3	784.5 kg/m^3

B. Working Process

At the primary test, heat pipes are filled with methanol and the second test is made with acetone as working fluids. Methanol and Acetone are charged with fill ratios of one hundred percent, the thermophysical properties of working fluids are shown in Table 1. The heat transfer fluid is chosen as water for the analysis.

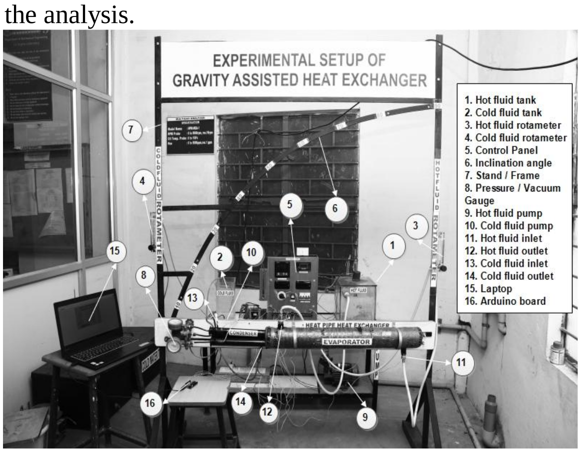

Fig 2 Experimental setup of the Multi-Heat pipe heat exchanger

At the primary stage, GAMHPIHE is kept at a 0º tilt angle (horizontal axis) and the WF as methanol and water as HTF as shown in figure 2. 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 32.5 ºC as the ambient temperature condition for the analysis. At the evaporator zone of a heat exchanger, hot water exchanges the heat to the methanol in the heat pipe. Thus WF absorbs the heat and latent heat of phase change have occurred. The investigation is further carried out with other tilt angles of 45º and 90º. 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 32.5 ºC. The above conditions are repeated for Acetone as WF and investigation is carried out for similar conditions.

III. RESULTS AND DISCUSSION

To investigate the fabricated GAMHPIHE, the analysis is carried out by the above-stated parameters, Figure 3 predicts the mass flow rate of hot water on effectiveness. This graph predicts that by using water as HTF and methanol as WF for the first test. The inlet temperature of hot water as 60^oC and for varying m_{hi} from 40 LPH to 120 LPH and ψ as 0^o, 45^o and 90^o. The maximum effectiveness observed is 34.5% at 100 LPH and ψ as 0^o than other tilt angles and mass flow rates of hot water. When the mass flow rate increases by 120 LPH the achieved effectiveness is 25.8% for 0^o. In the second test, WF is chosen as Acetone and HTF as water. The above-stated conditions are fixed, at 100 LPH the observed effectiveness is 59.27% for 0^o. At 120 LPH the achieved effectiveness is 45.45% for 0^o. In this investigation also similar trends of graphs are predicted for 100 LPH and 120 LPH. While comparing the tilt angles also 0^o and 90^o show similar ranges of effectiveness than 45^o. In both working fluids, the 45^o shows inferior values than other tilt angles, this is due to the effect of gravitational there is a formation of a liquid film at vapour core region, which reduces the phase transformation of working fluids at evaporator region inside the heat pipe, this reduces the heat absorption capacity. Similarly while improving the m_{hi} from 100 LPH to 120 LPH the same decrement in effectiveness is achieved for both working fluids. 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. This graph reveals that acetone has maximum effectiveness than methanol at a tilt angle of 0^o, T_{hi} as 60^oC and m_{hi} as 100 LPH. Therefore, the effectiveness is calculated by equation (1)

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

Figure 4 depicts the inclination angle on effectiveness to the temperature of the hot fluid inlet with water as HTF and methanol as WF, the observed maximum mass flow rate of hot water is 100 LPH for various inclination angles (ψ) as 0^o, 45^o and 90^o. The observation stated that the increment of effectiveness is attained from 30.85% to 34.54% for ψ as 0^o for T_{hi} of 50^oC to 60^oC. Similarly, for T_{hi} as 60^oC to 70^oC the effectiveness starts reducing from 34.54 % to 19.73 % for ψ as 0^o. In the above observation, it reveals that at 100 LPH at a tilt angle of 0^o maximum effectiveness have been achieved while comparing with other tilt angles. While comparing the temperatures of hot water mass flow rate at 60^oC shows increment in effectiveness than 50^oC and 70^oC. Similarly for Acetone also same trends of graphs are observed at ψ as 0^o for T_{hi} as 60^oC the observed effectiveness is 59.27 %. At inclination angle of 45^o and 90^o for temperature increment, there is increasing in effectiveness is observed but while comparing with 0^o effectiveness of the system gets reduced. This graph also clearly reveals that at 0^o, 60^oC and 100 LPH the acetone shows superior results than methanol.

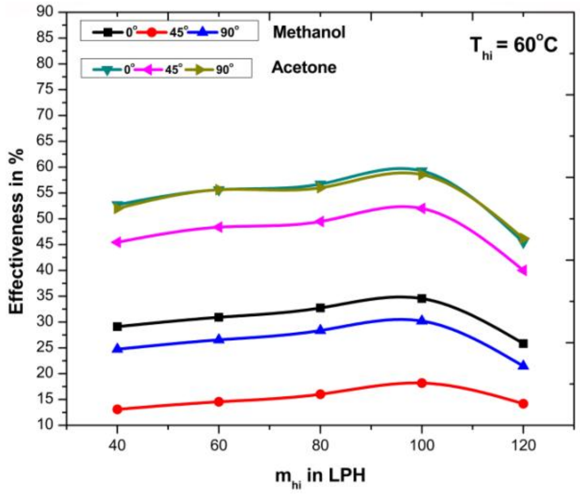

Fig 3 Mass flow rate of hot fluid on Effectiveness

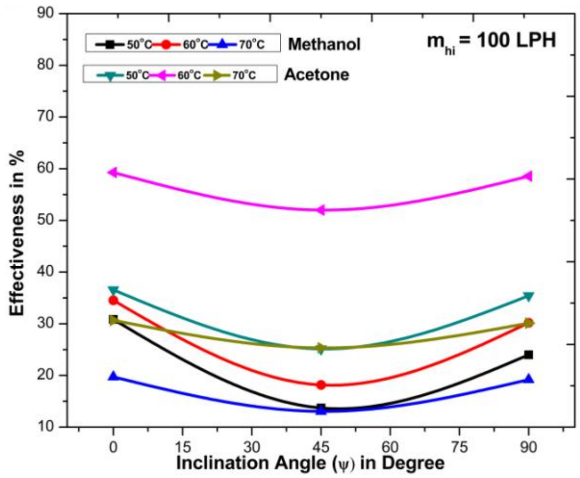

Fig 4 Inclination angle on Effectiveness

Figure 5 inferred the mass flow rate on the heat transfer rate. The conditions for the observation are T_{hi} as 60ºC, m_{hi} ranges from 40LPH to 120 LPH and varying the inclination angles from 0°, 45° and 90°. In the first test, methanol is used as WF. The heat transfer rate (Q) shows increment for 40 LPH to 100 LPH at the range of 186W to 552W for ψ as 0°. Similarly, for 120 LPH, the Q value is 495W for ψ as 0°. This plot reveals that 100 LPH shows the highest heat transfer rate in the system. In the second test with acetone as WF. The similar type of trends is achieved. The heat transfer rate (Q) shows increment for 40 LPH to 100 LPH at the range of 337W to 948W for ψ as 0°. Similarly, for 120 LPH, the Q value is 872W for ψ as 0°. 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 and ψ as 0° has highest results, but by comparing both the working fluids acetone shows superior heat transfer rate than methanol. 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 60ºC there is maximum heat transfer happens between HTF and working fluids at the evaporator zone. This decrease in trends shows lack of heat transfer at the 45° with a minimum release of sensible heat and effect of friction occurs due to gravitational effect at condenser region of the heat pipe. Hence, the heat transfer rate is calculated using the below formula (2) and (3)

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

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

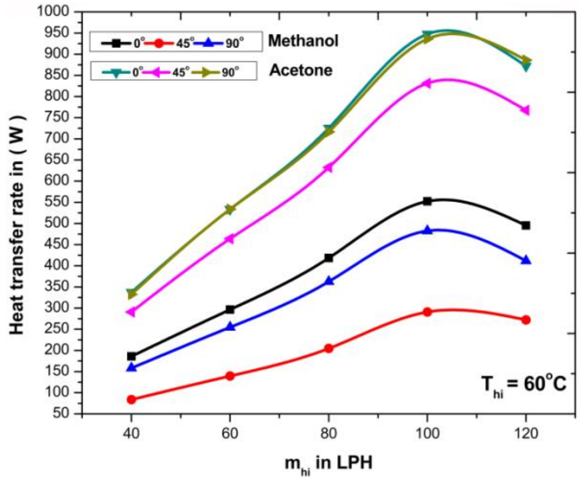

Fig 5 Mass flow rate on Heat transfer rate

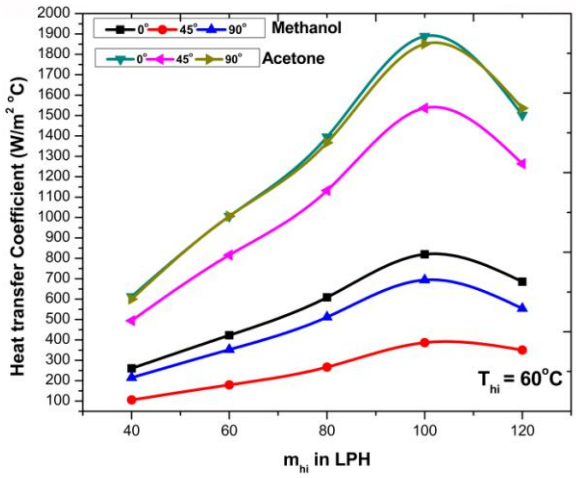

Fig 6 Mass flow rate on heat transfer coefficient

Figure 6 shows that mass flow rate on the heat transfer coefficient with water as HTF. The conditions for observation are T_{hi} as 60ºC, m_{hi} from 40LPH to 120 LPH and varying inclination angle from 0°, 45° and 90°. The observed heat transfer coefficient (h) at 40 LPH to 100 LPH for ψ as 0° is 260.37 W/m² ºC to 819.41 W/m² ºC. At 120 LPH, ψ as 0° the observed value is 685.60 W/m² ºC. In Acetone as WF the similar value of trends is observed. At 40 LPH to 100 LPH the observed (h) value ranges as 613.11 W/m² ºC to 1888.67 W/m² ºC for ψ as 0°. Similarly for 120 LPH the observed (h) as 1508.28 W/m² ºC for ψ as 0°. This both working fluid shows similar trends in the investigation at 100 LPH highest value of (h) is achieved than 120 LPH. While considering the tilt angles the horizontal axis ψ as 0° possess maximum heat transfer coefficient than ψ as 45° and 90°. Using the below equation the convective heat transfer coefficient of cold fluid on GAMHPIHE is analysed by the equation (4)

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

In comparing the 0^o and 90^o the similar range of values are achieved than at 45^o. This predicts the higher heat transfer coefficient at hot fluid for 100 LPH and 60°C with the 0^o 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 with 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 60°C, the inclination angle (ψ) as 0^o (Horizontal axis).
- While comparing both working fluids for above-revealed conditions, acetone shows maximum results when comparing with methanol. There is an increment in results of 71.57% for effectiveness, 72% for heat transfer rate, 130.49% for heat transfer coefficient are achieved.
- This investigation reveals that Multi heat pipe induced in the heat exchanger with acetone shows superior in results while comparing with methanol 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 ($W/m^2\,^oC$)
L - Length (mm)
m - Mass flow rate of fluid (LPH)
Q - Heat transfer rate (W)

Abbreviations

GAMHPIHE - Gravity Assisted 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)
$\in$ - Effectiveness, (%)
ψ - Tilt angle / Inclination angle, (◦)

REFERENCES

[1] Alicetin Gurses, Cannistrano. C, "The inclination effect on the performance of water-filled heat pipes," Renewable Energy, 1991, 1, pp. 667-674
[2] Khalid Joudi. A, Witwit. A. M, "Improvements of gravity assisted wickless heat pipes," Energy Conversion and Management, 2000, 41, pp. 2041-2061
[3] Didi Zhang, Gang Li, Yuging Liu, Xialiang Tian, "Simulation and experimental studies of R134a flow condensation in a pump assisted separate heat pipe," International Journal of heat and mass transfer, 2018, 126, pp. 1020-1030
[4] Lydia Wermer. R, Martin Ward. J, Justin Simpson. D, Robert Zimmerman. A, James Stewart. A, "A high capacity self priming counter gravity heat pipe," International Journal of Heat and Mass Transfer, 2018, 125, pp. 1369-1378
[5] Esarte. J, Domiguez. M, "Experimental analysis of a flat heat-pipe working against gravity," Applied Thermal Engineering, 2003, 23, pp. 1619-1627
[6] Luis Diego Fonseca, John, Franklin Miller, "Result of a three evaporator in cryogenic helium heat pipe," International Journal of Heat and Mass Transfer, 2018, 120, pp. 1275-1286
[7] Shabgard. H, Bergman. T.L, Shariti. N, Faghri. A, "High temperature latent heat thermal energy storage using heat pipes," International Journal of Heat and Mass Transfer, 2010, 53, pp. 2979-2988
[8] Hossain. R.A, M.A.K. Chowdhuri, Feroz. C.M, "Design fabrication and experimental study of heat transfer characteristics of a Micro Heat Pipe," Jordan Journal of Mechanical and Industrial Engineering, 2010, 4, pp. 531-542
[9] Kempers. R, Ewing. D, Ching. C. Y, "Effect of number of mesh layers and fluid loading on the performance of screen mesh wicked heat pipes," Applied Thermal Engineering, 2006, 26, pp. 89-595
[10] Shafai. M, Blanoco. V, Vafai. K, and Manco. O, "An investigation of the thermal performance of cylindrical heat pipes using nanofluid," International Journal of Heat and Mass Transfer, 2010, 53, pp. 376-383
[11] Said Salem. A, Bilal Akash. A, "Experimental performance of a heat pipe," International Communication of Heat and Mass Transfer, 1999, 26 (5), pp. 679-684
[12] Pis mennyi. E.N, Khayrnasov. S.M, Rassamakin. B.M, "Heat transfer in evaporation zone of aluminium grooved heat pipes," International journal of Heat and Mass Transfer, 2018, 127, pp. 80-88
[13] Durga Bastakoti, Hongna Zhang, WeihuaCai, Fengchen Li, "An experimental investigation of thermal performance of pulsating heat pipe with alcohols and surfactant solutions," International Journal of Heat and Mass Transfer, 2018, 117, pp. 1032–1040
[14] Vivek Patel. K, "An efficient optimization and comparative analysis of ammonia and methanol heat pipe for satellite application," Energy conversion and Management, 2018, 165, pp. 382–395
[15] Işık. H.G, Ömür. C, Uygur. A.B, Horuz. I, "A novel burst test approach for the qualification of heat pipes developed for space applications," International Journal of Pressure Vessels and Piping, 2018, 165, pp. 241–248

AUTHORS PROFILE

Mr. P.Ramkumar, Assistant Professor in Mechanical Engineering at Kalasalingam University. I have completed B.E (Mechanical Engineering), M.E (Thermal Power Engineering), pursuing Ph.D. (Thermal Engineering) having five years of teaching experience for U.G and P.G students. I am life time member of Indian Society of Heat and Mass Transfer (ISHMT – IIT Madras). I have published two papers in International journal, three papers published in International conference and four papers in National conference. I am doing my research in the field of heat pipe and compact heat exchanger.

Dr. M. Sivasubramanian, Associate Professor in Automobile Engineering at Kalasalingam University. I have completed Ph.D in thermal engineering, I am having twenty years of teaching experience. I am life time member of Indian Society of Heat and Mass Transfer (ISHMT – IIT Madras), MISTE, SAE. Seven papers in International journal and twenty five papers in International / National conference. Research area in the fluid flow.

Dr. P. Rajesh Kanna, Professor in Mechanical Engineering at Al Ghurair University, Dubai, United Arab Emirates. I have completed in Ph.D in IIT – Guwahati. Post Doc at National Taiwan University of Science and Technology, Department of Mechanical Engineering, CFD, Taiwan, Taipei. Research expert in experimentation and numerical analysis in heat transfer, fluid mechanics, CFD. His h-index is 16, i-10-index is 21, and Citation Statistics is 611.

Dr. P. Raveendiran, Associate Professor at Alagappa Chettiar Government College of Engineering and Technology, Alagappa University, Karaikudi. Ph.D has been completed in Annamalai University. I have published Eight International journal, one national journal, and two national / international conferences. One book published in heat and mass transfer. I am having teaching experience of seventeen years. I am expertise in the field of Heat pipe, heat exchanger.