Volume: 10 Issue: X Month of publication: October 2022

DOI: https://doi.org/10.22214/ijraset.2022.47165

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue X Oct 2022- Available at www.ijraset.com

Experimental Study on Thermal Performance of Dual Diameter Closed Loop Pulsating Heat Pipe Using ZnO/water Nanofluid

Shreyas R. Harne[1], Prof. R.S. Mohod[2]
[1]PG Student, [2]Prof. Dept. of Mechanical Engineering Govt. College of Engineering Amravati, India

Abstract: In this paper, experimental study on the thermal performance of closed loop pulsating heat pipe (CLPHP) with single diameter and dual-diameter structure is investigated. The CLPHP with dual-diameter configuration is made of copper capillary tubes with two diameters; greater in the condenser section (inner diameter of 3mm) and smaller in the evaporator and adiabatic sections (inner diameter of 2mm). Experiment was conducted in vertical orientation with bottom heating mode having two-turns and 50% filling ratio (FR). The water and zinc oxide (ZnO/water) nanofluid with 0.25% and 0.5% w/v used as working fluids. The heat power was supplied from 8 W to 80 W, in the steps of 8 W. The various temperatures were recorded on the outer wall of the evaporator and condenser section of single diameter and dual diameter CLPHP. The thermal performance is measured in terms of thermal resistance. The thermal resistance at different heat inputs was measured. It is concluded that, the thermal performance of the dual-diameter configuration is better than the single-diameter.
Keyword: Pulsating heat pipe, Dual-diameter, Thermal resistance, Nanofluid

I. INTRODUCTION

Thermal control is a basic need for any heat dissipation system. In many engineering applications higher heat flux is important. Two phase passive devices are recognized solutions for modern microelectronics thermal management. The expectation of sustainable development of energy and environment has broadly attracted public's attention, and the high-efficiency heat transfer device is greatly needed. Heat pipes emerge as the most suitable technology and most thermal effective solution due to their outstanding heat transfer capability, heat transfer efficiency and structural simplicity. There are some types of heat pipes, including rotating heat pipes, wick heat pipes, thermosiphons, and pulsating heat pipes (PHPs). Numerous researchers are not only committed to enhance heat transfer performances of PHPs from the aspects of working fluids, but also to further understand the operation mechanisms.

Pulsating heat pipe (PHP), also known as oscillating heat pipe (OHP), a new type of heat pipe, has attracted wide attention since it was proposed by Akachi in the 1990s due to its unique working principle and excellent thermal performance. PHP is composed of a capillary pipe, which can be bent into various shapes according to the requirements of working environment.

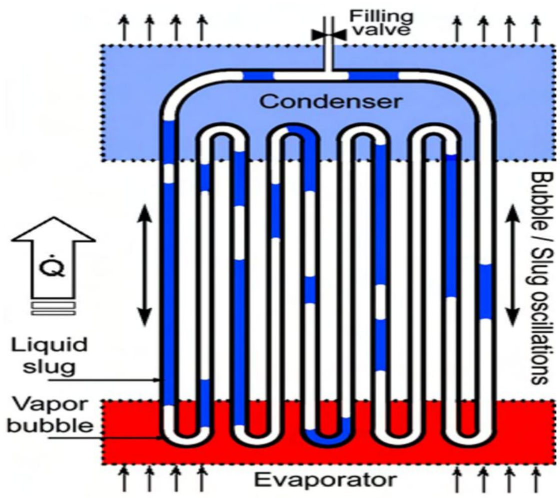

Fig. 1. Closed Loop PHP

Pulsating heat pipes can be divided into three parts, i.e., evaporator, adiabatic section and condenser. The structure of PHP is simpler and more compact compared with traditional heat pipes. In addition, PHPs also have the advantages of high flexibility, fast-thermal response and excellent heat transfer performance. Fig. 1. Closed loop PHP.

Many studies mainly focus on the effects of geometrical parameters such as materials, diameter and length of tube, cross-section shape, number of turns, fins, etc. and operational parameters such as evacuation pressure, filling ratio, heat load, inclination angle, etc. The working fluid is the most important parameter in the CLPHP. At the same time, nanofluids are viewed as advanced heat transfer fluids in heat transfer devices. In general, the nanoparticles suspended in the base fluid forming the nanofluid are of size about less than 100 nm. The heat transfer performance of the base fluid is crucially improved due to increased surface area.

II. LITERATURE REVIEW

The pulsating heat pipe, proposed and patented by Akachi [1], is a new member of the wickless heat pipes. Due to its excellent features, such as high thermal performance, rapid response to high heat load, simple design and low cost, PHP has been considered as one of the promising technologies for electronic cooling, heat exchanger, cell cryopreservation, the spacecraft thermal control system, etc.

G.H. Kwon and S.J. Kim et al. [2] They performed series of experiment on single-turn pulsating heat pipes. the dual-diameter tube helps to promote a circulating flow in the PHP, and it causes a circulating flow to start at a lower input power. this is advantageous for PHP functionality as the PHP thermal resistance was reduced by as much as 45%. There is an optimum ratio of diameter difference to the average tube diameter in which the thermal performance enhancement is maximized, for a single-turn PHP, though the optimum ratio depends on given constrains, the optimal dimensionless diameter difference was suggested to be $0.25 < \Delta D/D_{avg} < 0.4$.

J. Wang et al. [3] they analysed by CFD simulation. The volume of fluid method is used to investigate the start-up characteristic and thermal performance of CLPHP with different ratios of the evaporator length to that of the condenser. the result show that, For the same filling ratio and input power, the increase of the length ratio of evaporator to condenser would help to accelerate the start-up and decrease the thermal resistance of closed loop pulsating heat pipe.

M. Lutfor Rahman et al. [4] they experimentally investigated and compare the effects on the heat transfer performances of CLPHP with finned and un-finned condenser section with inclination angle of 0° (vertical), 30° and 45°. Methanol is used as working fluid with 50% filling ratio in CLPHP with 8 loops during the experimentation. A closed loop pulsating heat pipe made of copper with 2 mm ID and 2.5 mm OD with fin in the condenser section is used to evaluate the heat transfer performances. The result show that finned structure provides better performance than normal structure in the experiment. Best thermal performance is obtained at 45° orientation. The thermal performance is a function of orientation, filling ratios, working fluid and use of fin.

V.K. Karthikeyan et al. [5] they perform experimental investigation on closed loop pulsating heat pipe with working fluid as nanofluid. Two different types of nanofluid is used. Copper nanofluid is prepared by a two-step method. Silver colloidal nanofluid solution is synthesized using chemical reduction method. The results show that the nanofluid charged CLPHPs enhance the heat transfer limit by 33.3% and have lower evaporator wall temperature compared to that of DI water.

H. Ahmad and S.Y. Jung et al. [6] they experimentally studied a closed-loop pulsating heat pipe subjected to active and passive cooling for its thermal performance and flow regimes. The active cooling was done using forced convection while the passive cooling was done by free convection. Methanol is used as working fluid with 50% filling ratio in closed loop pulsating heat pipe with 2 turns during the experimentation. They concluded that the free convective CLPHP will be effective to transfer heat for a low Qin. Whereas, the forced convective CLPHP can be effective to use for a longer duration of the operation and high Qin based on its dry-out conditions.

J.Venkata suresh et al. [7] they performed CFD simulation in ANSYS CFX with two turns of PHP. CFD analysis for the PHP is tested with different working fluids binary mixtures like water-methanol and water-ethanol for 50% fill ratio viz., for different inner diameters of 2mm and 3mm. The obtained CFD results are compared with the experimental data. The result show that two PHPs with inner diameter 2mm pipe with water-methanol with 50% filling of PHP giving optimum results.

C. Y. Tseng et al. [8] they studied the effect of uniform and alternating tube diameter on the performance of closed loop pulsating heat pipe. The uniform CLPHP is equipped with 2.4 mm ID tube while half of the test tubes of the alternating design is identical to that of the uniform design but the rest of the tubes are compressed to an oval-like configuration with a minor diameter being 1.5 mm. the distilled water, methanol and HFE-7100 used as working fluid. They concluded that the thermal resistance subject to the working fluids for the CLPHP depends on the input power and working fluids. For a low input power.

G.H. Kwon, S.J. Kim [9] Conducted experimental investigations to study the effect of a dual-diameter channel on the flow and heat transfer characteristics of flat plate micro pulsating heat pipes. The rectangular channels with dual hydraulic diameters were etched on a silicon wafer to form a meandering closed-loop MPHP with 5 turns. The series of experiments was performed to study the effect of a dual-diameter channel on operational characteristics of the MPHP filled with Ethanol and FC-72 at various input powers and inclination angles. The experimental result show that the dual-diameter channel makes the MPHP operate independent of the orientation. It is because the capillary pressure difference produced by the channel diameter difference is larger than the frictional pressure drops.

L. Aref, R. Fallahzadeh and S.R. Shabanian et al. [10] they experimentally studied effect of dual-diameter configuration on operational characteristics of CLPHP. The test data for comparison between the single-diameter and dual-diameter CLPHP are carefully selected and classified according to similar conditions, such as heat input power and working fluid and different factors, such as filling ratio and inclination angle. Also, this research experimentally investigated the thermal performance of a flat plate solar collector coupled with the proposed dual-diameter CLPHP. They concluded that thermal performance of dual-diameter CLPHP has a significant performance compared to the single diameter CLPHP.

III. EXPERIMENTAL

A. *Preparation of Nanofluid*

Nanofluid is prepared by suspending a small quantity of nanoparticles in base fluids such as water, ethylene glycol etc. The average size of nanoparticles is below 100 nm. Nanofluids have novel properties that make them potentially useful application in heat transfer. For this research, water–ZnO nanofluid was prepared using the two-step approach. The sonicate had a bath type, operating frequency, and power source of 40 kHz and 230V AC, 50Hz. The nanofluid was prepared by a sonicated for two hours. The nanoparticles were mixed with de-ionized water in a sonicator to obtain a stable suspension.

B. *Experimental set-ups description*

Figure 2 illustrates that, the schematic of experimental setup. The set-up comprises the CLPHP, cooling water unit, heater and a control panel. The CLPHP is divided in three main sections. The evaporator zone, where the device receives a controlled heat input by means of heating coil. The adiabatic zone ideally insulated from the environment. The condenser zone where the PHP releases the heat by means of a liquid cooled heat sink. The dimensions for two configurations (single-diameter and dual-diameter) were presented in table 1.

Table: 1 Dimensions of different sections of the CLPHPs

Configuration	Specifications	Condenser section	Adiabatic section	Evaporator section
Dual-diameter	Inner diameter (mm)	3	2	2
	Outer diameter (mm)	5	3.5	3.5
	Length (mm)	100	110	100
Single-diameter	Inner diameter (mm)	2	2	2
	Outer diameter (mm)	3.5	3.5	3.5
	Length (mm)	100	110	100

The capillary tubes in the three sections (i.e., evaporator, adiabatic and condenser) are made of copper in order to minimize the thermal resistance between the tube and the heat input/output zones while the straight tubes in the adiabatic section are covered with insulated material so that there is no contact with the environment. The central distance between two tubes was maintained 30mm.

In the evaporator section, insulation paper is provided on the copper tube and then a nichrome wire is wound on the tube. For safety, again a layer of insulation is used. The condenser section was cooled by normal water through a cooling box of dimension 100×20×100 mm3 and inlet and outlet temperature was measured.

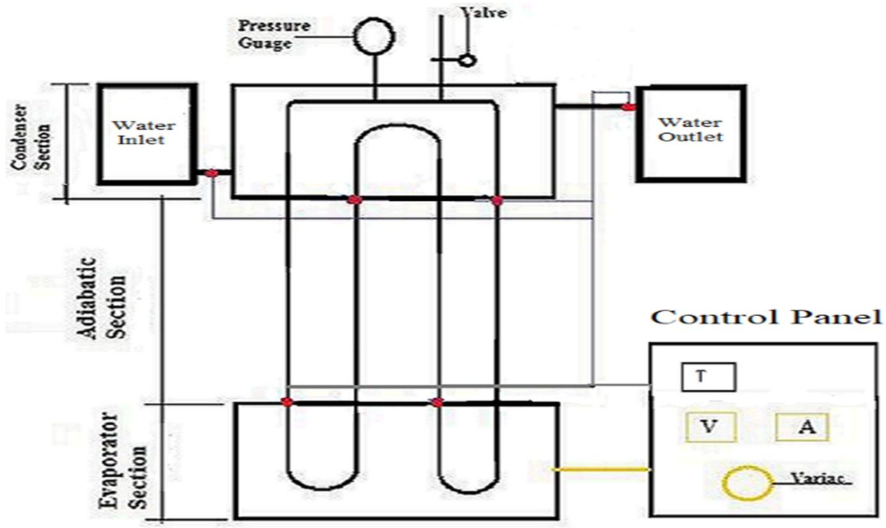

Fig. 2. Schematic of Experimental Setup

The control panel comprises of power measuring and temperature measuring equipment as shown in fig. 1. The heat input is measured in terms of electrical power supply through Dimmerstat (0 – 1000 W). The voltmeter (0 – 300 V) and Ammeter (0 – 3 A) was connected in line for the input power measurement. The output of the experimental setup is calculated in terms of thermal resistance, for that, the various temperatures were recorded at different location by means of thermocouple wires (K-type, accuracy ±0.2°C). Pure water and ZnO-water nanofluid concentrations of 0.25% and 0.5%are selected as working fluids for experimentation.

The Thermal Resistance of PHP is calculated by equation,

$$Rth = \frac{Te-Tc}{Qin} \quad \text{........ (1)}$$

Where,
R_{th} - Thermal resistance (°C/W)
T_e - Average temperature of evaporator (°C)
T_c - Average temperature of condenser (°C)
Q_{in} – Heat input (W)

C. Experimental Procedure

1) The primary requirement of CLPHP is to create a vacuum inside the tube. In order to create vacuum inside the PHP, a reciprocating vacuum pump is connected to the filling valve.
2) Thereafter the device is fill with the desired working fluids and closed the valve.
3) The water was supplied from storage tank to the condenser section.
4) Wait till the condenser tank is completely filled. Then flow rate was measured with beaker and stop watch.
5) Power was supplied to the control panel and checked well for the data collection.
6) Control panel was connected to the PHP setup with the help of power cord, the nichrome wire starts heating. This in turn heats the evaporator section.
7) Provide a constant heat input to the heater up to steady state reached and temperature at different points of CLPHP note down between 10-minute intervals. The heat input is increased with step of 8 W input powers after steady state reached.
8) After a quasi-steady state was reached, note down the readings. At steady state from the inlet - outlet temperature and mass flow rate of the coolant, the heat transfer could be calculated.
9) The above procedure was repeated with two configurations (uniform diameter and dual-diameter) of CLPHP with DI water and ZnO-water nanofluid concentrations of 0.25% and 0.5% are selected as working fluids for experimentation.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 10 Issue X Oct 2022- Available at www.ijraset.com

IV. EXPERIMENTAL RESULTS

A. Effect Of Different Configuration On Thermal Resistance

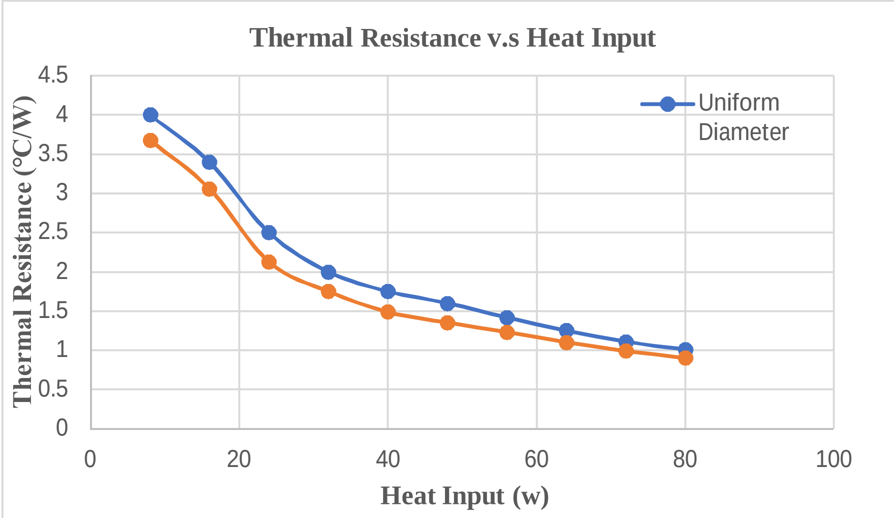

Fig. 3. Comparison of thermal resistance for uniform diameter and dual diameter CLPHP with DI-water as working fluid.

From the experimental analysis, graphs are plotted showing comparison of single diameter and dual diameter configuration on thermal resistance with different heat inputs and working fluid as shown in figure 3, 4, and 5 respectively. Fig.3. show the effect on thermal resistance on uniform diameter and dual diameter CLPHP with DI water as working fluid.

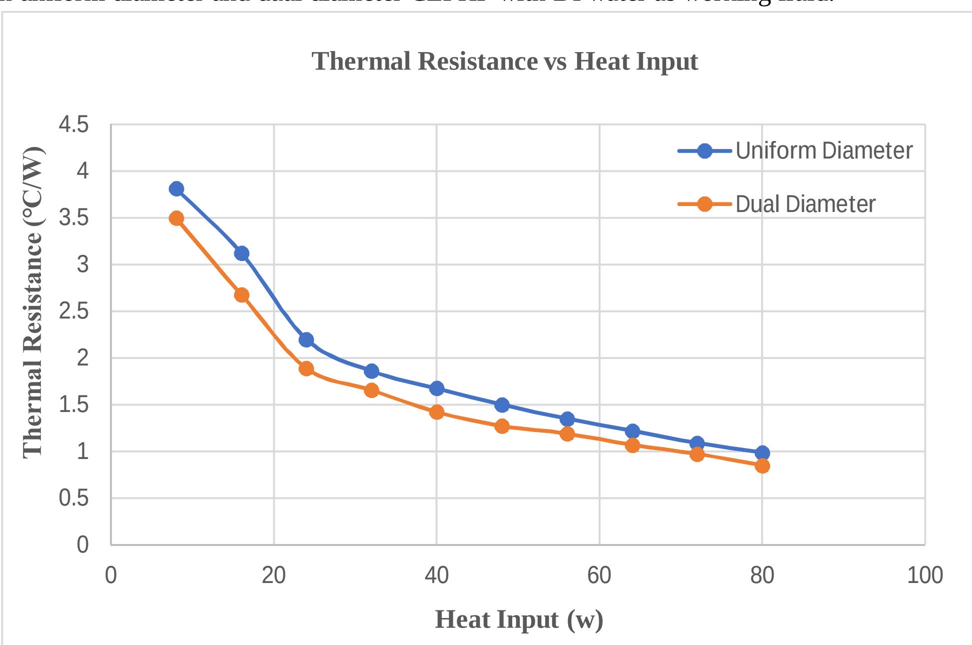

Fig. 4. Comparison of thermal resistance for uniform diameter and dual diameter CLPHP with 0.25% w/v ZnO/water nanofluid as working fluid.

The diameter variation in the dual-diameter structure causes an unbalanced capillary force and makes the bubble to move in a diverging direction. On the other hand, the larger diameter part of the CLPHP (condensation section) contains more vapor bubbles leading to an unbalance in gravitational force promoting the pulsating flow. In addition, larger diameter of the condensation section gives the advantage of greater heat exchange surface area.

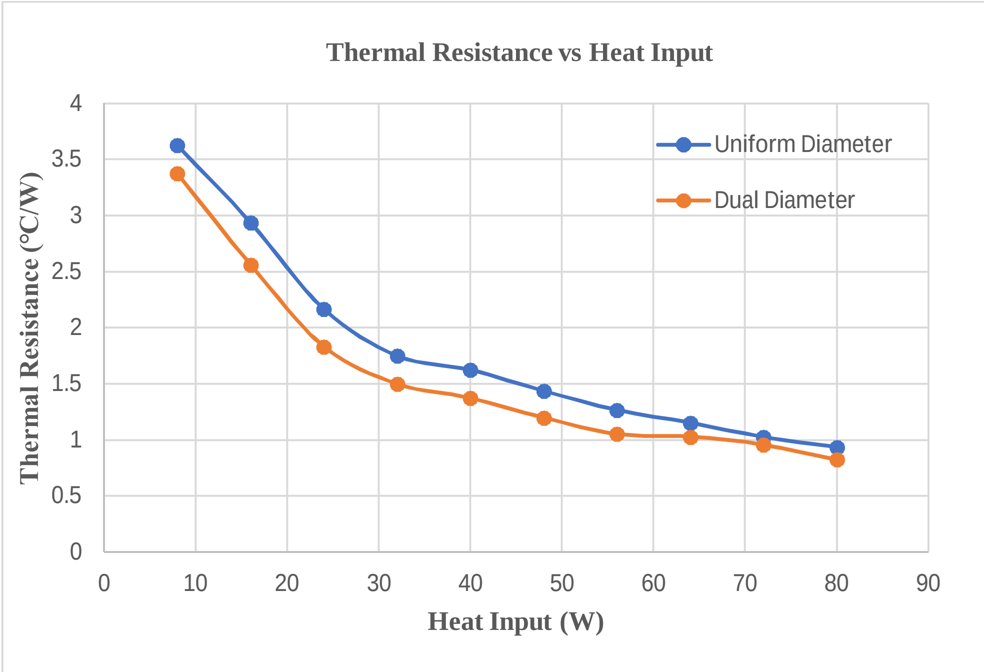

Fig. 5. Comparison of thermal resistance for uniform diameter and dual diameter CLPHP with 0.5% w/v ZnO/water nanofluid as working fluid.

Fig 4. Show the effect on thermal resistance on uniform diameter and dual diameter CLPHP 0.25w/v % of ZnO/water nanofluid with as working fluid and fig.5. show that the effect on thermal resistance on uniform diameter and dual diameter CLPHP 0.5w/v % of ZnO/water nanofluid with as working fluid.

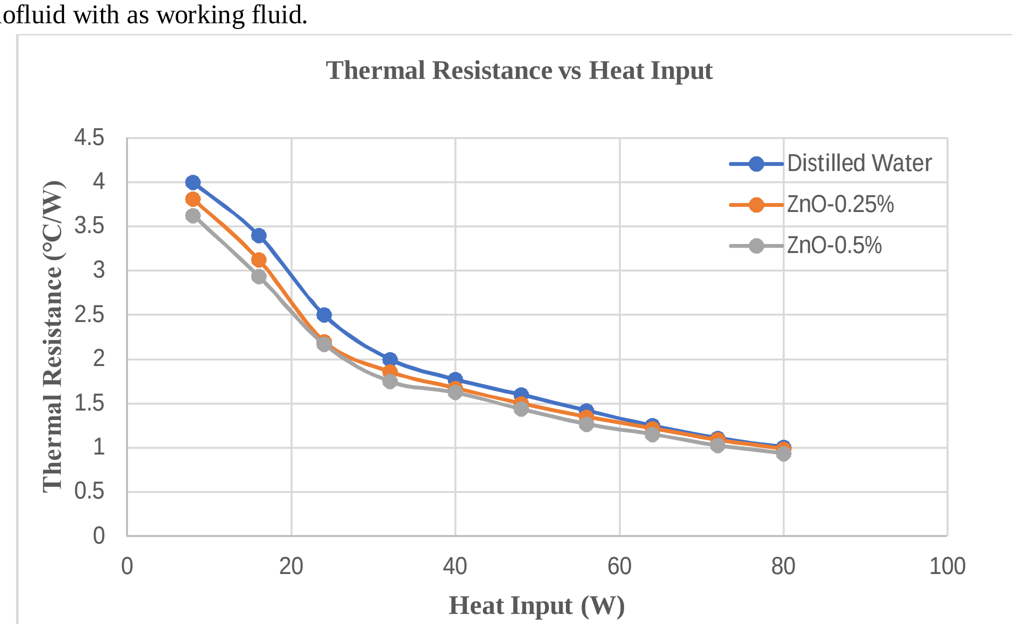

Fig. 6. Variations of thermal resistance for uniform diameter CLPHP for DI water and ZnO nanofluid.

The symmetrical loops in each section (evaporation and condensation) and asymmetric overall, would help to optimize the conventional asymmetric configurations by effectively promoting pulsating flows. In this manner, it doesn't matter that the bubble slugs decide to flow which side of the evaporation turns. In any direction, the tubes are diverging into the condensation section. Hence the flow is clockwise or counter clockwise and the pulsating flow is achieved ultimately.

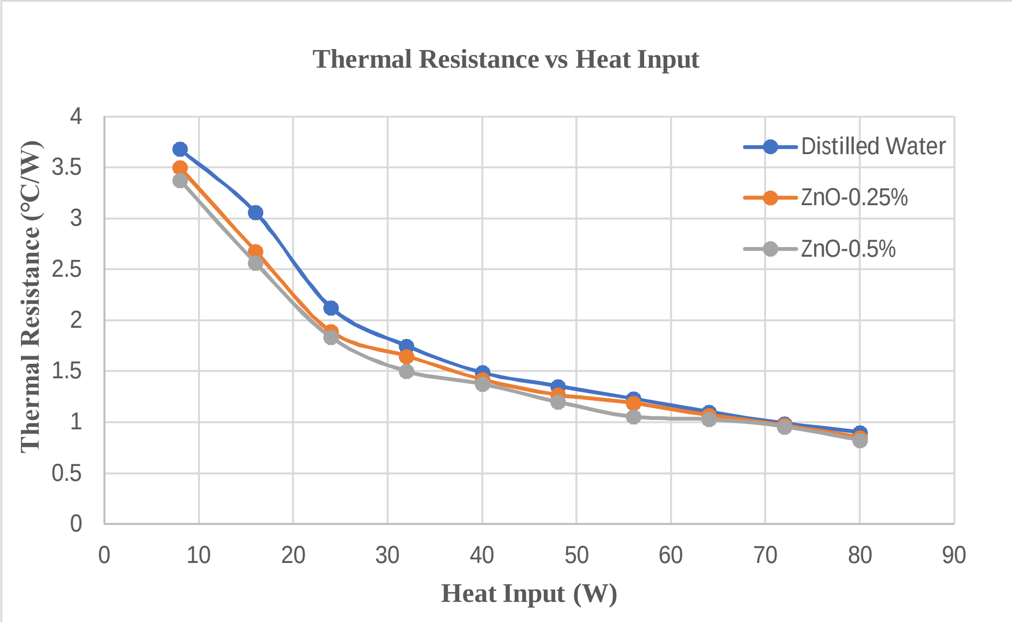

Fig. 7. Variations of thermal resistance for dual diameter CLPHP for DI water and ZnO nanofluid.

Fig.6 and fig.7. show thermal resistance of uniform and dual diameter closed loop pulsating heat pipe with DI water and 0.25% w/v and 0.5% w/v of ZnO/water Nanofluid and result show that for both configurations thermal performance decrease with decrease in heat input.

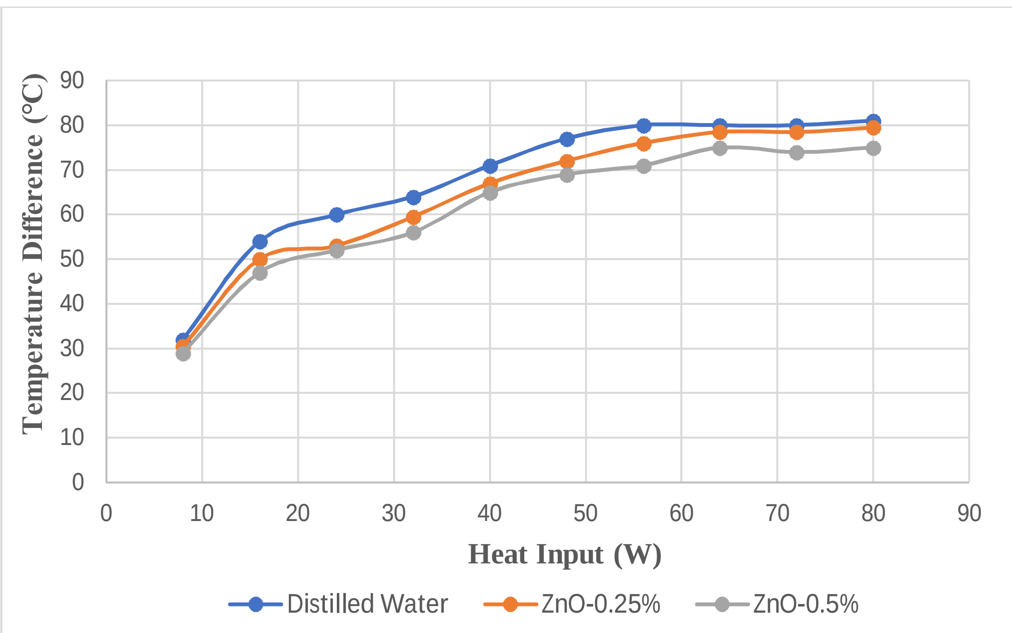

Fig.8. Variations of Evaporator-condenser temperature difference of uniform diameter CLPHP.

Due to larger diameter in condenser section. It can be found that increasing the condensation heat exchanging area leads to more heat transfer and improving the CLPHP performance. Owing to mentioned reasons, unbalanced capillary/gravitational force and greater heat exchange surface obtained from dual-diameter structure, the dual-diameter configuration's thermal performance is much better in comparison with the uniform-diameter configuration.

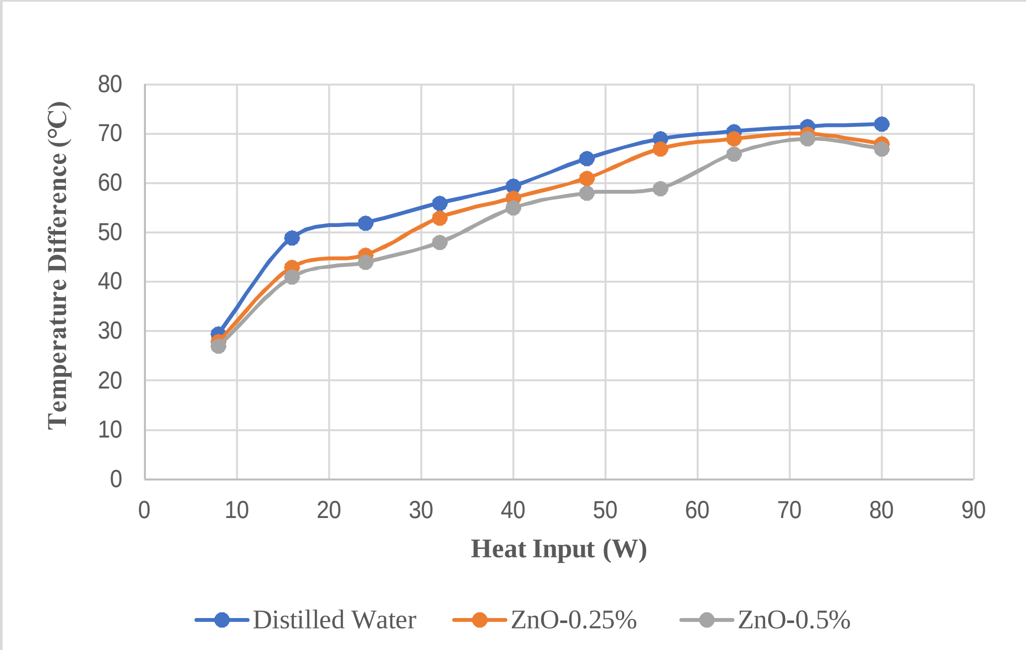

Fig.9. Variations of Evaporator-condenser temperature difference of dual diameter CLPHP.

Fig 8. Show the variation in Evaporator-condenser temperature difference for uniform diameter with working fluid. and fig.9. show that variation in Evaporator-condenser temperature difference for dual diameter with working fluid.

V. CONCLUSIONS

In this paper, an experimental study of the thermal performance of a single diameter and dual-diameter CLPHP under different heat input has been presented. The results show that dual-diameter CLPHP has a significant performance compared to the single diameter. The working fluids used were water and nanofluids (0.25% ZnO–water and 0.5% ZnO– water) The following conclusions can be drawn from the study:

1) Thermal performance of dual diameter CLPHP is significantly better than single diameter configuration.
2) Thermal resistance decreases with increase in mass concentration of ZnO/water nanofluid for both single diameter and dual diameter CLPHP.
3) For single diameter and dual diameter configuration, With the increase in the heat input, the performance of the PHP improves.
4) For single diameter and dual diameter configuration, ZnO/water nanofluid PHP gives the good thermal performance than water PHP.

REFERENCES

[1] Akachi H, Structure of a heat pipe. US Patent No. 4921041, (1990).
[2] Kwon, Gi Hwan, and Sung Jin Kim. "Operational characteristics of pulsating heat pipes with a dual-diameter tube." International Journal of Heat and Mass Transfer 75 (2014): 184-195.
[3] Wang, Jiansheng, He Ma, and Qiang Zhu. "Effects of the evaporator and condenser length on the performance of pulsating heat pipes." Applied Thermal Engineering 91 (2015): 1018-1025.
[4] Rahman, M. Lutfor, et al. "An experimental investigation on the effect of fin in the performance of closed loop pulsating heat pipe (CLPHP)." Procedia Engineering 105 (2015): 137-144.
[5] Karthikeyan, V. K., et al. "Effect of nanofluids on thermal performance of closed loop pulsating heat pipe." Experimental Thermal and Fluid Science 54 (2014): 171-178.
[6] Ahmad, Hibal, and Sung Yong Jung. "Effect of active and passive cooling on the thermo-hydrodynamic behaviors of the closed-loop pulsating heat pipes." International Journal of Heat and Mass Transfer 156 (2020): 119814.
[7] Bhramara, P. "CFD analysis of copper closed loop pulsating heat pipe." Materials Today: Proceedings 5.2 (2018): 5487-5495.
[8] Tseng, Chih-Yung, et al. "Investigation of the performance of pulsating heat pipe subject to uniform/alternating tube diameters." Experimental thermal and fluid science 54 (2014): 85-92.
[9] Kwon, Gi Hwan, and Sung Jin Kim. "Experimental investigation on the thermal performance of a micro pulsating heat pipe with a dual-diameter channel." International Journal of Heat and Mass Transfer 89 (2015): 817-828.

[10] Aref, Latif, et al. "A novel dual-diameter closed-loop pulsating heat pipe for a flat plate solar collector." Energy 230 (2021): 120751.
[11] Charoensawan, P., Khandekar, S., Groll, M., & Terdtoon, P. (2003). Closed loop pulsating heat pipes: Part A: parametric experimental investigations. Applied thermal engineering, 23(16), 2009-2020.
[12] Ali, Abu Raihan Ibna, and Bodius Salam. "A review on nanofluid: preparation, stability, thermophysical properties, heat transfer characteristics and application." SN Applied Sciences 2.10 (2020): 1-17.
[13] Haddad, Zoubida, et al. "A review on how the researchers prepare their nanofluids." International Journal of Thermal Sciences 76 (2014): 168-189.
[14] Pachghare, Pramod R., and Ashish M. Mahalle. "Thermo-hydrodynamics of closed loop pulsating heat pipe: an experimental study." Journal of Mechanical Science and Technology 28.8 (2014): 3387-3394.
[15] Pradeep, G. V., and K. Rama Narasimha. "Experimental investigations on the thermal performance of a single closed loop pulsating heat pipe using TiO2 Nanofluid." Journal of Heat Transfer 141.9 (2019).