Thermal performance of Pulsating Heat Pipe on Electric Motor as Cooling Application

Nurhalimah Aprianingsih[1], *Adi* Winarta[1], *Nandy* Putra[1*]

[1]Applied Heat Transfer Research Group, Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Kampus Baru-Depok, Jawa Barat, 16424
*Corresponding Author: nandyputra@eng.ui.ac.id

Abstract. Heat generated on an electric motor can increase the working temperature. Excessive working temperature will reduce its performance and shorten the life. Therefore, an appropriate thermal management system is required in order to reduce the working temperature. The purpose of this study is to know the thermal performance of pulsating heat pipe which applied in electric motor as a thermal management system. A prototype of thermal management on an electric motor with a cartridge heater is constructed instead of a heat-generating rotor and stator. Six pieces of pulsating heat pipe are mounted, each mounted on the side mounting hexagonal mounted inside the electric motor. Pulsating heat pipe is made of a capillary tube with copper material using acetone as working fluid with a filling ratio of 0.5, with variation of power input. The surface temperature of the electric motor is reduced by 55.348 ^{o}C, with minimum thermal resistance of 0.151 ^{o}C/W.

1. Introduction

In general, the electric motor is divided into two main component parts; stator and rotor, which can be flowed electric current to produce output in the form of motion or rotation on the rotor. Electric current flowing (and resistance) in the process of energy conversion that occurs in an electric motor will increase the its working temperature. Electric motors will work optimally at a certain working temperature. If the operation of the electric motor has exceeded its working temperature, will reduce the performance of the electric motor. This corresponds to one of the electric motor power losses; Joule losses, in which losses caused by electric current, I, and electrical resistance of the conductor, R, expressed as I^2R [1].

The conventional electric motors cooling method typically used fins mounted on the outer surface of the electric motor housing. The fins are used to extend the surface area of the electric motor housing to increase heat transfer rate from the electric motor to the ambient air by convection. The fin installation is usually accompanied by an axial fan installation at one end of the motor shaft. The fan serves as a tool for generating forced convection by passing air through the fins, thereby increasing the rate of convection heat transfer. Several studies have been conducted to improve the cooling performance of conventional electric motors.

Farsane et al. [2] conducted experimental research on cooling closed-circuit electric motors, experiments were performed by measuring cooling temperatures by fans and fins. Li [3] proposed design modifications for improved performance of cooling of permanent magnetic electric motors with centrifugal impeller. Davin [4] conducted an experimental study on the use of lubricating oil as a coolant for electric motors. For electric motors with high heat, some other techniques can be applied to release heat to ambient air. One example is an electric motor cooling method using a cooling liquid flowing through a jacket placed between the stator and the use of motor housing. The use of liquid cooling aims to improve the effectiveness of electric motor cooling. Lee [5] undertook research on the development of a motor cooling system through forced cooling methods by providing channels for cooling the motor shell and hollow shaft on rotor cooling.

The heat pipe is a thermal device that has a high heat transfer capacity with a compact size and light weight and does not require additional external energy [6]. Putra et al. [7-9], Weng et al. [10], and Wang [11] have conducted studies on the use of heat pipe in thermal management of electronic devices. Studies on the use of heat pipe on the thermal management of electric vehicle batteries have also been carried out [12]. Putra et al. also undertook research on heat development of capillary axis combined with nanofluid as working fluid [13-15]. The results show that the combination of working fluid axis and nanofluid biomaterials improves thermal pipe heat performance.

Putra et al. [16] conducting experimental research on the thermal motor management system of electric motors using heat pipe that is attached to the electric motor housing. The heat pipe used is L-type compressed flat, attached to the motor housing between the fins. The results show a significant decrease in temperature on the electric motor casing. The type of heat pipe used is a commercial heat pipe with a relatively expensive price.

Pulsating heat pipe (PHP), or oscillating heat pipe, was first proposed by Akachi [17] in 1990. Since then he is considered to have excellent application prospects in the field of solar energy utilization, wasted heat recovery, aerospace thermal management and refrigeration electron. Pulsating heat pipe has many advantages [18-20]: (1) simple structure and low cost: PHP is made of capillary pipe, which can then be bent as needed. The characteristic absence of a capillary axis structure in the pipeline is very supportive in manufacturing. Small PHP diameter is also useful for savings; (2) excellent heat transfer capabilities: according to Shang et al. [21], PHP's thermal conductivity can reach tens of times of copper; (3) easy to miniaturization: the size of the PHP heat transfer device can be very small because the inside diameter of PHP is very small, which is one of the most interesting characteristics of PHP; and (4) high flexibility: PHP channels can be configured for various configurations according to the situation of the application. In general, PHP proved to be a simple, reliable, noiseless tool and an economical choice for heat transfer.

This study discusses the phenomena of heat transfer in electric motors using prototype electric motors by modifying where rotor and coil are replaced by cartridge heater to generate the desired heat to facilitate research in heat transfer settings. Motion and work system on electrical motor components is not the main focus in this research. The simulation is done assuming the electric motor is working at a maximum state, with standard environmental conditions. The purpose of this study is to determine the value of electric motor performance using pulsating heat pipe as a thermal management system by reducing the working temperature of the electric motor in experimental.

2. Methodology

2.1 Pulsating Heat Pipe

The pulsating heat pipe studied was constructed from copper tubing (alloy 122), having an outer diameter of 3.1 mm and inner diameter of 1.6 mm. The material was chosen because of its thermal conductance, as well as malleability for constructing the serpentine design. The tube diameter was chosen based on the limited sizes available and meets the dimension constraint of Eq. (1) suggested by Akachi et al. [23] for critical diameter.

$$D_{crit} = Bo\sqrt{\frac{\sigma}{g\ (\rho_1 - \rho_v)}}$$

Based on gravitational acceleration (g), surface tension (σ), liquid and vapor densities (ρ_1 and ρ_v), Bond number (Bo) relates surface tension force to gravitational force, which has been used for numerous studies, but variation exists with relation to what Bond number should be used for PHP calculations. Khandekar et al. [24] acknowledged the issue and mentioned relevant parameters from other studies such as the Laplace constant and Confinement number for defining channel size since Eq. (1) is not an accepted universal's criteria. They also noted that each classification accounts for channel size, surface tension and fluid density effects on flow within these devices. Some studies have referenced a Bo number of 1.84 [25,26], others have used a value of 2 for diameter calculations [23,27-29] while others examined a range of Bo numbers [30]. For this study a Bo of 2 was used, as Akachi et al. [23] originally suggested. The critical diameter was calculated for each of the three fluids tested. Calculations were also made for various temperatures since the PHP was exposed to a range from ambient to 120ºC. The smallest critical diameter calculated for all conditions was found to be 2.592 mm, which is still larger than the 1.6 mm inner diameter of the copper tube used.

Working fluid	D_{min}, mm	D_{max}, mm	$D_{max}\mu g$, mm
Water	1.90	4.98	28.77
Acetone	1.21	3.17	11.66
Ammonia	1.28	3.36	12.98
R-134a	0.56	1.52	2.61
HFO-1234yf	0.53	1.40	2.18

Table 1 PHP minimum and maximum diameters.

The working fluid used is acetone. In **Table 1**, it appears that acetone meets the capillary pipe diameter criteria used. Acetone has a low boiling point, which is 56.53ºC at atmospheric pressure. The lower the boiling point of a working fluid, the resulting latent heat is also lower. Lower latent heat will be useful for forming and breaking bubbles faster, as well as shortening the starts up time in PHP. When the latent heat of the working fluid is low, the lower superheat in the pipe wall can be started in PHP [31]. **Figure 1** shows that acetone has a low superheat temperature compared to other working fluids.

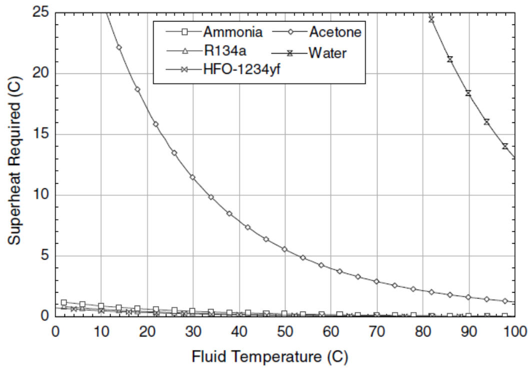


Figure 1 Superheat required for PHP start up as a function of bulk fluid temperature (ε = 2.5 μm) {reference}

Charge ratio is defined as the ratio of working fluid volume to the total volume of the PHP. Due to fact that the relative amounts of liquid plugs and vapor slugs depends on the charge ratio, the charge ratio has a significant influence on the performance of PHP. Experimental studies have shown that when the charge ratio is between 0.2 and 0.8, the PHP can operate normally [32,33]. Some researchers have reported the existence of the optimal charge ratio. Yang et al. [34] indicated that the charge ratio of 0.50 was optimal charge ratio to obtain the best performance. Yang et al. [35] investigated the heat transfer performance of PHP with ethanol and it was pointed out that the optimal range of charge ratio was 0.50–0.65 when the inclination angle of the PHP was 0° and -90°. While for the PHP with the inclination angle of 90°, the optimal charge ratio was about 0.15 when the heat flux was very low and was 0.40–0.70 when the heat flux was higher. In order to better identify the range of optimal charge ratio, the experimental data in the above literatures were collected and presented in **Figure 2**. It could be seen that the optimal charge ratio almost fell in the range of 0.35–0.65, so this range was generally recommended as the "optimal range" for PHPs. The working fluid ratio determined in this research is 0.5, according to the optimal range.

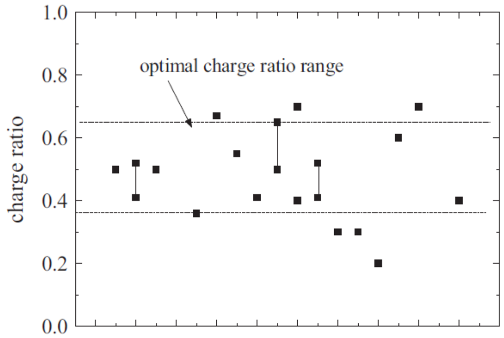


Figure 2 The recommended charge ratio of the PHP{reference}

2.2 Electric Motor Prototype

The study was conducted using a conventional electric motor simulator, modified in such a way as to simulate the heat transfer in an electric motor. The rotor components are replaced with cartridge heater with a diameter of 12.5 mm and a length of 8 mm to stimulate heat and simplify installation, while the stator or magnetic winding components are replaced by a component designed with a prism-6 shape, named hexagonal mounting, a pulsating heat pipe mounting component with each the side of the prism is closed by the side of the arch in such a way as to form a cylinder. So that the design can resemble the shape and size of the components in an electric motor, the stator. The ready-to-use pulsating heat pipe is then mounted on each side of the 6-sided prism, as shown in **Figure 3.**

The pulsating heat pipe is then placed on each side of the hexagonal mounting, with the evaporator side positioned near the cartridge heater, which acts as a heat absorber side which is stimulated by the cartridge heater. While on the side of the condenser is added an axial fan that serves to accelerate the heat dissipation with the phenomenon of forced convection. The axial fan is mounted in such a way with a DC motor drive source connected to the fan. To prevent heat transfer from cartridge heater to excessive pulsating heat pipe, a polyurethane isolator is used. In general, the design of electric motor prototype and its components can be seen in **Figure 4.**

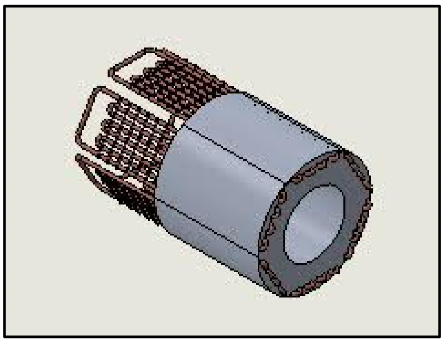
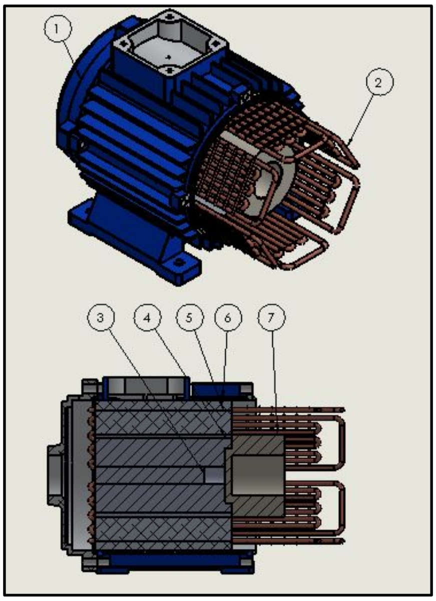


Figure 3. Hexagonal mounting with pulsating heat pipe.



1	Electric motor housing
2	Pulsating heat pipe
3	Cartridge heater
4	Cylinder cartridge heater mounting
5	Hexagonal mounting
6	Pulsating heat pipe upper mounting
7	Isolator

Figure 4. Electric motor prototype with pulsating heat pipe.

The temperature measuring instrument used in this research is K-type thermocouple Thermocouple is installed at several points on the electric motor simulator. Installation of thermocouple is to know the distribution of temperature on electric motor on the inside and outside of electric motor. The inner thermocouples are placed on a twelve-point mounting cartridge heater, six points on one side, and six on the other. While the outer thermocouples placed on the electric motor casing that amounted to twelve points. The installation of each thermocouple on the motor housing is aligned with the inside thermocouple point. This is done to determine the radial temperature distribution from the cartridge heater to the motor shroud. The thermocouple installation illustration for the temperature distribution can be seen in **Figure 5**.

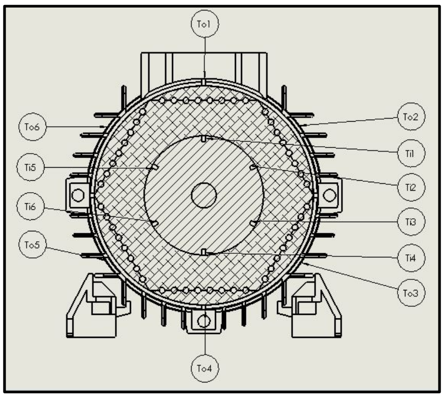


Figure 5. Thermocouple placement.

Thermocouple installation is also performed on each pulsating heat pipe. The thermocouple point is attached to each pulsating heat pipe, one on the evaporator side and one on the condenser side. Each of the thermocouples paired to the same one pulsating heat pipe should be aligned. This is done to know the temperature distribution at pulsating heat pipe, then based on the temperature data can be obtained the thermal resistance value of each pulsating heat pipe.

If total calculation of thermocouple is applied, then total thermocouple mounted on motor is 39 thermocouples. To obtain the temperature measurement data, the thermocouple is attached to the NI DAQ thermocouple terminal (National Instrument Data Acquisition). The terminal is then connected to a NI DAQ adapter.

2.3 Eksperimental Schematic

The required device in the study as shown in **Figure 6.** The electric motor simulator as the main tool to be measured, the AC voltage regulator as a tool that will provide power input on the cartridge heater, digital power meter as a tool to see the input power provided from the AC voltage regulator, NI DAQ device as a tool to connect thermocouple with computer, and a computer as a medium for connecting NI DAQ with LabView program so that temperature measurements can be measured in real time.

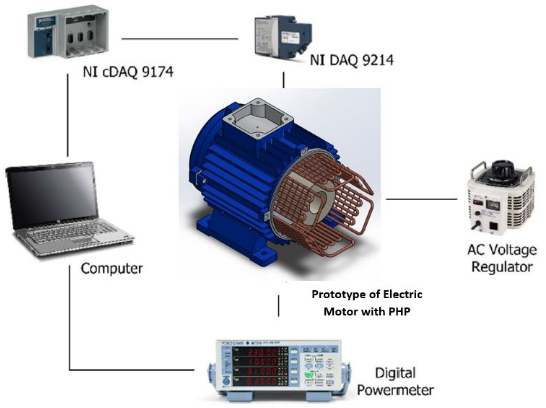


Figure 6. Schematic of experimental setup.

For every single variation of working fluid and orientation, temperature data with 30, 60, 90, 120 and 150Watt heat loads was performed. Each heat load is measured from a transient condition to a steady state. After reaching steady condition, heat transfer can be done. The same is done for the next variation or without using pulsating heat pipe. The measured data is then stored in the .lvm file.

3. Result and Discussion

3.1. Temperature and Heat Load Measurement

Experiments were carried out in the laboratory at ambient temperatures of 26-30ºC. The experiment started on a 30Watt heat load. The heating is done until the steady state is reached. Once the steady state is reached, twenty minutes later, the heat load is increased to 60Watt. This procedure is repeated at 90Watt, 120Watt and 150Watt heat loads. The experiments were done twice, the first by using PHP and the second by using PHP. **Figure 7** shows the results of the temperature measurement and the heat load. The heat load fluctuation is increased rapidly with the voltage because the heater is a quadratic function of the voltage [16]. The inner surface temperature on the cylinder shows little differences, this is due to the non-uniform heat propagation due to the difference in length, x, from the cartridge heater to the cylinder. While the external surface temperature shows a significant difference due to the placement of one thermocouple adjacent to the axial fan, resulting in lower temperature.

Temperature measurements on an electric motor without PHP are done by measuring the temperature on a PHP's mounting. This is to facilitate the retrieval of data. Then to know the external surface temperature of electric motor, used theoretical approach, as follows.

a. Calculation of the rate of conduction of electric motor heat transfer from cartridge heater to hexagonal mounting

Using heat rate equation,

$$Q = kA\frac{dT}{dx} \qquad (1)$$

with $k_{al} = 250\ W/m.K$; $A = 0.0054\ m$; and $x = 0.0475\ m$
then the heat rate from cartridge heater to hexagonal mounting,

$$Q = 250 \times 0.0054 \times \frac{(119.103 - 112.199)}{0.0475}$$

$$\boldsymbol{Q = 196.219\ Watt.}$$

b. Calculation of outer surface temperature of electric motor

Using heat rate equation for cylinder,

$$Q = \frac{2\pi L k \Delta T}{\ln{(r_2/r_1)}} \qquad (2)$$

with $L = 0.1\ m$; $r_1 = 0.0475\ m$; and $r_2 = 0.0548\ m$
then the difference temperature between inner and outer surface,

$$Q = \frac{2\pi L k \Delta T}{\ln{(r_2/r_1)}}$$

$$196.219 = \frac{2\pi \times 0.1 \times 250 \times \Delta T}{\ln(0.0548/0.0475)}$$

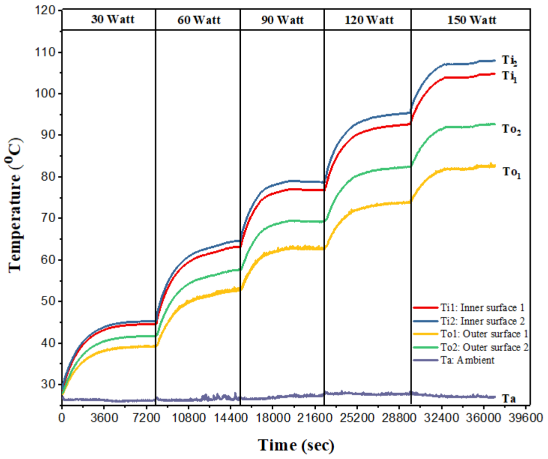
$$\Delta T = 0.178℃$$

So, the outer surface temperature,

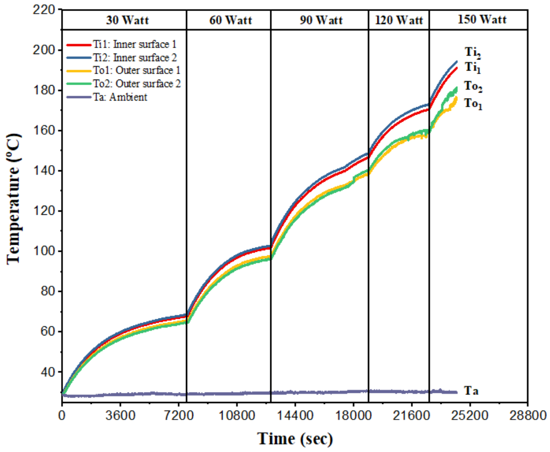
$$\Delta T = T_{o,1} - T_{o,2} \qquad (3)$$

$$T_{o,2} = (112.199 - 0.178)℃$$

$$\boldsymbol{T_{o,2} = 112.02℃}$$



(a)



(b)

Figure 7. Temperature and heat load measurement; (a) With PHP and (b) Without PHP.

3.2. Steady state temperature versus heat load

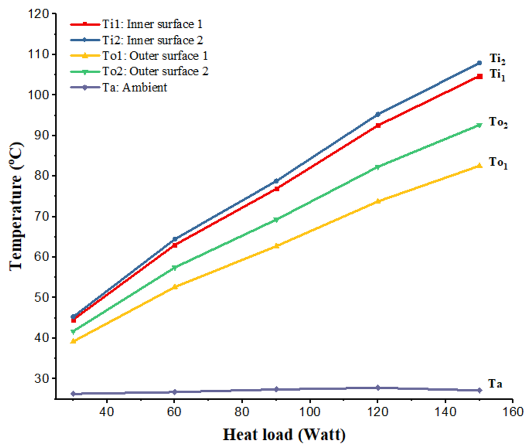


Figure 8. Steady state temperature vs. heat load.

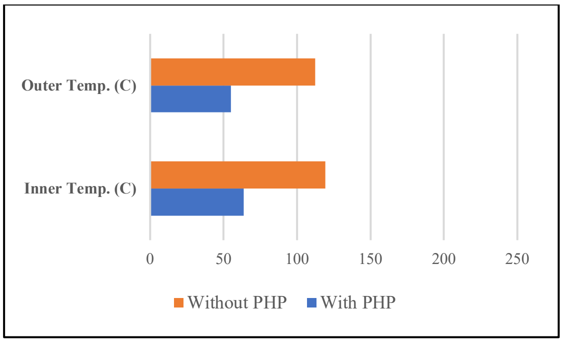


Figure 9. Temperature comparison.

The steady state temperatures are determined by averaging temperature value over the last twenty minutes during the steady state period. Figure 8 shows the steady temperature results on the inside and outside surfaces of the electric motor at each heat load. Steady temperatures on the prototype, as shown in the internal and external temperatures of the electric motor, increase with increasing heat load. This is consistent with the theory that the greater the heat load the greater the temperature difference shown in the equation of the heating rate.

The average temperature of the surface without PHP is compared to the surface with PHP. Figure 9 shows the effect of PHP implementation in the electric motor thermal management system. The temperature of the inner and outer surface of the cylinder increases with the heat load. At the heat load of 60W without PHP, the temperature of the inner and outer surface of the cylinder reach 119.10°C and 112.20°C, respectively. The use of the PHP reduces the inner and outer surface of the cylinder to 63.75°C and 55.07°C, or a reduction by 55.35°C and 57.13°C, respectively.

Lee et al. [37] used water jacket and hollow shaft with a 170 mm stator diameter motor run at a speed of 2300 rpm and torque of 7.38 Nm, i.e. about 1.78 kW. Assuming the motor has an efficiency of 90%, then the heat load is about 180 W. The use of heat pipes was capable to reduce the motor housing temperature to 68°C at heat load 150W with a stator diameter of 100 mm. Meanwhile, a water jacket-cooled and a hollow shaft-cooled motor were able to reduce the motor housing temperature to 43°C and 40°C respectively at a heat load about 180W with a stator diameter of 170 mm.

Putra et al. [16] using the similar method in electric motor thermal management system using L-shaped flat heat pipes showed the motor surface temperature was reduced from 102.2°C to 68.4°C or a reduction by 33.8°C.

3.3. Thermal Resistance

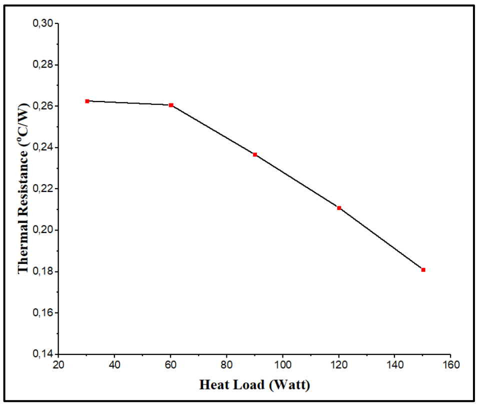


Figure 10. Thermal resistance of PHP

The thermal performance of a PHP is calculated based on the time-averaged evaporator and condenser temperature as per Eqs. (4) and (5). Total heat supplied is calculated through Eq. (6) and thermal resistance is calculated through Eq. (7). Negligible heat is observed to dissipate to surround based on the measured temperatures of the insulation box and surrounding. Hence, heat loss (Qloss) is neglected.

Average evaporator temperature, $T_e = \frac{1}{5}\sum_{i=1}^{5} T_i$ (4)

Average condenser temperature, $T_c = \frac{1}{5}\sum_{i=1}^{5} T_i$ (5)

Total heat supply, $Q = VI$ (6)

Thermal resistance, $R = \frac{T_e - T_c}{Q - Q_{loss}}$ (7)

Based on Figure 10 thermal resistance increases with increasing heat loads. This is in accordance with the theory of heat transfer rate where the value of the heat rate, Q, is inversely proportional to the thermal resistance, R.

4. Conclusions

The experiment to determine the performance of the electric motor thermal management system using pulsating heat pipes with acetone as working fluid has been conducted successfully. At the heat load of 60W, the outer surface temperature of the motor can be decreased from 112.20ºC to 55.07ºC, or a decrease by 57.13ºC, with thermal resistance of o.26ºC/W. The use of pulsating heat pipes can significantly reduce the temperature of the motor.

Acknowledgement

The authors would like to thank the DRPM (Directorate of Research and Community Service) Universitas Indonesia for funding the research.

References

[1] Y. Huai, R.V.N. Melnik, P.B. Thogersen, Computational analysis of temperature rise phenomena in electric induction motors, Appl. Therm. Eng. 23 (2003) 779–795.

[2] K. Farsane, P. Desevaux, P.K. Panday, Experimental study of the cooling of a closed type electric motor, Appl. Therm. Eng. 20 (2000) 1321–1334.

[3] H. Li, Cooling of a permanent magnet electric motor with a centrifugal impeller, Int. J. Heat Mass Transf. 53 (2010) 797–810.

[4] T. Davin, J. Pellé, S. Harmand, R. Yu, Experimental study of oil cooling systems for electric motors, Appl. Therm. Eng. 75 (2015) 1–13.

[5] K.-H. Lee, H.-R. Cha, Y.-B. Kim, Development of an interior permanent magnet motor through rotor cooling for electric vehicles, Appl. Therm. Eng. 95 (2016) 348–356.

[6] H.N. Chaudhry, B.R. Hughes, S.A. Ghani, A review of heat pipe systems for heat recovery and renewable energy applications, Renew. Sust. Energ. Rev. 16 (2012) 2249–2259.

[7] N. Putra, F.N. Iskandar, Application of nanofluids to a heat pipe liquid-block and the thermoelectric cooling of electronic equipment, Exp. Thermal Fluid Sci. 35 (2011) 1274–1281.

[8] N. Putra, W.N. Septiadi, R. Sahmura, C.T. Anggara, Application of Al2O3 nanofluid on sintered copper-powder vapor chamber for electronic cooling, Advanc. Mater. Res 789 (2013) 423–428.

[9] N. Putra, W.N. Septiadi, Improvement of heat pipe performance through integration of a coral biomaterial wick structure into the heat pipe of a CPU cooling system, Heat Mass Transf. (2016) 1–12.

[10] Y.-C. Weng, H.-P. Cho, C.-C. Chang, S.-L. Chen, Heat pipe with PCM for electronic cooling, Appl. Energy 88 (2011) 1825–1833.

[11] J.-C. Wang, L-type heat pipes application in electronic cooling system, Int. J. Therm. Sci. 50 (2011) 97–105.

[12] N. Putra, B. Ariantara, R.A. Pamungkas, Experimental investigation on performance of lithium-ion battery thermal management system using flat plate loop heat pipe for electric vehicle application, Appl. Therm. Eng. 99 (2016) 784–789.

[13] N. Putra, W.N. Septiadi, R. Saleh, R.A. Koestoer, S. Purbo Prakoso, The effect of CuO-water nanofluid and biomaterial wick on loop heat pipe performance, Advanced Materials Research, vol. 875, Trans Tech Publ., 2014, pp. 356–361.

[14] N. Putra, R. Saleh, W.N. Septiadi, A. Okta, Z. Hamid, Thermal performance of biomaterial wick loop heat pipes with water-base Al2O3 nanofluids, Int. J. Therm. Sci. 76 (2014) 128–136.

[15] N. Putra, W.N. Septiadi, H. Rahman, R. Irwansyah, Thermal performance of screen mesh wick heat pipes with nanofluids, Exp. Therm. Fluid Sci. 40 (2012) 10–17.
[16] Paper pak Bambang
[17] H. Akachi Structure of a heat pipe. Kanagawa. US Patent 4921041; 1990.
[18] Khandekar S, Schneider M, Groll M. Mathematical modeling of pulsating heat pipes: state of the art and future challenges. In: Proceedings of 5th ISHMT- ASME-joint international conference on heat and mass transfer, India; 2002.
[19] Groll M, Khandekar S. Pulsating heat pipes: progress and prospects. In: Proceedings of international conference on energy and the environment, China; 2003.
[20] Khandekar S, Groll M, Charoensawan P, Rittidech S, Terdtoon P. Closed and open loop pulsating heat pipes. In: Proceedings of the 13th international heat pipe conference, China; 2004.
[21] Shang FM, Liu DY, Xian HZ, Liu JH. Experimental investigation on enhanced heat transfer of self-exciting mode oscillating-flow heat pipes. J EngThermophys (China) 2009; 30(3): 461–4.
[22] Wright, W.H., M.S. Thesis, Georgia Institute of Technology, 1-225, 1960. TPRC Data Series Volume 1, pages 75, 80 and 1465.
[23] H. Akachi, F. Polásek, P. Stulc, Pulsating heat pipes, in: Proceedings of the Fifth International Heat Pipe Symposium, Melbourne, Australia (1996) 208e217.
[24] S. Khandekar, P.K. Panigrahi, F. Lefèvre, J. Bonjour, Local hydrodynamics of flow in a pulsating heat pipe: a review, Frontiers in Heat Pipes 1 (2010).
[25] H.B. Ma, C. Wilson, B. Borgmeyer, K. Park, Q. Yu, S.U.S. Choi, et al., Effect of nanofluid on the heat transport capability in an oscillating heat pipe, Applied Physics Letters 88 (2006) 143116.
[26] B. Borgmeyer, C. Wilson, R.A. Winholtz, H.B. Ma, D. Jacobson, D. Hussey, Heat transport capability and fluid flow neutron radiography of three-dimensional oscillating heat pipes, Journal of Heat Transfer 132 (2010) 061502.
[27] S. Khandekar, M. Schneider, P. Schafer, R. Kulenovic, M. Groll, Thermofluid dynamic study of flat-plate closed-loop pulsating heat pipes, Microscale Thermophysical Engineering 6 (2002) 303e317.
[28] R.R. Riehl, Characteristics of an open loop pulsating heat pipe, in: Proceedings of 34th International Conference on Environmental Systems, Colorado Springs, CO (2004).
[29] Y. Zhang, A. Faghri, Advances and unsolved issues in pulsating heat pipes, Heat Transfer Engineering 29 (2008) 20e44.
[30] S. Rittidech, N. Pipatpaiboon, P. Terdtoon, Heat-transfer characteristics of a closed loop oscillating heat-pipe with check valves, Applied Energy 84 (2007) 565e577.
[31] Zhang YW, Faghri A. Advances and unsolved issues in pulsating heat pipes. Heat Transf Eng 2008; 29 (1): 20–44.
[32] Shafii MB, Faghri A, Zhang YW. Thermal modelling of unlooped and looped pulsating heat pipes. J Heat Transf 2001; 123: 1159–72.
[33] Vassilev M, Avenas Y, Schaeffer C, Schanen JL, SchulzHarder J. Experimental study of a pulsating heat pipe with combined circular and square section channels. In: Proceedings of the record of the 2007 IEEE industry applications confence forty-second IAS annual meeting, New York.
[34] Yang HH, Khandekar S, Groll M. Operational limit of closed loop pulsating heat pipes. Appl Therm Eng 2008; 28(1): 49–59.
[35] Yang HH, Khandekar S,Groll M. Performance characteristics of pulsating heat pipes as integral thermal spreaders. Int J Therm Sci 2009; 48(4): 815–24.
[36] review working fluid php
[37] K.-H. Lee, H.-R. Cha, Y.-B. Kim, Development of an interior permanent magnet motor through rotor cooling for electric vehicles, Appl. Therm. Eng. 95 (2016) 348–356.

Gmail

Adi Winarta <artawina@gmail.com>

---

paper motor

Adi Winarta <artawina@gmail.com> Tue, May 8, 2018 at 1:23 PM
To: Bambang Ariantara <bambang.ariantara@gmail.com>

Dr. Bambang

Please, review or paper about management thermal of an electric motor using OHP. Thanks for your support and contributions.

regards

adi winarta

---

i-TREC FULL PAPER - Nurhalimah Aprianingsih (rev1).docx
439K

Gmail

Adi Winarta <artawina@gmail.com>

Fwd: Camera Ready Paper Submission to i-trec 2018

Nasruddin Abdullah <nasruddin.aaf@gmail.com> Mon, Sep 3, 2018 at 6:55 PM
To: Adi Winarta <artawina@gmail.com>

---------- Forwarded message ----------
From: **Nurhalimah Aprianingsih** <nurhalimah3092@gmail.com>
Date: Sun, Sep 2, 2018 at 7:11 AM
Subject: Fwd: Camera Ready Paper Submission to i-trec 2018
To: Nasruddin Abdullah <nasruddin.aaf@gmail.com>

---------- Forwarded message ---------
From: **i-TREC 2018** <itrec2018@easychair.org>
Date: Sat, 1 Sep 2018, 18:36
Subject: Camera Ready Paper Submission to i-trec 2018
To: Nurhalimah Aprianingsih <nurhalimah3092@gmail.com>

Dear Prof./Dr/Ms/Mr. Nurhalimah Aprianingsih

Greetings from Bali!

Congratulation on having your paper 225 titled "Thermal performance of Pulsating Heat Pipe on Electric Motor as Cooling Application" accepted for presentation at the 3rd I-TREC 2018 held on 6 - 8 September 2018 in Bali, Indonesia.

The camera-ready submission will open on 1 September 2018. Please submit your camera ready paper with the correct format according to the E3S template (http://i-trec.ui.ac.id/wp-content/uploads/2018/04/woc_2col.doc.) latest by 8 September 2018. We will return the papers which do not follow the E3S format. Please make sure that you pay attention to every detail of the format. Otherwise, it will delay the publication process.

In addition, we recommend you to include at least one reference, if possible, from the International Journal of Technology (IJTech) available at http://ijtech.eng.ui.ac.id/.

PLEASE NOTE that any accepted paper included in the final program is expected to have at least one author attending and presenting the paper at the conference to get published.
We are looking forward to welcoming you in Bali.

Kind regards,
Eny Kusrini, Ph.D.
The 3rd i-TREC 2018 General Chair
TREC Faculty of Engineering
Universitas Indonesia
Website: https://i-trec.ui.ac.id
Email: i-trec@ui.ac.id

Gmail

Adi Winarta <artawina@gmail.com>

Fwd: Update on 3S Publication of your paper 225

1 message

nandyputra@eng.ui.ac.id <nandyputra@eng.ui.ac.id> To: artawina@gmail.com

Sat, May 6, 2023 at 7:32 PM

-------- Pesan Asli --------

Judul: Update on 3S Publication of your paper 225
Tanggal: 2018-11-27 06:22
Pengirim: "i-TREC 2018" <itrec2018@easychair.org>
Penerima: Nandy Putra <nandyputra@eng.ui.ac.id>

Dear Prof./Dr./Mr./Ms. Nandy Putra

Greetings from the 3rd i-TREC committee.

We would like to inform you that the proceedings of the 3rd i-TREC 2018 have been available online at the following link

https://www.e3s-conferences.org/articles/e3sconf/abs/2018/42/e3sconf_i-trec2018_03035/e3sconf_i-trec2018_03035.html

We thank you for your excellent contribution to the 3rd i-TREC 2018. We are looking forward to seeing you again in the 4th i-TREC 2019.

Warmest Regards,
Eny Kusrini, Ph.D.

Bagian 1.asc
1K