A Preliminary Investigation of Oscillating Heat Pipe Using Aluminum Capillary Tube

by Adi Winarta

AIP Conference Proceedings

RESEARCH ARTICLE | MAY 08 2023

A preliminary investigation of oscillating heat pipe using aluminum capillary tube

Adi Winarta ✉; Nandy Putra

AIP Conference Proceedings 2706, 020097 (2023)
https://doi.org/10.1063/5.0122650

AIP Publishing

A Preliminary Investigation of Oscillating Heat Pipe Using Aluminum Capillary Tube

Adi Winarta[1, a)] and Nandy Putra[2, b)]

[1]*Department of Mechanical Engineering, Politeknik Negeri Bali, 80364, Bali, Indonesia*
[2]*Department of Mechanical Engineering, Universitas Indonesia, 16425, Depok, Indonesia*

[a)] *Corresponding author: adi.winarta@pnb.ac.id*
[b)] *nandy.putra@ui.ac.id*

Abstract. Oscillating Heat Pipe (OHP) is one of the newest heat pipe family which have a potential application at space and aerial application. This application usually has strict constrain in weight and flexibility. In this early-stage studies, an aluminum OHP was tested with different filling ratio of distilled water (DI) water as working fluid. Method of vacuum charging was applied to injected the working fluid into the heat pipe properly. Aluminum OHP was constructed with 12 turns and formed into close loop. The heat supplied to the evaporator was varied from 10 until 60 watts. The result show that there is an effect of generation non-condensable gas which obstruct the heat transfer performance of aluminum OHP.

INTRODUCTION

In recent years Oscillating Heat Pipe (OHP) as one of the two-phase heat transfer technologies has attracted the attention of many scientists. With the excellent performance capabilities, simple structure and low production costs, OHP promises huge potential in a wide range of heat transfer applications [1, 2]. This technology was first introduced by Akachi et al. [3] on USA Patent at 1990. Although the fundamental concept of OHP has been claimed by Smyrnov and Savchenkov at Russia Patent on 1975 [4]. In 2003, Smirnov returned to patent the method, construction and basic concept of this heat pipe type [5] in USA Patent. In OHP, the heat transfer from evaporator to condenser was generated by oscillations or circulation of the working fluid inside the OHP. This oscillations or circulation of the working fluid was caused by pressure difference at the evaporator and condenser. This occurs due to heat input at the evaporator section and rejected heat at the condenser. The evaporator heat input would create the bubble growth and simultaneously, rejected heat at the condenser would result bubble collapse. This condition, which is coupled by the distribution of the working fluid in the form of the composition of liquid and vapor, would cause complex displacement in the form of pulsating and oscillating movements in the OHP [6].

The OHP research in the last decade focused on some aspects, such as flow pattern of working fluid, thermal performance, global orientation, gravity effects and mathematics analysis [6-13]. From the flow pattern study, we also known if some patterns such as bubbly flow, slug flow, annular and semi annular occur during the operational process [10, 12]. Each pattern has different heat transfer characteristics which would affect the performance of OHP [14]. As one of the prime parameters, heat input to the evaporator greatly affects the flow pattern and contribute to the oscillating motion of liquid and vapor plug inside the OHP tube. Certain flow pattern causes a different heat transfer potentiality. When heat input was rising, heat transfer capability would also rise as a result of stronger oscillating movement [15]. Observation of the flow pattern such as oscillation, circulation, changes in flow direction and unidirectional flow of this circulation was closely associated with the change of heat input [16] .

Observations visualization on OHP typically uses material with transparent tube. However, the use of these materials has some drawbacks such as transient temperature that would be difficult to recognize due to its low thermal conductivity [17]. Karthikeyan et al. [18] made observations with thermograph technique for the thermal profile of working fluid of the OHP to obtain thermal performance relationship with the character of the flow pattern. Their work used water as working fluid with filling ratio 60% and the OHP has 10 turns. Their results showed that the

3rd Borobudur International Symposium on Science and Technology 2021
AIP Conf. Proc. 2706, 020097-1–020097-7; https://doi.org/10.1063/5.0122650
Published by AIP Publishing. 978-0-7354-4447-8/$30.00

Infrared thermograph was a very interesting tool for transient heat transfer conditions such as OHP. In this work, an oscillating heat pipe which made from aluminum capillary tube was tested using different filing ratio (45%) of OHP with water as working fluid. The performance and effect of aluminum as heat pipe container was observed and analyzed in this first stage work.

METHOD

Experimental Setup

The structure of the OHP was made by capillary tube with inside and outside diameter 1.6 and 2.18 mm respectively. The capillary dimension of pipe tube is used to ensure the formation of the liquid and vapor slug regarding with maximum diameter formula as shown in equation 1 [3] below:

$$d_{max} = 1.8 \cdot (\sigma / (\rho_l - \rho_v))^{\frac{1}{2}} \tag{1}$$

Figure 1 shows the schematic of the experimental setup of OHP test. The dimension of OHP was 230 mm x 110 mm with 10 turns. Evaporator, adiabatic and condenser length were 40, 120 and 70 mm respectively. The walls of each part of this section (evaporator, adiabatic and condenser) were solder with thermocouple type K 0.3 mm in diameter, with the ± 0.5°C accuracy. To provide the heat input to the evaporator section, a pair of copper block with semicircular groove were made fix into evaporator section. The copper block has dimension of 131.5 x 5 x 40 mm3 and semicircular groove is manufactured in order to improve thermal contact with round geometry of pipe. Thermal paste was applied between the capillary tube and copper block to reduce thermal contact resistance. Cartridge heater (Omega CSH-104 400) was used as a heat source for the evaporator section. The heater was inserted into aluminum block through interference fit hole. Between these two metal blocks (copper and aluminum) stainless steel block with dimensions 131.5 x 25 x 40 mm^3 was inserted as conduction block. Each side of the stainless-steel blocks which contact with copper and aluminum were soldered with the thermocouple to measure the temperature difference. The conduction stainless steel block helps calculate the input heat (Q) for the evaporator section based on the equation 2.

$$Q = k \cdot A \cdot \Delta T / L \tag{2}$$

With is k the thermal conductivity of stainless steel, ΔT is temperature difference between each side of stainless steel which is in contact with copper and aluminum block and L is thickness of the stainless steel. All the experimental data captured at bottom heating mode or it means the evaporator section placed at the bottom of test section.

A thermostatic bath was used to supply the cold water with ±15°C for cooling the condenser section in the acrylic cooling box. The mass flow rate of cold water was measured using a rota meter (±450 mL/sec). Some type-K thermocouples (bead diameter 0.3mm and accuracy of ± 0.1°C) were used to measure wall temperature, i.e., two points (T1 and T2) at evaporator, two points (T3 and T4) at adiabatic and two points (T5 and T6) at part of condenser. To record temperature data, we used NI-9174, NI-9219 and LabVIEW data acquisition with sampling rate of 3 data per second. This refers to the characteristic frequency range of internal OHP oscillating phenomena tube 0.1 and 3 Hz [19]. Temperature observation was also accomplished by using a infrared camera (FLIR i50 with 140 x 140 pixels image resolution). The thermography observation would be done to the painted black part of adiabatic, to give a higher emissivity (Ɛ=1).

Charging fluid in OHP was done using back filling method [20]. OHP is vacuumed first, then DI Water as working fluid was injected into it. Filing ratio was the ratio between injected fluid volume with OHP tube total volume. The ratio of the working fluid used was 45%.

Total thermal resistance of OHP (R_{tot}) is the ratio of the temperature difference between the evaporator and condenser $(T_{evap} - T_{condenser})$ then divided by the heat input. The equation for calculating (R_{tot}) is given as follows:

$$R_{tot} = \frac{\bar{T}_{evap} - \bar{T}_{condenser}}{Q} \tag{3}$$

Where,

$$\bar{T}_e = \frac{T_1 + T_2}{2}, \ \bar{T}_c = \frac{T_3 + T_4}{2} \tag{4}$$

Effective thermal conductivity (K_{eff}) computed by

$$K_{eff} = \frac{L_{tot}}{A_{cr}} \frac{1}{R_{tot}} = \frac{L}{A_{cr}} \frac{Q}{(\overline{T}_{evap} - T_{\infty})} \quad (5)$$

$$\text{Where, } A_{cr} = n \cdot \pi \cdot \frac{d_{out}^2}{4} \text{ and } L_{tot} = \frac{1}{2}(L_e + L_c) + L_a \quad (6)$$

$A_{cr}, \overline{T}_{evap}, T_{\infty}$, L_e, L_c, L_a respectively are area of tube cross section, average evaporator temperature, fluid cooling temperature evaporator length, condenser length, adiabatic length.

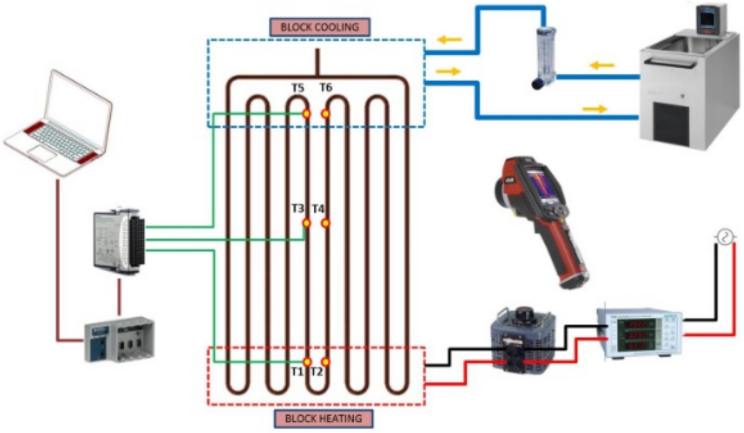

FIGURE 1. Experiment set-up

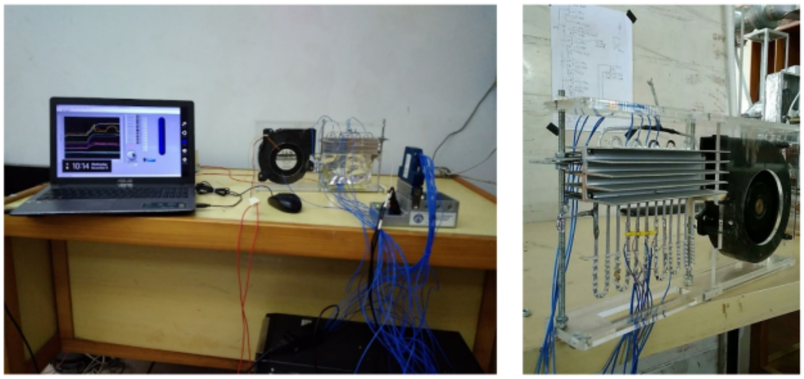

FIGURE 2. Implementation of experiments in the laboratory

RESULT AND DISCUSSION

The profile temperature distribution observed by Karthikeyan et al [18] with infra-red technique clearly indicates that there were different flow patterns on OHP. By using infra-red camera and thermocouple temperature observation this test seeks to observe transient temperature distribution of the OHP at various heats input. Without the use of visualization techniques, it was difficult to determine the dynamic behavior of liquid slug and slug of vapor inside the tube of OHP [21] at the appropriate heat input (Figure 3).

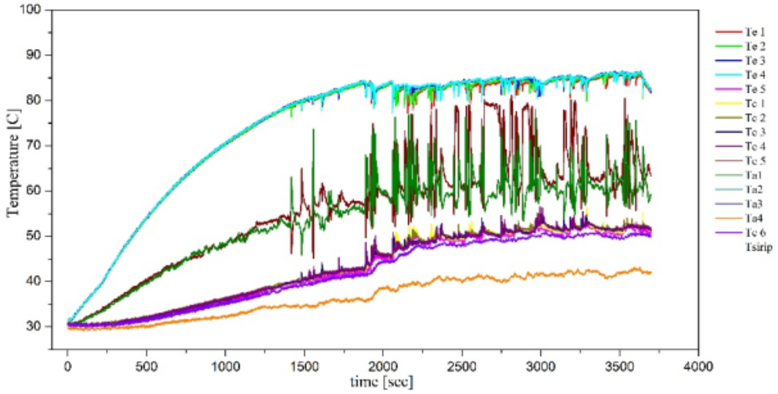

FIGURE 3. Test no 1 to aluminium OHP with DI water as working fluid and heat load 25 watt

Figure 3 shows the global temporal evolution of the evaporator and condenser temperatures for all heat input variation. Each of heat input as shown in Figure 2 would be analyzed separately (see Figure 4).

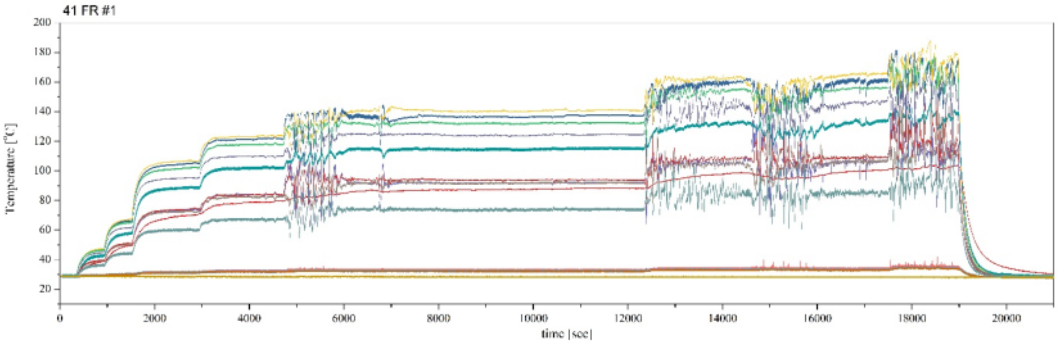

FIGURE 4. Test no 1 to aluminium OHP with DI water as working fluid and heat load 25 watt

Start-up process of oscillating heat pipe as observed by Xu et al [22] very easily to do when using this technique (pairing thermocouple and infra-red). It can be clearly concluded that there had no motion of the working fluid at all section in the OHP. The gradual increase temperature of the evaporator and condenser due to conduction heat transfer process at copper capillary tube. There's not enough heat energy to produce bubble growth at the evaporator section to initiated pumping motion from the pressure difference.

Small temperature fluctuations on the evaporator and condenser were started at the 24 Watt heat input. Conversely from the infra-red picture the fluid oscillation motion clearly seen from different temperature spatial distribution on each adjacent channel. These thermal footprints indicate the occurrence of macro working fluid movement on adiabatic section. Although the oscillation still in random motion due to the device it is not fully initiated or intermittent oscillations. In evaporator, the temperature fluctuation occurs with lower amplitude than in condenser. These temperature fluctuations in the evaporator and condenser indicated the movement of liquid slugs and vapor plug. Heat absorption which generates bubble growth was taking place at a relatively constant temperature. Consequently, evaporator temperature did not change much and tend to look steady. While in the condenser, temperature fluctuations amplitude appears higher due to the difference between the high temperature vapor slug flow and very low condenser cooling temperature (15°C). Sensible heat dominated the heat rejection at the condenser cooling section. The more vigorous temperature fluctuations occur in the next heat input rise. Therefore, decreasing thermal resistance occurred at 36 Watt to 47 Watt heat input due to the higher frequency of oscillation of the working fluid (Figure 5).

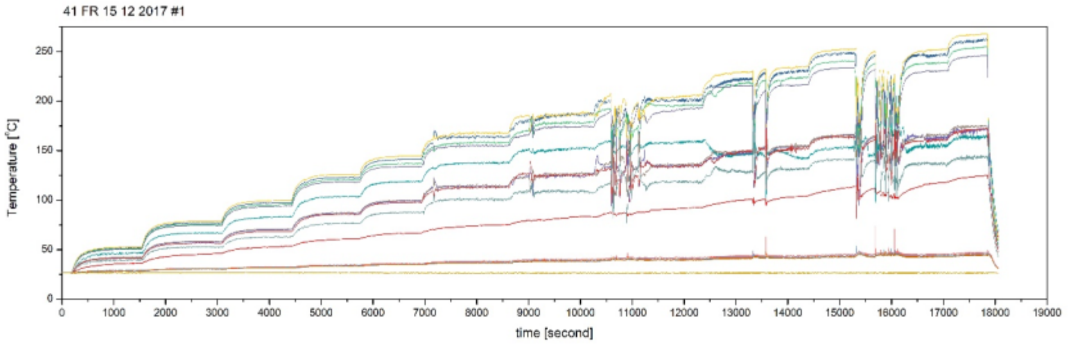

FIGURE 5. Test no 1 to aluminium OHP with DI water as working fluid and heat load 25 watt

Figure 5 shows the evolution of the temperature on 51 watt of heat input. From the graph, we can see if the evaporator's temperature tends would be steady at an average of 101.15 °C, which was indicates the absorption of heat by the heat pipe. The presence of temperature fluctuations at the evaporator and condenser also supports this case. The high amplitudes fluctuation on the condenser (20-22°C) is shown an exchange of heat due to the oscillating movement of the liquid slug. Temperature fluctuations that occur in the evaporator were much lower than the temperature fluctuations in the condenser section. This may indicate a bubble growth at the evaporator section which creates sufficient pumping action to move the liquid slug in oscillatory motion. Oscillation motion of liquid slug and vapor slug can be seen from the thermal footprint in Figure 5.

The frequency of temperature fluctuations on the condenser and evaporator higher at 65 watts of heat input. The increase in heat input provides sufficient energy to the liquid slug momentum so that changes in flow patterns of oscillation into circulation. This flow pattern changes lowers thermal resistance resulting from OHP. The circulation flows of working fluid increasing heat transfer performance of the OHP. There are sufficient decreases thermal resistance from increasing heat load from 51 to 65 Watt.

From temperature fluctuations and thermogram, it can be said that during circulation the liquid slug also oscillates axially. It was also stated by Borkar et al. [16] that the proper definition for this movement was "oscillatory circulation" or often said as bulk circulation. Oscillatory movement of the working fluid circulation can change direction and may also have a fixed direction. Raising the heat load to 88 Watt will augment the frequency of temperature fluctuations in the evaporator and condenser. The average temperature of the evaporator increases around 102.2°C. Rising frequency fluctuations resulted in a decrease in thermal resistance. At 109 watts of heat load, evaporator and condenser has a temperature fluctuation frequency remains high. However, the average temperature evaporator will rise to 106.6°C. The average temperature of the condenser also increased from 34.2°C the heat input 88 Watt became 41.47°C the heat input 109 Watt. The raise of average temperature can be seen on the temperature distribution in the infra-red camera picture. From the thermal point of view, the entire surface of the OHP has higher temperature. This resulted in the accession of the working fluid vapor fraction.

CONCLUSION

We have made a copper OHP using water as working fluid with filing ratio of 45% and 10 turn at evaporator and condenser. From the experimental work, we summary some major conclusions as follows:

1. Spatial thermal distribution temperature able to provide qualitative identification picture for analyzing the flow patterns appear inside OHP tube. The occurred flow pattern was depending on the heat input supplied. The qualitative and quantitative analysis of this flow pattern were made by combining thermocouple temperature data observation and Infra-red thermography. There are three types of flow pattern could be clearly identified with these methods i.e. oscillating motion of capillary slug, circulatory oscillation or bulk circulation of slug flow and circulation of annular flow.

2. The thermal resistance of the OHP tends to decrease with increasing of input level. The effective thermal conductivity of OHP at 142 Watt was 8 times higher than pure copper metal.
3. The experiment is conducted with the working fluid of water, filling ratio of 40% and a high stage heat input, and the dry out conditions was reached at 142 Watt heat input. The dry out process can be seen from the spatial distribution of OHP transient surface temperature and qualitatively can be captured easier by infra-red cameras.

ACKNOWLEDGMENTS

The author would like to thank the financial support from Kemenristek/BRIN with contract number of 22/PL8/PG/2021.

REFERENCES

1. Y. Zhang and A. Faghri, "Advances and unsolved issues in pulsating heat pipes," *Heat Transfer Engineering,* vol. 29, pp. 20-44, 2008.
2. X. Han, X. Wang, H. Zheng, X. Xu, and G. Chen, "Review of the development of pulsating heat pipe for heat dissipation," *Renewable and Sustainable Energy Reviews,* vol. 59, pp. 692-709, 6// 2016.
3. H. Akachi, "Structure of a heat pipe," 1990.
4. S. G. Smyrnov G, USSR Patent, 1975.
5. G. Smyrnov, "Method of action of the pulsating heat pipe, its construction and the devices on its base," US Patent, 2003.
6. B. Y. Tong, T. N. Wong, and K. T. Ooi, "Closed-loop pulsating heat pipe," *Applied Thermal Engineering,* vol. 21, pp. 1845-1862, 12// 2001.
7. S. Khandekar, M. Schneider, and M. Groll, "Mathematical modeling of pulsating heat pipes: state of the art and future challenges," *Heat and Mass Transfer, SK Saha, SP Venkateshen, BVSSS Prasad, and SS Sadhal, eds., Tata McGraw-Hill Publishing Company, New Delhi, India,* pp. 856-862, 2002.
8. S. Khandekar, M. Groll, P. Charoensawan, S. Rittidech, and P. Terdtoon, "Closed and open loop pulsating heat pipes," in *K-4, Proceedings of 13th International Heat Pipe Conference, China Academy of Space Technology, Shanghai, China*, 2004, pp. 38-51.
9. J.-S. Kim, N. H. Bui, J.-W. Kim, J.-H. Kim, and H. S. Jung, "Flow visualization of oscillation characteristics of liquid and vapor flow in the oscillating capillary tube heat pipe," *KSME International Journal,* vol. 17, pp. 1507-1519, 2003.
10. S. Khandekar, M. Schneider, P. Schafer, R. Kulenovic, and M. Groll, "Thermofluid dynamic study of flat-plate closed-loop pulsating heat pipes," *Microscale Thermophysical Engineering,* vol. 6, pp. 303-317, 2002.
11. P. Charoensawan and P. Terdtoon, "Thermal performance of horizontal closed-loop oscillating heat pipes," *Applied Thermal Engineering,* vol. 28, pp. 460-466, 4// 2008.
12. S. Khandekar, P. Charoensawan, M. Groll, and P. Terdtoon, "Closed loop pulsating heat pipes Part B: visualization and semi-empirical modeling," *Applied Thermal Engineering,* vol. 23, pp. 2021-2033, 11// 2003.
13. H. Yang, S. Khandekar, and M. Groll, "Performance characteristics of pulsating heat pipes as integral thermal spreaders," *International Journal of Thermal Sciences,* vol. 48, pp. 815-824, 4// 2009.
14. C. Wilson, B. Borgmeyer, R. Winholtz, H. Ma, D. Jacobson, and D. Hussey, "Thermal and visual observation of water and acetone oscillating heat pipes," *Journal of Heat Transfer,* vol. 133, p. 061502, 2011.
15. H. B. Ma, *Oscillating Heat Pipe*. New York Springer, 2015.
16. R. Borkar and P. Pachghare, "Thermo-Hydrodynamic Behavior of Methanol Charged Closed Loop Pulsating Heat Pipe," *Frontiers in Heat Pipes (FHP),* vol. 5, 2014.
17. S. Thompson, H. Ma, R. Winholtz, and C. Wilson, "Experimental investigation of miniature three-dimensional flat-plate oscillating heat pipe," *Journal of Heat Transfer,* vol. 131, p. 043210, 2009.
18. V. K. Karthikeyan, S. Khandekar, B. C. Pillai, and P. K. Sharma, "Infrared thermography of a pulsating heat pipe: Flow regimes and multiple steady states," *Applied Thermal Engineering,* vol. 62, pp. 470-480, 1/25/ 2014.
19. S. Khandekar, A. P. Gautam, and P. K. Sharma, "Multiple quasi-steady states in a closed loop pulsating heat pipe," *International Journal of Thermal Sciences,* vol. 48, pp. 535-546, 2009/03/01 2009.

20. D. Reay, R. McGlen, and P. Kew, *Heat pipes: theory, design and applications*: Butterworth-Heinemann, 2013.
21. M. Mameli, "Pulsating Heat Pipes: Numerical Modeling and Experimental Assessment," *UNIIVERSIITA''DEGLII STUDII DII BERGAMO Facollttà dii IIngegnerriia,* 2012.
22. J. Xu and X. Zhang, "Start-up and steady thermal oscillation of a pulsating heat pipe," *Heat and Mass Transfer,* vol. 41, pp. 685-694, 2005.

A Preliminary Investigation of Oscillating Heat Pipe Using Aluminum Capillary Tube

ORIGINALITY REPORT

19%	12%	17%	6%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Universitas Indonesia Student Paper	3%
2	J. Torres, Z. N. Buck, H. Kaiser, X. He, T. White, M. Tyagi, R. A. Winholtz, F. Y. Hansen, K. W. Herwig, H. Taub. "A neutron scattering and electron microscopy study of the structure, wetting, and freezing behavior of water near hydrophilic CuO-nanostructured surfaces", Journal of Applied Physics, 2019 Publication	2%
3	Tingting Hao, Hongbin Ma, Xuehu Ma. "Heat transfer performance of polytetrafluoroethylene oscillating heat pipe with water, ethanol, and acetone as working fluids", International Journal of Heat and Mass Transfer, 2019 Publication	1%
4	S. Y. Nagwase, P. R. Pachghare. "Experimetal and CFD analysis of closed loop pulsating heat pipe with DI-water", 2013 International	1%

	Conference on Energy Efficient Technologies for Sustainability, 2013 Publication	
5	Nine, Md J., Md. Riyad Tanshen, B. Munkhbayar, Hanshik Chung, and Hyomin Jeong. "Analysis of pressure fluctuations to evaluate thermal performance of oscillating heat pipe", Energy, 2014. Publication	1%
6	elar.usfeu.ru Internet Source	1%
7	aisberg.unibg.it Internet Source	1%
8	heatpoweredcycles.org Internet Source	1%
9	Naoko Iwata, Hiroyuki Ogawa, Yoshiro Miyazaki. "Temperature-Controllable Oscillating Heat Pipe", Journal of Thermophysics and Heat Transfer, 2011 Publication	<1%
10	G. Gürsel, A.J.H. Frijns, F.G.A. Homburg, A.A. van Steenhoven. "A mass-spring-damper model of a pulsating heat pipe with a non-uniform and asymmetric filling", Applied Thermal Engineering, 2015 Publication	<1%

11	Qu, Jian, and Qian Wang. "Experimental study on the thermal performance of vertical closed-loop oscillating heat pipes and correlation modeling", Applied Energy, 2013. Publication	<1 %
12	Submitted to School of Business and Management ITB Student Paper	<1 %
13	www.me.ntu.edu.tw Internet Source	<1 %
14	Chinphat Patanathabutr, Phrut Sakulchangsatjatai, Pradit Terdtoon, Niti Kammuang-lue. "Effect of meandering turn numbers on maximum heat flux of rotating closed-loop pulsating heat pipe integrated on energy conversion devices", AIP Publishing, 2022 Publication	<1 %
15	arc.aiaa.org Internet Source	<1 %
16	vdoc.pub Internet Source	<1 %
17	www.worldscientific.com Internet Source	<1 %
18	Adi Winarta, James Julian, I. Made Rasta, I. Made Sugina, I. Ketut Adi. "Experimental	<1 %

study of thermoelectric cooler box using phase change material for thermal energy storage", AIP Publishing, 2023
Publication

---

19 Chunrong Yu, Yulong Ji, Lilin Chu, Zongyu Wang, Yadong Li, Hongbin Ma. "The Phenomenon of Unidirectional Circulating Flow in an Oscillating Heat Pipe", ASME 2019 6th International Conference on Micro/Nanoscale Heat and Mass Transfer, 2019 <1%
Publication

---

20 Hao, Tingting, Xuehu Ma, and Zhong Lan. "Effects of Surface Wetting Characteristics on Start-Up Performance of an Oscillating Heat Pipe", Volume 1 Micro/Nanofluidics and Lab-on-a-Chip Nanofluids Micro/Nanoscale Interfacial Transport Phenomena Micro/Nanoscale Boiling and Condensation Heat Transfer Micro/Nanoscale Thermal Radiation Micro/Nanoscale Energy Devices and Systems, 2016. <1%
Publication

---

21 Hari Prasad, Tarigonda, Pol Reddy Kukutla, P. Mallikarjuna Rao, and R. Meenakshi Reddy. "Experimental Investigation on Performance of Pulsating Heat Pipe", ASME 2015 Gas Turbine India Conference, 2015. <1%
Publication

22	www.iosrjournals.org Internet Source	<1 %
23	Dilawar, Mahendra, and Arvind Pattamatta. "A parametric study of oscillatory two-phase flows in a single turn Pulsating Heat Pipe using a non-isothermal vapor model", Applied Thermal Engineering, 2013. Publication	<1 %
24	Idrus, Fairosidi, Nazri Mohamad, Ramlan Zailani, Wirachman Wisnoe, and Mohd Zulkifly Abdullah. "Experimental Model to Optimize the Design of Cylindrical Heat Pipes for Solar Collector Application", Applied Mechanics and Materials, 2013. Publication	<1 %
25	Karthikeyan, V.K., Sameer Khandekar, B.C. Pillai, and Pavan K. Sharma. "Infrared thermography of a pulsating heat pipe: Flow regimes and multiple steady states", Applied Thermal Engineering, 2014. Publication	<1 %
26	Thompson, Scott M., Bradley S. Tessler, Hongbin Ma, Douglas E. Smith, and Annette Sobel. "Ultrahigh Thermal Conductivity of Three-Dimensional Flat-Plate Oscillating Heat Pipes for Electromagnetic Launcher Cooling", IEEE Transactions on Plasma Science, 2013. Publication	<1 %

27	Submitted to University of South Alabama Student Paper	<1%
28	Yulong Ji, Mengke Wu, Yanmin Feng, Chunrong Yu, Lilin Chu, Chao Chang, Yantao Li, Xiu Xiao, Hongbin Ma. "An experimental investigation on the heat transfer performance of a liquid metal high-temperature oscillating heat pipe", International Journal of Heat and Mass Transfer, 2020 Publication	<1%
29	macsphere.mcmaster.ca Internet Source	<1%
30	opus.lib.uts.edu.au Internet Source	<1%
31	tigerprints.clemson.edu Internet Source	<1%
32	Rostam Akbari Kangarluei, Majid Abbasalizadeh Ranjbari, Ahad Ramezanpour. "An experimental comparison of thermal performance: Smooth and inner-grooved closed loop pulsating heat pipes in different angles", International Communications in Heat and Mass Transfer, 2021 Publication	<1%
33	Thompson, Scott M., Hongbin Ma, Robert A. Winholtz, and Corey Wilson. "An Experimental	<1%

Investigation of Three-Dimensional Flat-Plate Oscillating Heat Pipe", Volume 3 Combustion Fire and Reacting Flow Heat Transfer in Multiphase Systems Heat Transfer in Transport Phenomena in Manufacturing and Materials Processing Heat and Mass Transfer in Biotechnology Low Temperature Heat Transfer Environmental Heat Transfer Heat Transfer Education Visualization of Heat Transfer, 2009.
Publication

34	Xiangdong Liu, Yongping Chen. "Fluid flow and heat transfer in flat-plate oscillating heat pipe", Energy and Buildings, 2014 Publication	<1 %

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		

A Preliminary Investigation of Oscillating Heat Pipe Using Aluminum Capillary Tube

GRADEMARK REPORT

FINAL GRADE

/0

GENERAL COMMENTS

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8