International Journal of Engineering Trends and Technology Volume 69 Issue 6, 43-49, June 2021
ISSN: 2231 – 5381 /doi:10.14445/22315381/IJETT-V69I6P207 © 2021 Seventh Sense Research Group®

Experimental Investigation of Effective Adiabatic Length As A Heat Pipe Heat Exchanger

S. Prathiban[#1], B. Sivaraman[*2]

[#]Research Scholar & *Professor, Department of Mechanical Engineering, Annamalai University, Tamilnadu – 608002, India

[1]srprathiban88@gmail.com, [2]sivgee@gmail.com

Abstract – *This experimental work analyzed the effect caused by factors such as adiabatic length, inclination angle, hot and cold-water mass flow rate, and heat input given to the heat pipe heat exchanger on its thermal resistance. The working fluid used in the heat pipe is a hybrid nanofluid. The hybrid nanofluid is prepared by blending aluminum and titanium oxide (0.2% concentration) nanofluid in the volume ratio of 70:30 with water as base fluid. Three adiabatic lengths (0 mm, 100 mm, and 200 mm) and four different inclination angles (0°, 15°, 30°, and 45°) are taken for the investigation. The study is carried out for various mass flow rates of hot water such as 0.8, 0.6, 0.4, and 0.2 liters per minute across the evaporator segment with heat inputs of 40, 60, and 80 Watts. The cold-water mass flow rate (M_c) is maintained at 50% of the hot water mass flow rate (M_h) for all the test conditions. The experimental research findings prove that an increase in M_h increases the thermal resistance of the heat pipe heat exchanger. It is also found from the investigation that the heat pipe heat exchanger shows higher thermal resistance for an adiabatic length of 200 mm with 30° inclination and 80 W heat input at all the hot water mass flow rates.*

Keywords: *Hybrid Nanofluids; Heat pipe; Thermal Resistance; wick structure*

Nomenclature:

C	-	Heat capacity rate, kJ/kg K
Q	-	Heat Input, W
Ds	-	Shell Diameter (mm)
D	-	Pipe Diameter (mm)
L	-	Heat pipe tube length (mm)
Ls	-	Shell length (mm)
M	-	Mass flow rate, lpm
lpm	-	litre per minute
ΔT	-	Difference in temperature, °C
N	-	Total number of heat pipes
T	-	Temperature, °C

SUBSCRIPTS

C	-	Cold water
H	-	Hot water
P	-	Pressure

I. INTRODUCTION

Many activities in everyday life depend heavily on energy. The supply of energy influences the quality and even the substance of life. Hence, energy is an important phenomenon required for every aspect of the present world. The usage and demand for energy are increasing steeply every year due to the increase in population growth rate and their usage of modernized appliances or technologies, which make their day-to-day living easier and sophisticated. Also, the energy resources are depleting at a faster rate, the engineers and researchers around the world are working to find a way to utilize any kind of energy most efficiently, especially in heat transfer applications. Since heat is low-grade energy, using it most efficiently and effectively is quite a big challenge for the researchers, scientists, and engineers who are all working in heat transfer applications. One such application is a heat pipe, which is designed for transmitting heat over a long distance [1]. A heat Pipe (HP) is a device that can transfer a large volume of heat in a limited amount of space with a small temperature difference over a long period, also reduces system moisture. The heat pipe contains working fluids that act as a heat transfer medium to transfer heat between the evaporator and condenser unit. The conventionally used fluids are n-butanol, graphene, methanol, etc. A review of the recent research works carried out in the field of heat pipe with different heat input, orientation, and fluid medium is given as follows.

II. REVIEW OF RELATED WORK

Shrivan et al. [2] investigated the transient study of forming a constrained convection stream inside concentric cylinders and round channels that were partly occupied with permeable materials. Their study discovered that the permeable substrate's outer warming entrance is more efficient than the fair liquid district's.

Curved tape embeds the heat transfer characteristics of heat exchangers, according to Ranjith et al. [3]. It reduces the weight, but their general execution of a twofold line heat exchanger with a turned tape whirl stream on both sides in a 5:3 ratio reduces the weight. They have investigated the display of an altered twofold line heat exchanger having turned tape which induced twirl on both ends of the heat pipe. Auxiliary streams are enabled in the bent tape of blending within the liquids to increase the viable stream duration and the blade effect of the turned tape during the heat exchanger's operation. When the warmth change and weight loss are compared, the overall improvement ratio (OER) results indicate that both wound tapes perform well in both the cylinder and annulus. The benefit of wound tape and a high OER is an estimation of warmth transfer upgrade in weight loss.

Ebrahimnia-Bajestan et al. [4] studied the warmth transfer properties of heat exchangers in the nearby planetary community by using Nano liquids for heat transfer. Both tentatively and mathematically, the convective laminar heating movement of a water-based TiO_2 Nano liquid coursing through a continuously warmed round cylinder.

The traditional two-stage Eulerian-Eulerian model is used to precisely predict the rate at which heat moves. The bury stage heat exchanger relationship is modified in this model with estimated details of TiO_2/Water Nano liquid has a higher warmth move coefficient than the base liquid.

The warmth is transferred from air to water through six water-filled Wickless warmth pipes, each with a single stream on the airside and two-stream passes on the waterside. Warmth move rate breaking point of 900W/pipe increases with higher temperatures and mass stream rate. Ramos J et al. [5] have attempted and tested the demonstration of thermosyphons as powerful bodies on logical inspection using the -NTU technique in CFD recreation, and the findings are extremely agreeable.

Using CFD and RSM, Sun et al. [6] proposed the hub proportion effect on the general warm pressure-driven execution of circular FTHE. In contrast to previous research, the CFD model considers convection heat transfer on both the air and cylinder sides, as well as conduction heat transfer across blades and cylinders. The partial factorial plan (FFD) is used to screen out those elements from the seven considered plan variables that have a cooperative effect on the pivot proportion: number of lines, hub proportion, cross-over cylinder pitch, longitudinal cylinder pitch, balance pitch, airspeed, and water volumetric stream rate.

The helically looped heat exchanger was tested by Pawar SS et al. [7] for Newtonian and non-Newtonian liquids. The liquids used in these experiments were water, and glycerol-water mix (10% and 20% glycerol) as Newtonian liquids, and 0.5-1 percent weaken watery polymer arrangement of sodium carboxyl methyl cellulose and sodium alginate as non-Newtonian liquids.

Senthilkumar et al. [8] investigated the warmth pipe's warm proficiency using copper Nano liquid as the working liquid. The Nano liquid was prepared by suspending copper nanoparticles in de-ionized water. The size of the Copper's nanoparticle size is 40 nm. A 100 mg of copper nanoparticle was centralization in a litre of water to produce nanofluid. The trials are conducted with different temperature inputs, and various warmth pipe tendencies with the flat, and readings are taken. Copper Nano liquid has been discovered to have a higher warm proficiency than base liquids such as DI water, and its warm obstruction is also substantially different from DI water.

The warmth movement of a two-stage closed thermosiphon was tentatively investigated by Karthikeyan et al. [9] with various tendencies and warmth input. For this investigation, a copper thermo guide with a length of 1000mm, an internal width of 17mm, and an external measurement of 19mm will be used. 60 mL deionized water and a watery mixture of n-butanol are used as the working solvent. Warm obstruction is inversely proportional to the warmth input (i.e.) With increasing warmth input, thermal resistance decreases. With each heat transfer, the warmth move coefficient increases. The bubbling warmth move coefficient is marginally higher than the warmth move coefficient that has built up. The efficiency given by closed two-stage thermosyphon using n-butanol as the fluid is superior to that of deionized water.

In the current work, a group of warmth pipes with aluminum blades is used to connect the natural air and return air from a cooled space, thus recovering the waste warmth. Gunabal et al. [10] played out the energy can be advanced through the waste warmth recuperation system. The work performed by the cooling framework would be decreased by 15% if the outside air temperature increases. When using the TiO_2 Nano molecule in combination with R134a, the most extreme viability is reached at the highest outside air temperature.

Rao et al. [11] constructed the exploratory and mathematical re-enactments of a single shell and multiple pass heat exchangers with tube calculations (i.e., Circular cylinders to curved cylinders). With roundabout cylinders at 60° cylinder direction and 25% perplex cut using familiar programming, the examination was completed with hot liquid on the cylinder side and cold liquid on the shell side. To improve the warmth move by limiting the weight drop, the cylinder measurement, tube path, and astound slice are considered. The weight drop over the cylinder side would be minimized as the cylinder math switches from the roundabout to circular. The weight reduction from a round cylinder to a curved cylinder with a 45° cylinder direction representing confound cut tends to be 25%.

Senthilkumar et al. [12] investigated copper tubes with the fluid arrangement of n-butanol with surface pressure being positive and inclination with the temperature being considered as a working mechanism. The tube has an outside radius of 11 mm and an inward radius of 9.8 mm. With different warmth inputs (40W, 60W, and 90W), stream rate, and various tendencies 0°, 45°, and 90° with the flat, a treated steel wick of wrapped screen structure was used. With a watery arrangement of n-butanol, the proficiency and warmth transfer coefficient is greatly increased. With a stream rate of 0.1 kg/min, the warmth pipe fluid arrangement n-butanol provides the best presentation of 45° inclination. When the warmth pipe is held vertical, the warmth move coefficient in the condenser area is high. On the condenser side, the warmth move coefficient is usually calculated to be about 220W/m2°C.

III. EXPERIMENTAL SETUP

Figure 1 depicts a photographic view of the experimental arrangement. The evaporator (heat) section, the adiabatic (transport) segment, and the condenser (cooling) segment were all part of the experimental Heat pipe heat exchanger system. Three copper pipes are the same size and weight. On the inside of each copper tubing, there are two layers of permeable wick hardened steel construction. Porous has a diameter of 0.3 mm, and the heat pipe has 2400 holes per meter. The wick is used to transfer the nanofluid from the condenser part to the evaporator part of the heat pipe using capillary movement. The amount of working liquid to be filled in each copper tube is found to be 18 ml. The working liquid used in this study is a hybrid Nanofluid which compromises 0.2 concentration of 70% aluminum oxide and 30% titanium oxide Nanofluids by volume. A 0.2 concentration of aluminum oxide and titanium oxide Nanofluid is prepared by mixing 4.4 g and 2.6 g of aluminum oxide and titanium oxide Nanoparticles in one litre of deionized water, respectively. The mixture was placed in an ultrasonic homogenizer for 6 hours which results in stable Nanofluids. The size of the aluminum and titanium oxides Nanoparticles used in the Nanofluid preparation is 45 nm and 32 nm, respectively.

The specifications of the shell and tube heat exchangers are shown in table 1. The wall temperature at eight different points across the heat pipe heat exchanger is estimated by T-type thermocouples (eight copper constantant) with an uncertainty of 0.1°C. In addition to this, the temperature at evaporator inlet and outlet, condenser inlet and outlet, condenser surface temperatures, and atmospheric temperatures are also measured using T-type thermocouples. A Galvanised iron (GI) pipe with an external and internal radius measurement of 24 mm and 22 mm, respectively, makes up the condenser tube. To heat the water, a 230 V AC electrical current is applied to the water bath through a heating filament. The water flow rate is measured with a 1% uncertainty using a rotameter on the jacket's inlet side, and the flow rate is varied. To avoid heat loss around the adiabatic segment of the heat pipe, glass wool is provided around the pipe. The amount of heat lost through the evaporator and condenser is insignificant. A rotameter regulates fluctuating mass flow rate of water in the evaporator and condenser segments.

In Heat pipes, the adiabatic and evaporator lengths are changed manually. The heat input for the optimum degree of hot fluid flow rate is set in the evaporator. Nanofluids are heated and transform to vapour, which is then cooled through the heat pipe condenser while Nanofluid passes through the small pores in the wick structure. The experiments are performed for different heat inputs (40, 60, and 80 watts) and various angles of the heat pipe (0°, 15°, 30°, and 45°) to the level plane and the perceptions are noted and classified. The temperatures of T-type thermocouples are observed using the module through an Agilent data logger with the module. The heat pipe has a vacuum gauge to set vacuum pressure inside the pipe. The vacuum gauge is associated with the condenser end of the heat pipe.

Figure .1Photographic view of shell and cylinder Heat Exchanger

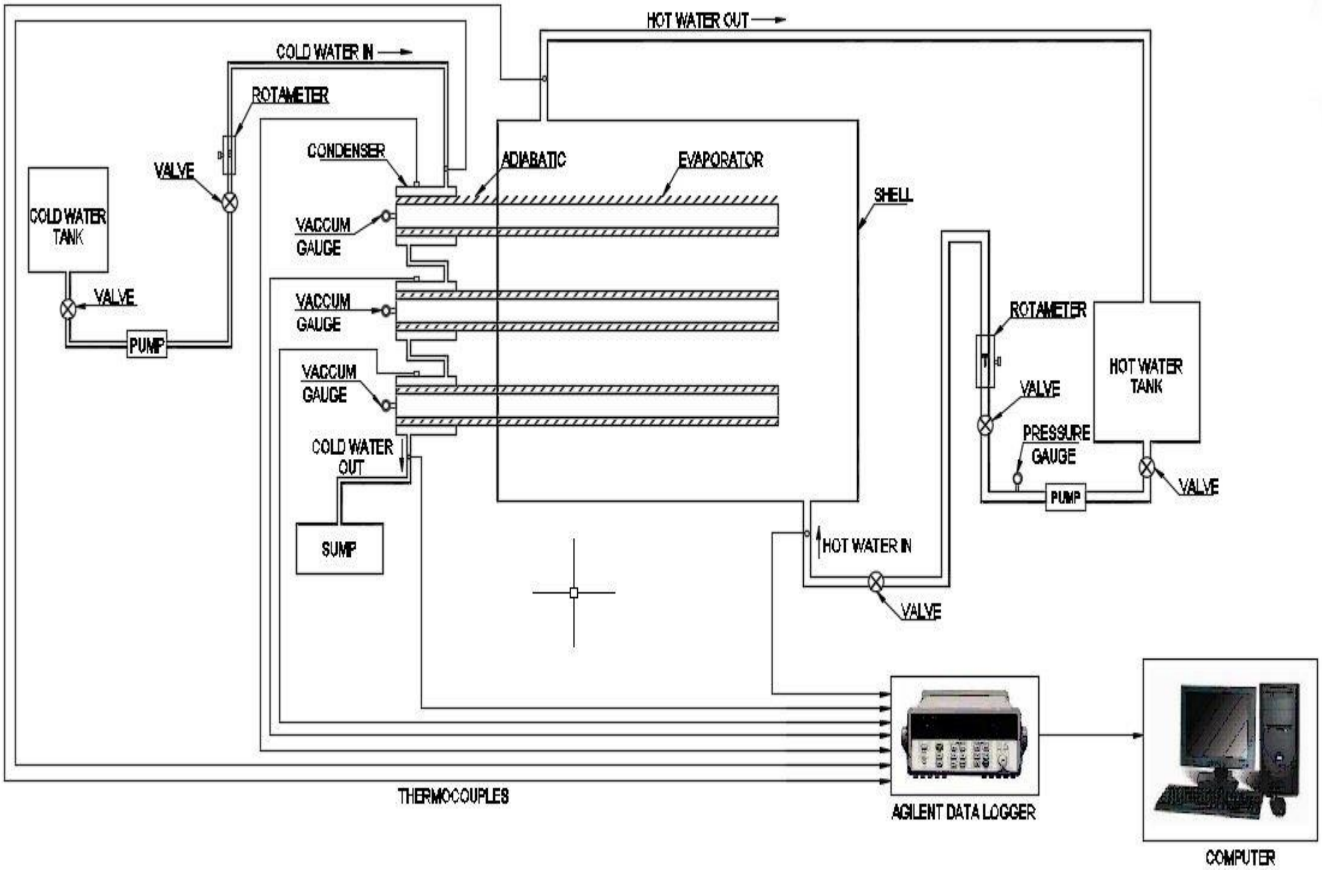

Figure .2 shcematic view of shell and tube heat exchanger

From the observed data, the thermal resistance heat pipe heat exchanger has been calculated as the first thermodynamics law, therefore, governs the heat transfer rate of hot water to cold water.

$$Q = m_h\, c_{ph} \Delta T_h = \; m_c c_{pc} \Delta T_c$$

Thermal resistance is defined as the ratio of the hot water average difference between the heat exchanger and condenser difference of water streams, given that the heat loss from the heat exchanger to the surrounding area is negligible.

Thermal Resistance= (ΔTh-ΔTC)/Q

Q = Heat Transfer (W)

Mh and Mc = Hot and Cold water mass flow rate of (kg/s)

Cph = Hot water Specific heat (KJ/Kgk)

Cpc = Cold water Specific heat (KJ/Kgk)

ΔTh= Hot water difference temperature (°C)

ΔTc = Cold water difference temperature (°C)

ΔC = Difference in Cold water temperature (°C)

mhi= Hot water flow rate at inlet (kg/s)

mci = Cold water flow rate at inlet (kg/s)

Table 1. Specifications of heat pipe heat exchange

Specifications	Dimensions
Outer diameter	19 mm
Inner diameter	17 mm
Shell diameter	620 mm
Shell length	850 mm
Evaporator length	600,700, 800 mm
Condenser length	200 mm
Adiabatic pipe length	200,100 and 0 mm
Total length of HPHE	1000 mm
Wick mesh size	2400 holes per meter
Wick porosity	0.60
Wick permeability	$4.426*10^{-4}$ mm^2
Capillary limit	0.092 kW
Sonic limit	60 kW
Entrainment limit	58 kW
Boiling limit	17.5 kW

VI. RESULT AND DISCUSSION

In this investigation mainly focused on the thermal resistance of an adiabatic length of fluid flow. The Adiabatic length of heat pipeline considers into three different lengths as 0mm, 100mm and 200mm. The four different flow rate of fluid flow admit through each pipe

A. 0 mm adiabatic length:

The thermal resistance of various heat pipes input at various flow rates and angles of inclination is shown in Figure 3-6. As the heat input and flow rates have increased, the thermal resistance of the the working fluids for different tilt angle has decreased in all cases. The thermal resistance variance at 0° inclination is shown in Fig-3. The plot indicates a maximum thermal resistance of about 0.51 in 0.8 l flow rate at 80 W heat input and minimum thermal resistance of 0.15 in 0.2 l flow rate at 40 W heat input. Since the 0 mm adiabatic length is used, the thermal resistance of 0.6 l flow rate at 60 W heat input is unexpectedly increased because adiabatic length is used so the heat transfer in that part is very low. The same pattern was inferred for 15° inclinations, as shown in fig-4, but with the exception of the only maximum thermal resistance of 0.44 observed in 0.8 l flow rate of 80 W heat input. Since the heating phase is very low in that adiabatic length, it is obvious that the flow rate increases as thermal resistance increases. So, at an 80 W heat input, the minimum thermal resistance is 0.28 in 0.2 l flow rate. The variance of thermal resistance when the heat exchanger is inclined 30 degrees is shown in fig.5. Though the overall thermal resistance of 0.45 observed in the 0.8 l flow rate at 80W heat input is similar to that of 15° inclination, the thermal resistance is decreased when compared to other flow rates. The thermal resistance for a 45° inclination is shown in Figure 6. The thermal resistance of 0.8 l flow rate at 80 W heat input is found to increase with the increase in flow rate as compared to 30° and 45° inclination of thermal resistance of 0.8 l flow rate at 80 W heat input.

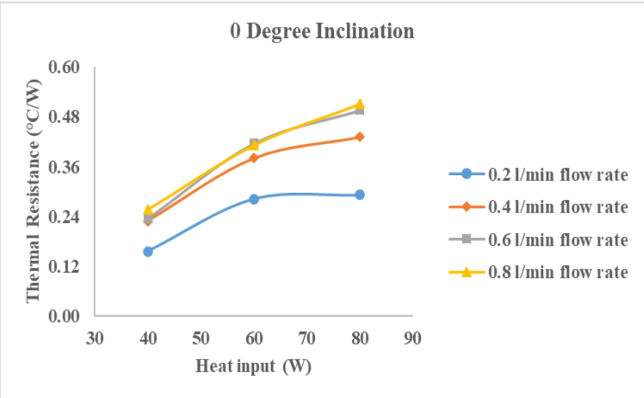

Figure 3 Variation in thermal resistance for different Heat Input with Zero degree and 0 mm Adiabatic length

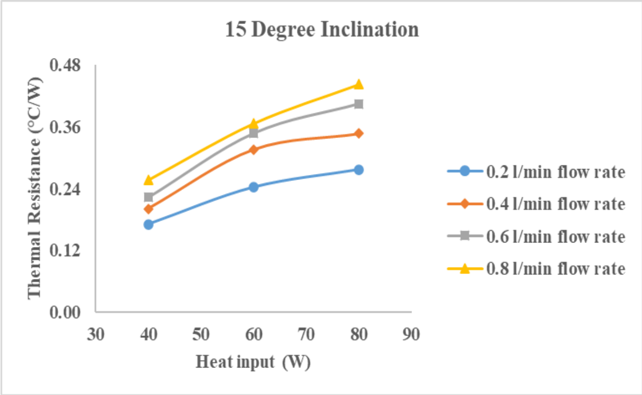

Figure 4 Variation in thermal resistance for different Heat Input with 15° angle and 0 mm Adiabatic length

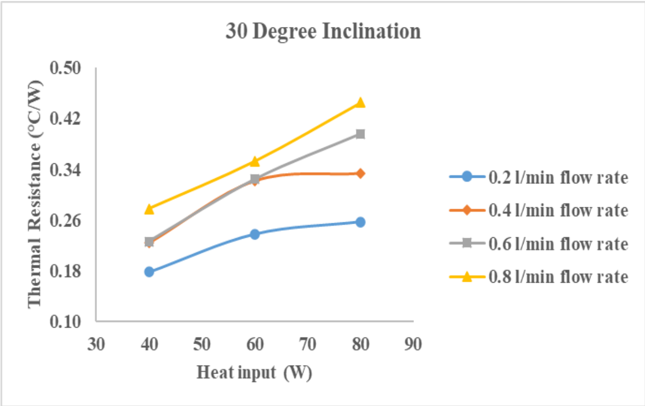

Figure 5 Variation in thermal resistance for different Heat Input with 30° angle and 0 mm Adiabatic length

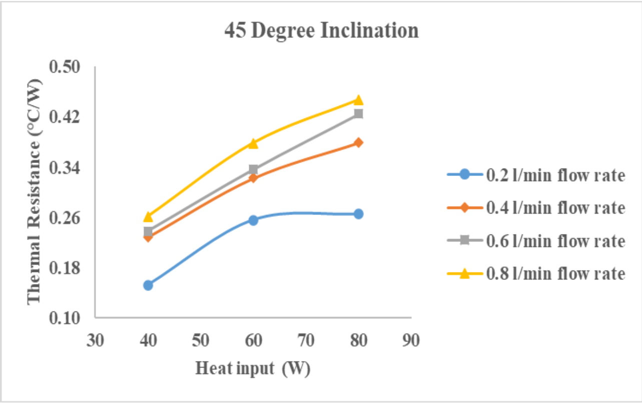

Figure 6 Variation in thermal resistance for different Heat Input with 45° angle and 0 mm Adiabatic length

B. 100 mm and 200 mm adiabatic length

The next experimentation trial used a 200 mm condenser, a 100 mm adiabatic length, and a 700 mm evaporator length. The variance of thermal resistance is shown in Figure 7-10. Figure 7 depicts an overall thermal resistance of 0.55 in 0.8 l flow rate at 80 W heat input and minimum thermal resistance of 0.26 in 0.2 l flow rate at 40

W heat input. Figure 8 shows a sudden decrease in 0.2 l flow rate at 15° inclination at 40 W heat input and a sudden increase in 0.2 l flow rate at 30° inclination at 60 W. It was also discovered that as compared to an adiabatic length of zero, the thermal resistance decreases in all situations. The plot of the variation of thermal resistance of the heat pipe heat exchanger for an adiabatic length of 200 mm and an evaporator length of 600 mm is shown in Figure 11-14. The maximum thermal resistance of 0.54 is observed at 0.8 l flow rate of 80 W heat input, and the minimum resistance is observed at 0.2 l flow rate of 40 W heat input, as shown in fig 11. The thermal resistance of other inclination angles is found to be lower than that of a 0-degree inclination.

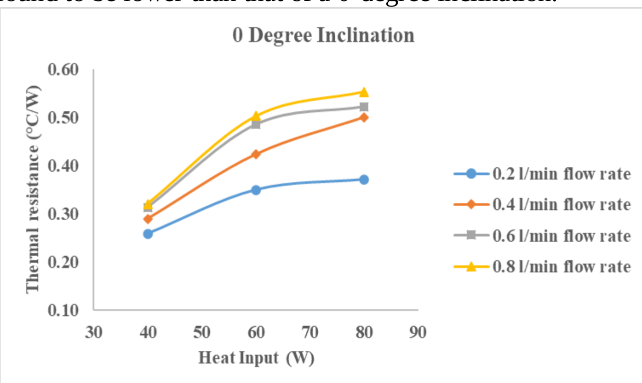

Figure 7 Variation in thermal resistance for different Heat Input with 0° and 100 mm Adiabatic

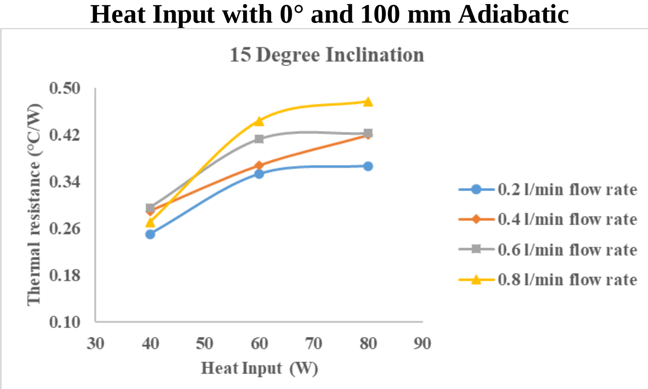

Figure 8 Variation in thermal resistance for different Heat Input with 15° angle 100 mm Adiabatic

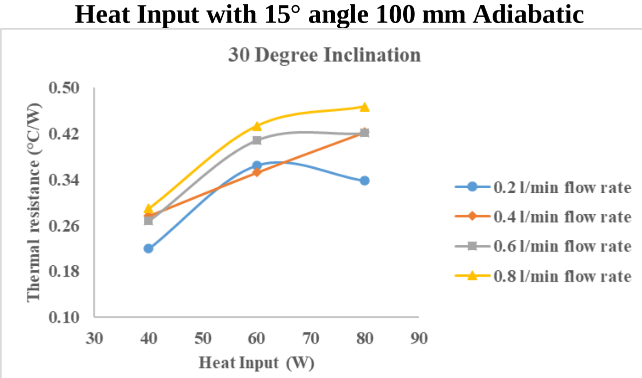

Figure 9 Variation in thermal resistance for different Heat Input with 30°angle 100 mm Adiabatic

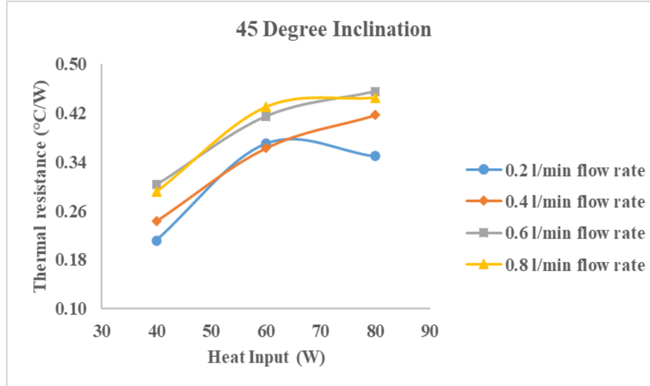

Figure 10 Variation in thermal resistance for different Heat Input with 45° angle 100 mm Adiabatic

C. 200 mm adiabatic length

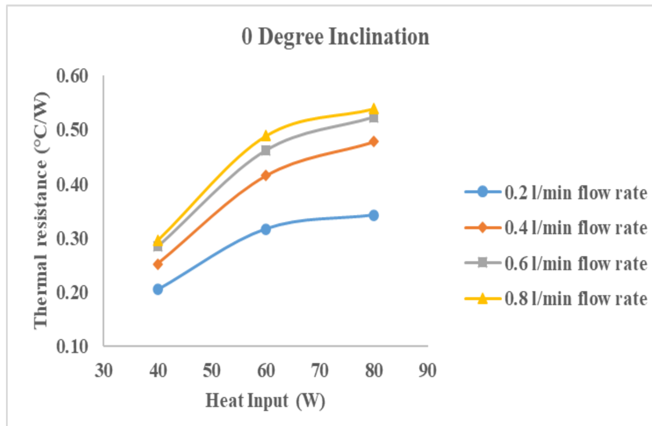

Figure 11 Variation in thermal resistance for different Heat Input with 0° angle and 200 mm Adiabatic

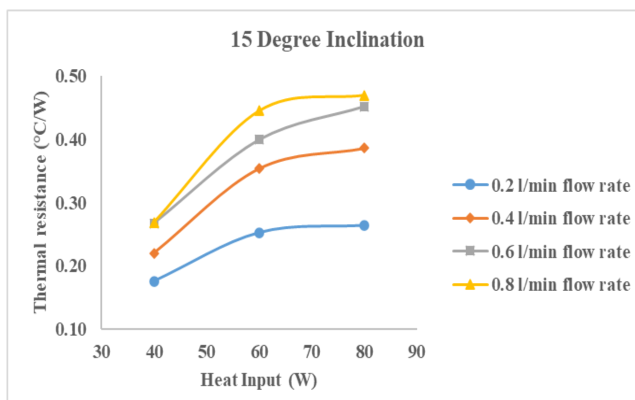

Figure 12 Variation in thermal resistance for different Heat Input with 15° angle and 200 mm Adiabatic

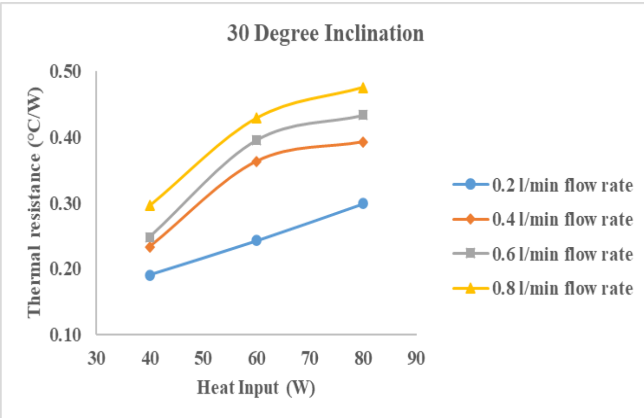

Figure 13 Variation in thermal resistance for different Heat Input with 30° angle and 200 mm Adiabatic

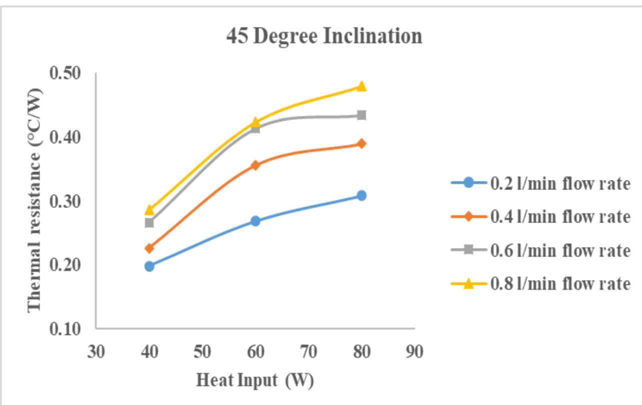

Figure 6 Variation in thermal resistance for different Heat Input with 45° angle and 200 mm Adiabatic

V. CONCLUSIONS

The effect of a fluid flow heat pipe of a heat exchanger with an adiabatic length of 0, 100, and 200 mm on flow inclination and the flow rate was investigated. The following findings are made as a result of this inquiry.

With an 80 W heat input and a 30° fluid flow angle through the 200mm adiabatic tubing, the maximum thermal resistance of 0.48 was obtained. The experiment shows that at 200mm Adiabatic with 30° angle in 80w heat input, the effective Adiabatic is 0.48. It denoted 0.05 higher thermal resistance than without Adiabatic. According to this research, the successful Adiabatic is 200mm at a 30° flow angle with an 80 W heat supply

REFERENCES

[1] Minghui Xie, Zhihu Xue, Wei Qu, Wei Li, Experimental Investigation of Heat Transfer Performance of Rotating Heat Pipe, Procedia Engineering, 99 (2015) 746-751.

[2] Shirvan KM, Ellahi R, Mirzakhanlari S, Mamourian M. Enhancement of Heat Transfer and Heat Exchanger Effectiveness in a Double Pipe Heat Exchanger Filled with Porous Media : Numerical Simulation and Sensitivity Analysis of Turbulent Fluid Flow. Appl Therm Eng (2016). https://doi.org/10.1016/j.applthermaleng.2016.08.116.

[3] Ranjith, Shaji K. Numerical Analysis on a Double Pipe Heat Exchanger with Twisted Tape Induced Swirl Flow on Both Sides. Procedia Technol., 24 (2016) 436–43. https://doi.org/10.1016/j.protcy.2016.05.060.

[4] Ebrahimnia-bajestan E, Charjouei M, Niazmand H. International Journal of Heat and Mass Transfer Experimental and numerical investigation of nanofluids heat transfer characteristics for application in solar heat exchangers. International Journal of Heat and Mass Transfer 92 (2016) 1041–52. https://doi.org/10.1016/j.ijheatmasstransfer.2015.08.107.

[5] Ramos J, Chong A, Jouhara H. International Journal of Heat and Mass Transfer Experimental and numerical investigation of a cross-flow air-to-water heat pipe-based heat exchanger used in waste heat recovery. International Journal of Heat Mass Transfer (102) (2016) 1267–81. https://doi.org/10.1016/j.ijheatmasstransfer.2016.06.100.

[6] Sun L, Zhang C. International Journal of Thermal Sciences Evaluation of elliptical finned-tube heat exchanger performance using CFD and response surface methodology. International Journal of Thermal Science 75 (2014) 45–53. https://doi.org/10.1016/j.ijthermalsci.2013.07.021.

[7] Pawar SS, Sunnapwar VK. Experimental and CFD investigation of convective heat transfer in helically coiled tube heat exchanger. Chem Eng Res Des (2014) 1–19. https://doi.org/10.1016/j.cherd.2014.01.016.

[8] Senthilkumar R, Vaidyanathan.S, Sivaraman.B, Effect of Inclination Angle in Heat Pipe Performance Using Copper Nanofluid. Procedia Eng 38 (2012) 3715–21. https://doi.org/10.1016/j.proeng.2012.06.427.

[9] Karthikeyan M, Vaidyanathan.S, Sivaraman.B, Heat Tarnsfer analysis of Two Phase Closed Thermosyphon using Aqueous solution of n-Butanol. International Journal of Engineering and Technology ,03 (2013) 661-667.

[10] Gunabal S, Sivaraman.B, Effect of TiO_2 nano particle in waste heat recovery system using heat pipes. International Journal of Engineering Science & Advanced Technology 4 (2014) 378–81.

[11] Bala Bhaskara Rao J, Ramachandra Raju V, Numerical and heat transfer analysis of shell and tube heat exchanger with circular and elliptical tubes. International Journal of Mechanical & Materials Engineering. (2016) 1–18. https://doi.org/10.1186/s40712-016-0059-x.

[12] Senthilkumar R, Vaidyanathan.S, Sivaraman.B, Study of Heat pipe Performane using an aqueous solution of n-Butanol, Indian Jounal of Science Technology. 3 (2010) 1–4.

[13] Albadr J, Tayal S, Alasadi M. Heat transfer through heat exchanger using Al2O3 nanofluid at different concentrations. Case Studies in Thermal Engineering, 1 (2013) 38–44. https://doi.org/10.1016/j.csite.2013.08.004.

[14] Nookaraju BC, Sohail M, Karthikeyan R. Experimental investigation and optimization of process parameters of hybrid wick heat pipe using with RSM historical data design. Materials Today Proceedings, (2020). https://doi.org/10.1016/j.matpr.2020.05.634.