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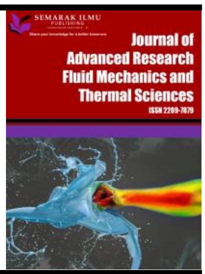

Investigation of Single-Phase Immersion Cooling for Modern Data Centers

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ABSTRACT

Compact servers with a high energy density are the result of the telecommunications industry's rapid advancement. Innovative cooling solutions are required due to the expanding scale of data centers and related cooling needs. Servers in the data center might be cooled via immersion cooling by immersing them in a thermally conductive die electric fluid. In this study, three distinct dielectric liquids were used with variable circulation rates to examine the effectiveness of single-phase immersion cooling with varying heat inputs of 300, 400 and 500 Watts. Deionized water, white mineral oil and propylene glycol were the three dielectric fluids being considered, at circulating rates of 1, 2 and 3 litres per minute. Among the three fluids tested, deionized water consistently outperformed the others by maintaining the lowest outlet temperature across various heat inputs and flow rates. The average heat transfer coefficient for deionized water was calculated as the highest, with a value of 349.29 W/m²·K. Propylene glycol had an intermediate heat transfer coefficient, which was 194.69 W/m²·K, and mineral oil exhibited the lowest heat transfer coefficient at 74.44 W/m²·K.

1. Introduction

Data Center is an amenity created to provide space, cooling and uninterrupted power to the storage devices. Data centers are densely packed with heat-generating electronic equipment. Rapid growth in the field of information technology has given rise to new challenges in the field of computing [1,2]. The concept of modern electronic design is that smaller and faster is better. High power densities, high operating temperatures, poor performance, and a short lifespan for electronic equipment are all consequences of this trend [3-5]. By 2030, it is predicted that data center's energy consumption might account for up to 13% of the world's electricity production [6]. Typically, around 30% to 50% of the total energy consumption in a data center is allocated to cooling purposes [7-9]. Data centers' energy requirements for cooling have significantly increased over the past decade as a result of a considerable rise in heat generated per unit volume of space. Cooling the servers effectively was the top priority rather than the energy efficiency in data centers. The challenge in

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front of the industry is to ensure the cooling needs of the data center without compromising on energy efficiency. The majority of electronic thermal management research considers 85°C as the maximum operating temperature for the safe and efficient operation of microprocessors. There are, however, a few other references in the literature that suggest junction temperature limitations that are slightly higher or lower [10]. Currently, the majority of data centers rely on traditional air cooling for their operations. Traditional methods of cooling the data center may not be able to satisfy the cooling demands soon [11]. The enhanced heat transfer capability of liquid cooling systems has boosted interest in them for data centers. On the positive side, this results in lower temperatures and more even heating of the electrical components. Conversely, the cooling system may function at greater temperatures, improving energy efficiency and providing other benefits like quieter operation. The working fluid for an immersion cooling system should be a good thermal conductor but not conduct electricity [12]. In comparison to liquid cooling, air cooling is superior in terms of its straightforward design, lightweight, low cost, and ease of maintenance. However, the cooling effectiveness is poorer due to the low thermal characteristics of air. Liquid cooling can be categorized as direct cooling or indirect cooling. Direct cooling is a method in which electronic components are immersed in dielectric liquid and indirect cooling is a method in which liquid doesn't directly come in contact with the electronic components instead a heat exchanger is used. Single-phase immersion cooling is a novel approach to the problem of high heat flux electronic equipment heating. Additionally, it has a simple construction and less expensive cooling fluid as compared to two-phase immersion cooling allowing power capacities in a single cabinet of up to 100 kW or even exceeding 200 kW [13-17]. Figure 1 depicts the commonly used data center cooling techniques. Out of all techniques immersion cooling holds the promise of enhancing energy efficiency, minimizing environmental consequences, and cutting costs, all while maintaining the reliability and scalability of data center facilities. The selection of fluids and operating conditions in the context of immersion cooling systems is of paramount importance. This study is primarily concerned with evaluating single-phase immersion cooling, with a focus on the selection of suitable cooling fluids and ideal operating conditions.

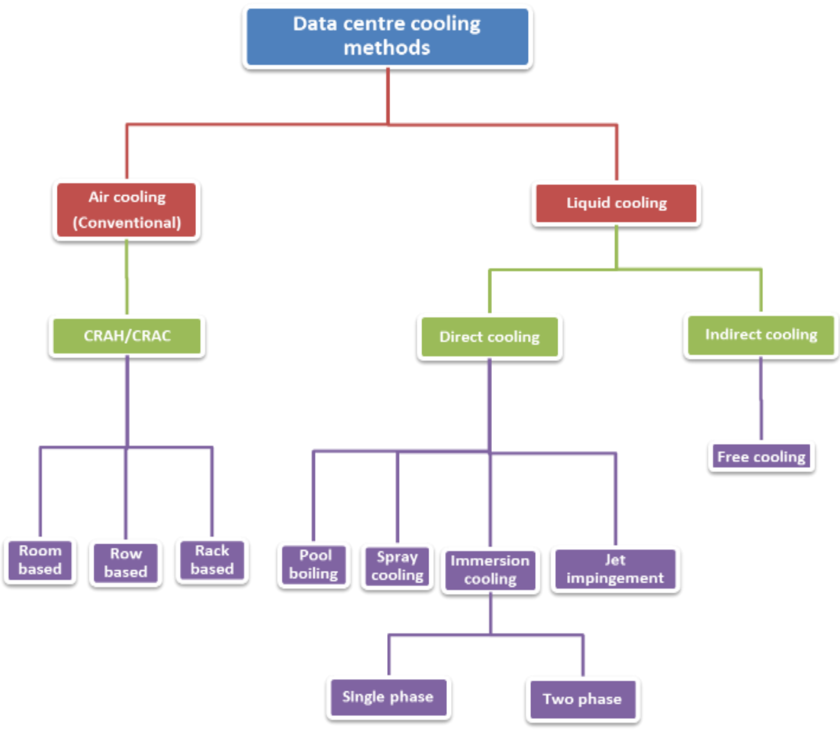


Fig. 1. Data center cooling methods

2. Literature Survey

Birbarah *et al.,* [18] experimentally demonstrated immersion cooling of electronics by using water instead of dielectric fluids. The author used water to overcome the disadvantages associated with the thermal properties of dielectric fluids. Printed circuit boards and electronic devices were insulated using conformal layers of parylene C of thickness 1µm, 5 µm and 25 µm. Cheng *et al.,* [19] modelled and simulated a CPU immersed in engineered fluid/ dielectric fluid 3 M Novec 7100 with forced circulation using the software. The variables included flow rate and different materials for the heat sink. The flow rates of 0.4, 0.8, and 1.2 m/s were considered and the materials of the heat sink considered were aluminium and copper. The simulated results were evaluated with an experiment test. The results showed that an increase in circulating speed reduced temperature, while the considered material for the heat sink had no significant effect on the temperature. Ramdas *et al.,* [20] studied how immersion cooling affects the thermo-mechanical properties of printed circuit boards and their reliability. According to this study, PCBs do not suffer any detrimental effects when submerged in dielectric fluid EC 100. Taddeo *et al.,* [21] studied 54 open computing project servers with a peak power of 400 Watts each were immersed and operated in a dielectric coolant. The testing, data gathering, and model validation of this system were encompassed. Results demonstrated how the system's thermal profile changed under both static and dynamic workloads, and they also illustrated a link between server energy consumption and system temperature. The system reaction to various cooling settings was investigated using the energy model, which was presented, tested against actual data, and utilized. The study supports the need for additional research and concludes by demonstrating the validity of the energy model. Shrigondekar *et al.,* [22] investigated the behaviour of heat transfer in a single-phase immersion cooling system using dielectric fluids FC40 and PAO-6 in a 1 U server. The thermal performance of the system was examined by several system factors, such as the fluid bypass (distance between the fluid tank and the heat sink), suction fans, heat sink fin pitch, fluid flow rate, fluid intake temperature, and heat load. Raising the fluid inlet temperature or heat load increased server temperatures and decreased thermal resistance. Numerical simulations provided insights into flow patterns and temperature distribution during fluid bypass [23]. White mineral oil and virgin coconut oil were the two fluids used in this study's experimental analysis of single-phase immersion cooling. According to research, temperatures achieved by immersion cooling were 13°C lower than those reached by traditional cooling. Utilizing a fan with an 800-rpm spin and a 1.5 litres per minute (LPM) flow rate was the most effective way to lower the temperature. Additionally, mineral oil outperformed virgin coconut oil in terms of how effectively the dielectric fluids cool. After five months of immersion in the fluid, there was no component degradation in the durability tests [24]. In this study, the reliability and characteristics of computer hardware immersed in mineral oil were investigated. The study looks at how mineral oil affected the physical characteristics of computer hardware, including its flow and electrical strength. Researchers found that using mineral oil to cool data centers has advantages including a reduction in problems like overheating, fan failures, noise, dust, and corrosion.

From the above discussions, it can be inferred that there is rising interest in cooling data centers using the immersion approach and that there is sufficient scope for improvement from fluid selection to ideal operating conditions for single-phase immersion cooling. It has been demonstrated via several tests that electronics can be submerged in a die-electric fluid. In the experiment designed, a heater of a size equivalent to 42 cubic millimetres was utilized to simulate the effect of a server rather than actual electronics because the current study is solely concerned with the best operating conditions and fluid selection. For heat inputs of 300, 400, and 500 watts, the heater with a surface area of 0.0106 m2 is subjected to heat fluxes of 28.34, 37.79, and 47.24 kW/m2, respectively.

3. Methodology

Table 1 shows the properties of fluids under consideration for the present study.

Table 1
Properties of Die electric fluids [25]

Fluids	ρ at 20^0 C (g/cc)	C (J/kg K)	k (W/m K)	υ (cSt)
Deionised Water	0.998	4200	0.610	0.658
Mineral oil	0.84	1670	0.130	9.6
Propylene glycol	1.036	3433	0.34	40.54

Figure 2 shows the methodology adopted for the experiments; the experimentation process involved the examination of three different fluids: deionized water, mineral oil, and propylene glycol. The primary variables considered during the experiments were the flow rates, with values set at 1 LPM, 2 LPM, and 3 LPM. Additionally, the heat input was adjusted at different levels, specifically 300 W, 400 W, and 500W. Following preliminary trials that showed little temperature fluctuations after 100 minutes hence period of 100 min was chosen for the experiment. During the experiments, the temperature at the inlet and outlet was recorded every 10 minutes for 100 minutes to gather information about the heat transfer characteristics of each fluid under different conditions. A pump, a valve with a rotameter for flow rate control and measurement, a variac for regulating heat input, and a radiator with a fan for controlling fluid temperature were all included in the experimental setup. Together, these components enable precise control and monitoring of fluid flow rate and heat input, ensuring the reliability and accuracy of the experimental results.

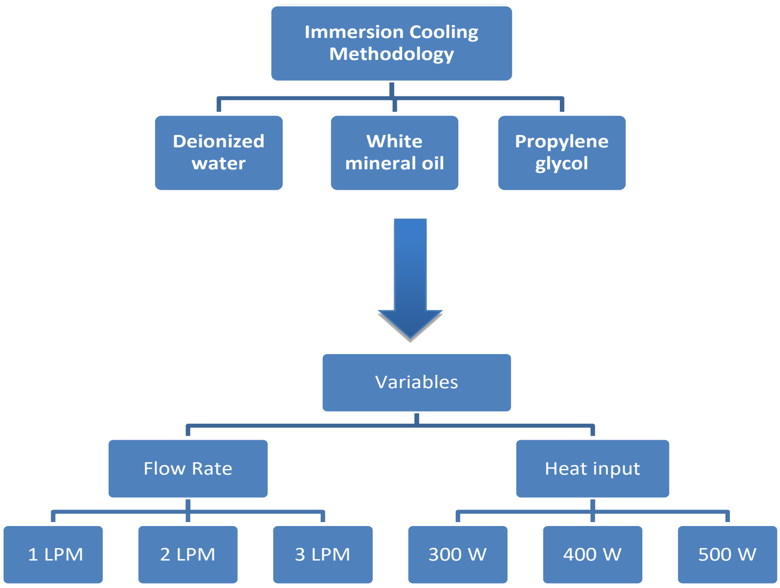


Fig. 2. Methodology

Figure 3 shows the modelling of the experimental setup and the fabricated experimental test rig. The immersion cooling structure has the following measurements: length of 320 mm, height of 240 mm, and width of 180 mm. A diaphragm-type pump was used in the experimental setup to circulate the fluid throughout the apparatus. By adjusting a valve, the fluid's flow rate was managed. A glass-tube rotameter with a float, which offers readings of the fluid's flow rate in real time, was used to precisely monitor and manage the flow rate. A standard variac with manual voltage adjustment was also used to examine the impact of various heat sources on the fluid. The system's heat input may be regulated and altered as necessary for the tests by altering the variac. A radiator with a fan was integrated into the setup to cool the liquid before recirculation.

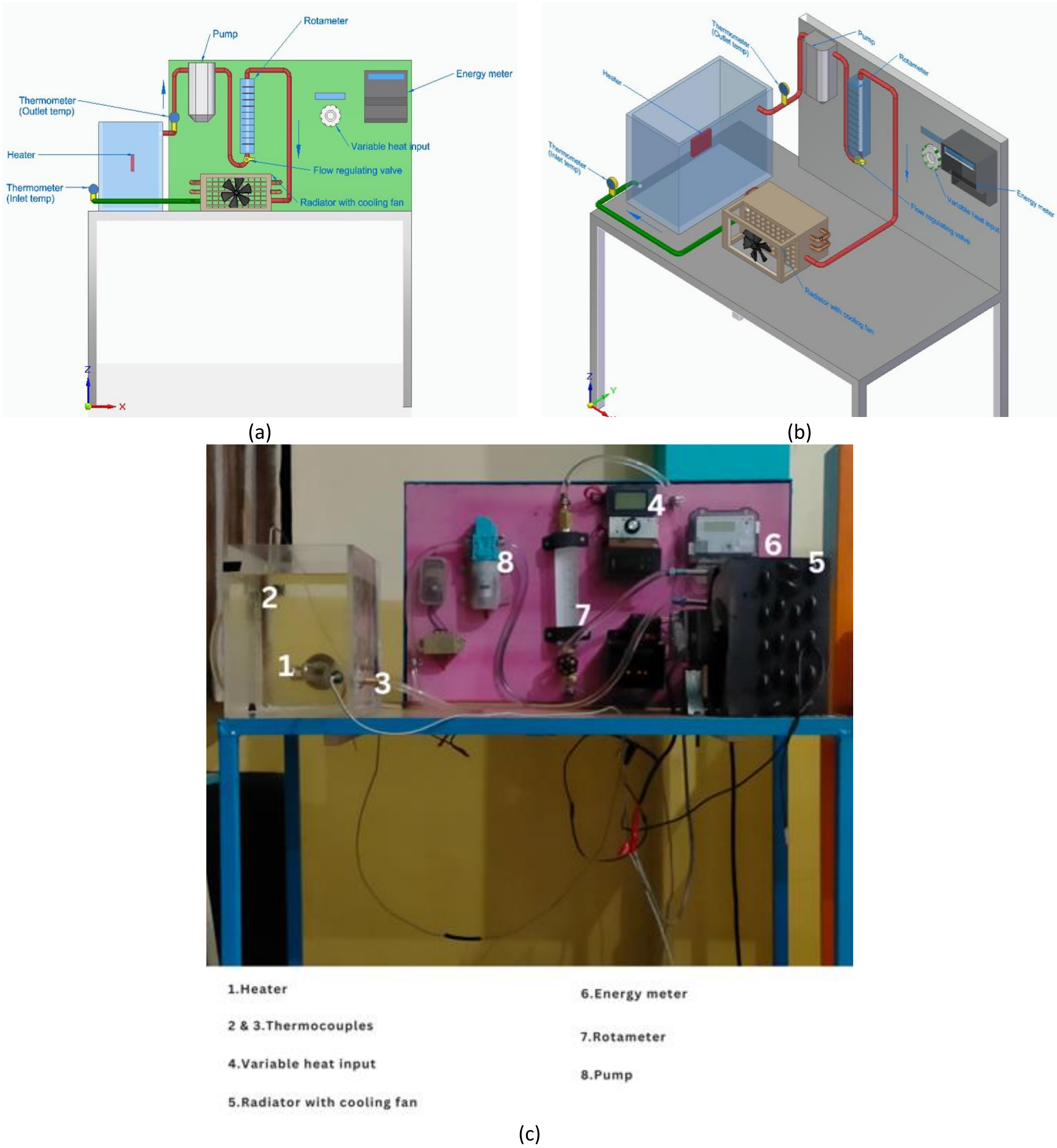


Fig. 3. Experimental setup (a) Front view of three-dimensional modelling (b) Isometric view of three-dimensional modelling (c) Fabricated experimental test rig

4. Results and Discussions

Three distinct fluids were chosen as the working mediums for the experiments, namely deionized water, mineral oil, and propylene glycol and analyzed their heat transfer characteristics under varying conditions.

4.1 Effect of Varying Heat Input and Flow Rate on the Temperature of Various Fluids

Figure 4, 5 and 6 show the effect of varying heat input and flow rate on the temperature of various fluids. Deionized water performed best among the three fluids because it has the lowest outlet temperature across all heat inputs and flow rates. The lower temperature of deionized water would be the result of its greater capacity to remove heat. Propylene glycol was the second-best fluid considering the outlet temperature.

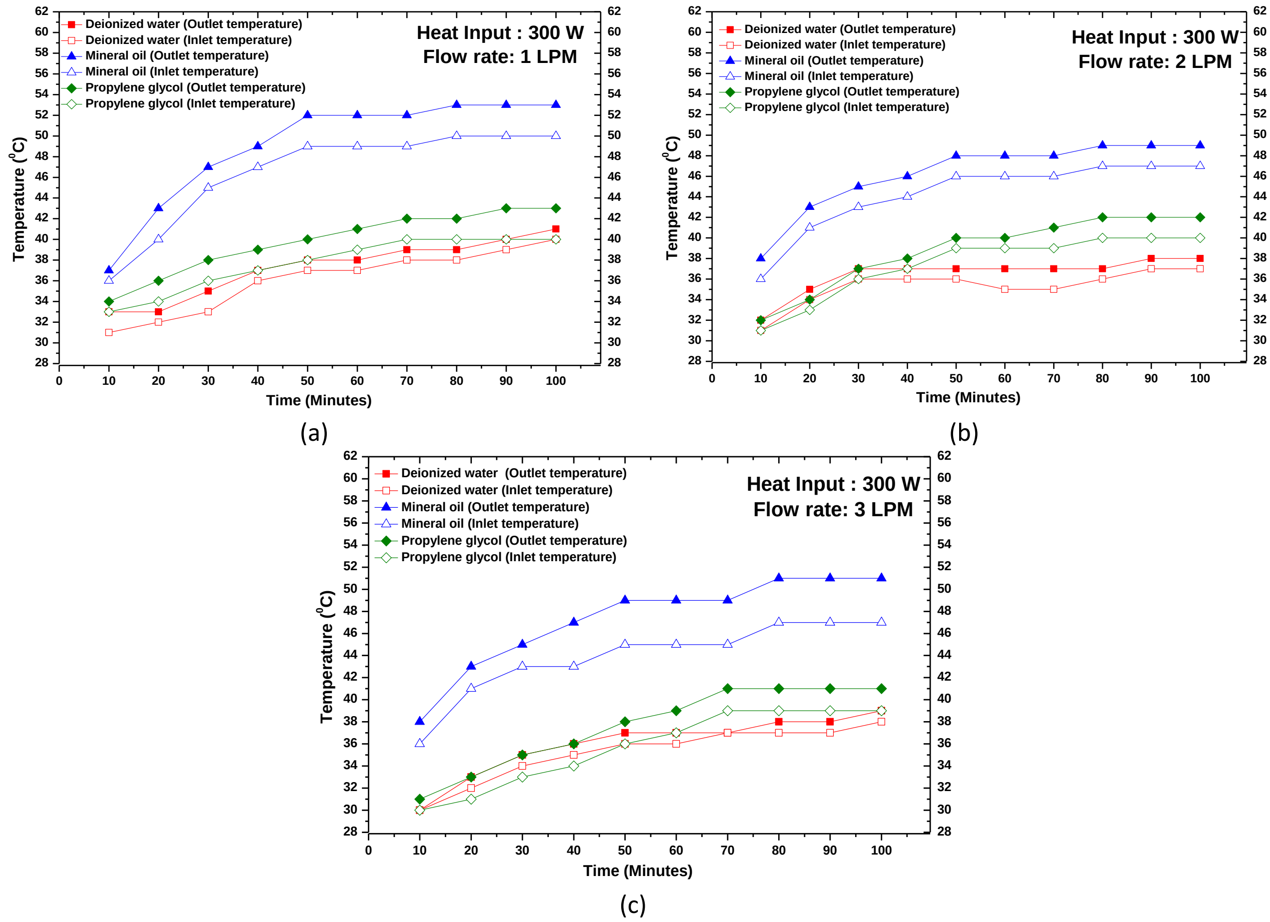
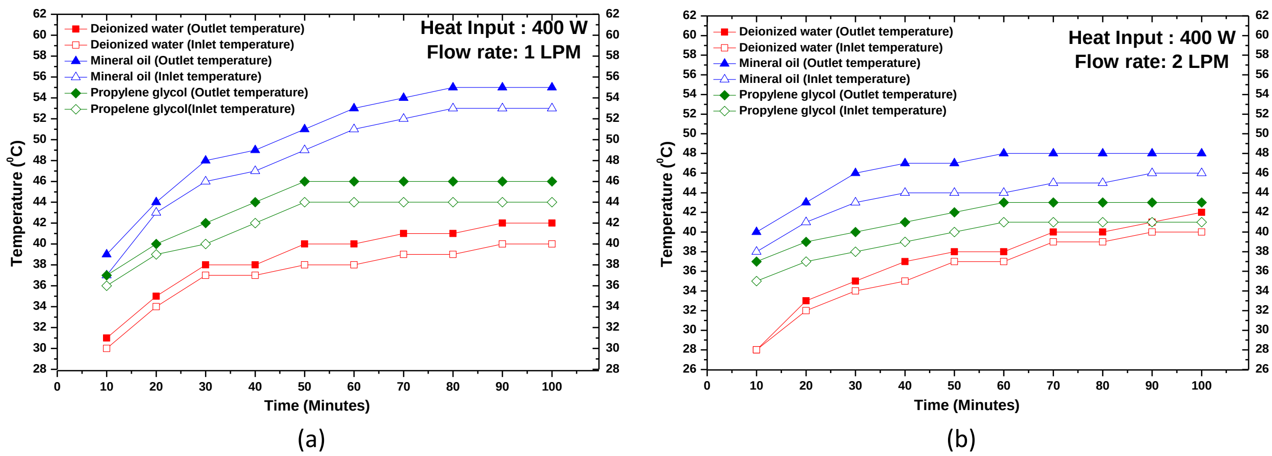
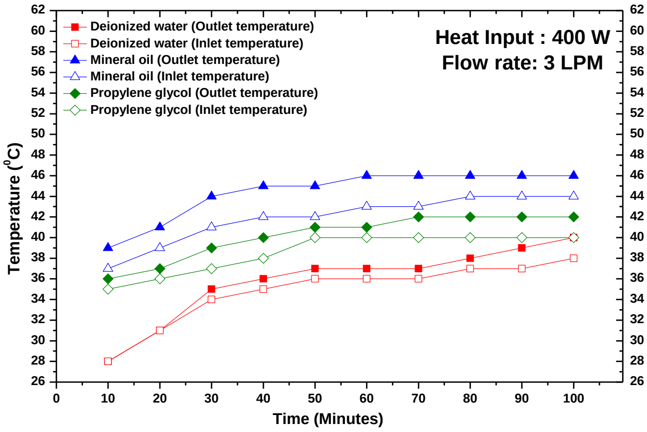


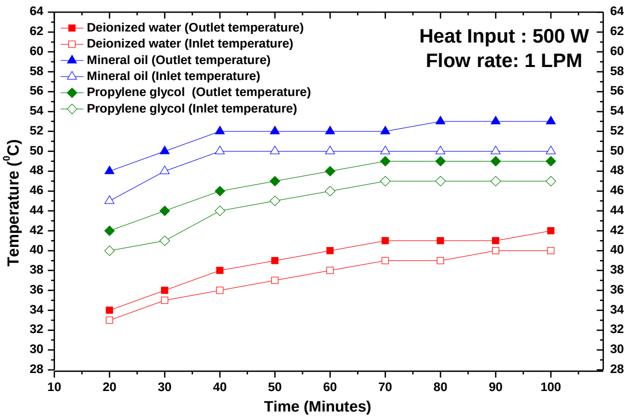
Fig. 4. Temperature variation for various fluids with 300 W heat input and varying flow rate(a) 1 LPM (b) 2 LPM (c) 3 LPM



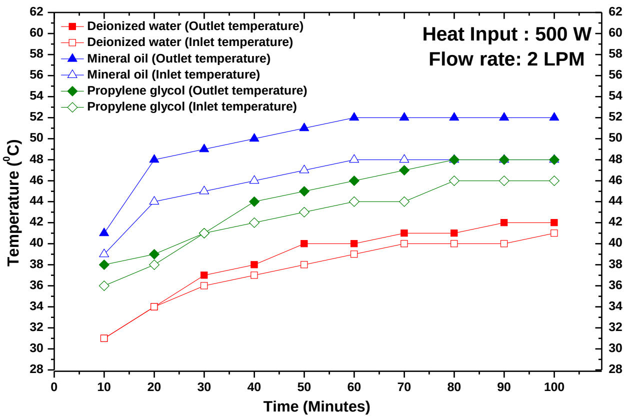


(c)

Fig. 5. Temperature variation for various fluids with 400 W heat input and varying flow rate(a) 1 LPM (b) 2 LPM (c) 3 LPM



(a)



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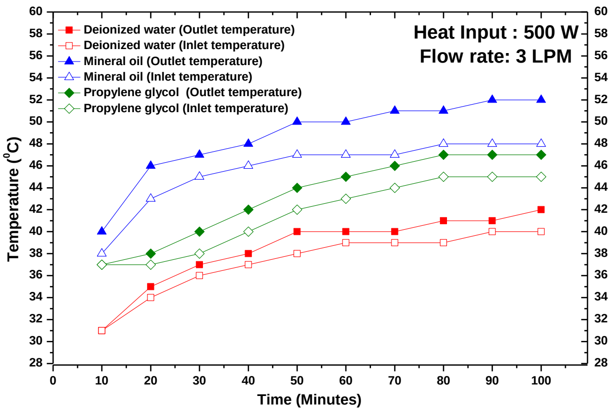


(c)

Fig. 6. Temperature variation for various fluids with 500 W heat input and varying flow rate (a) 1 LPM (b) 2 LPM (c) 3 LPM

4.2 Effect of Varying Heat Input and Fluid on Temperature at Various Flow Rates

To investigate the impact of flow rates on heat transfer, three different flow rates were employed 1 LPM, 2 LPM, and 3 LPM. Figure 7, Figure 8 and Figure 9 show the effect of varying heat input and fluid on temperature at various flow rates. This allowed for the assessment of how fluid flow rate affected heat transfer performance. It can be stated that increasing the flow rate resulted in a drop in exit temperature for all fluids at all heat inputs. The increase in flow rate had less of an impact on fluid temperature at 500 W heat input than it does at lower heat inputs.

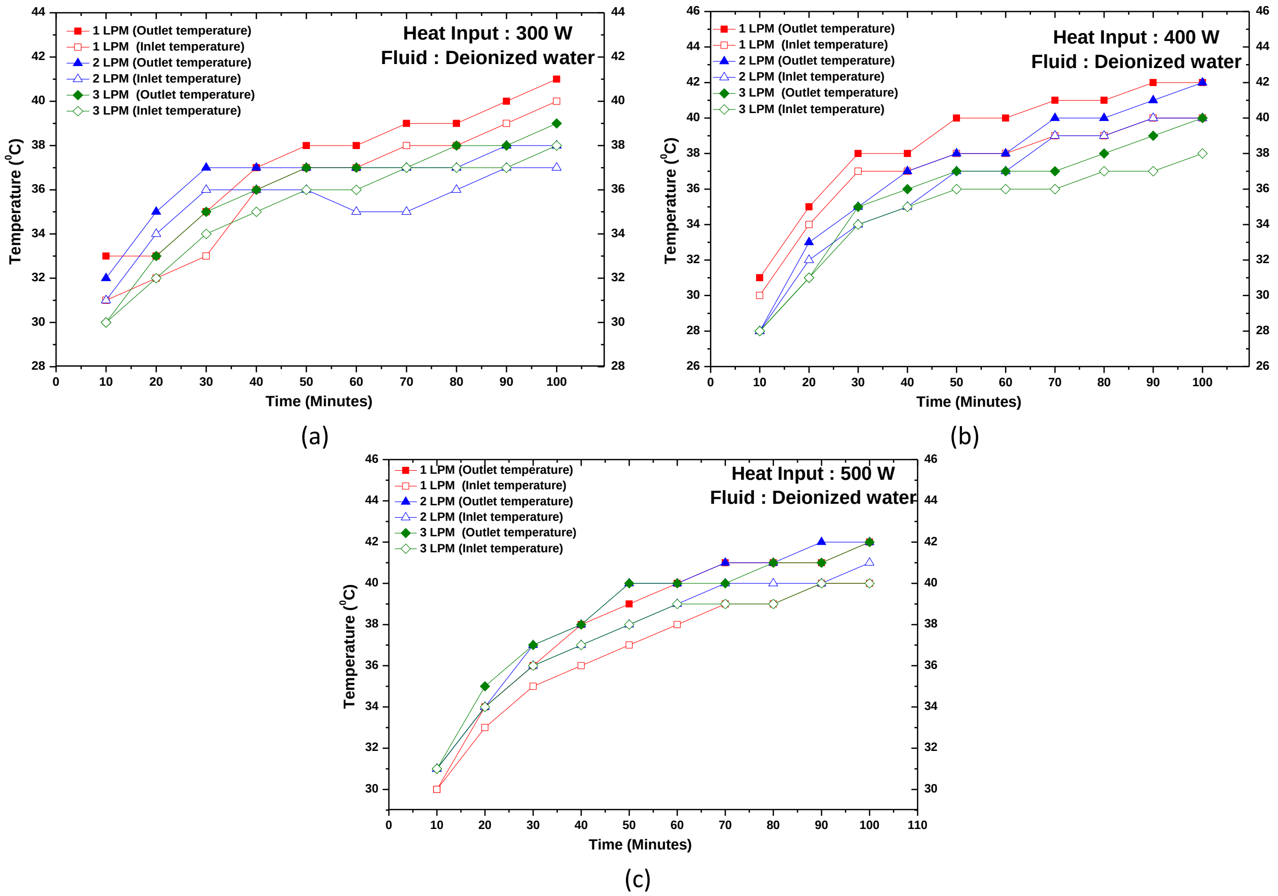
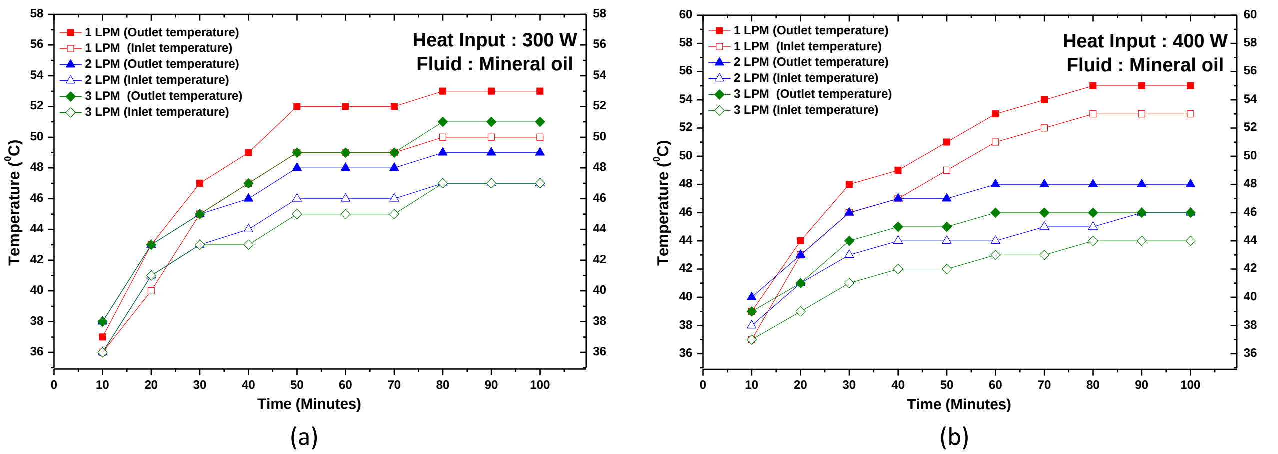


Fig. 7. Temperature variation of deionized water with varying flow rate and heat input of (a) 300 W (b) 400 W (c) 500 W



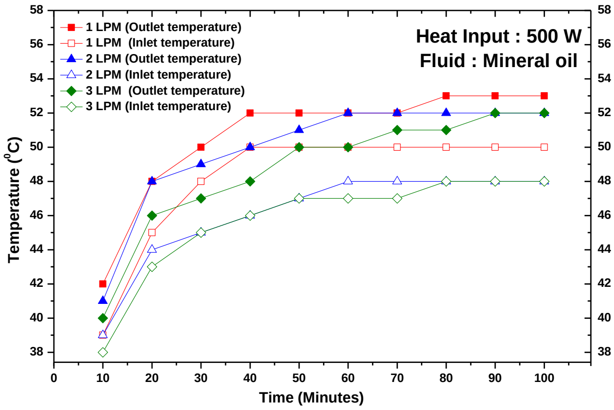


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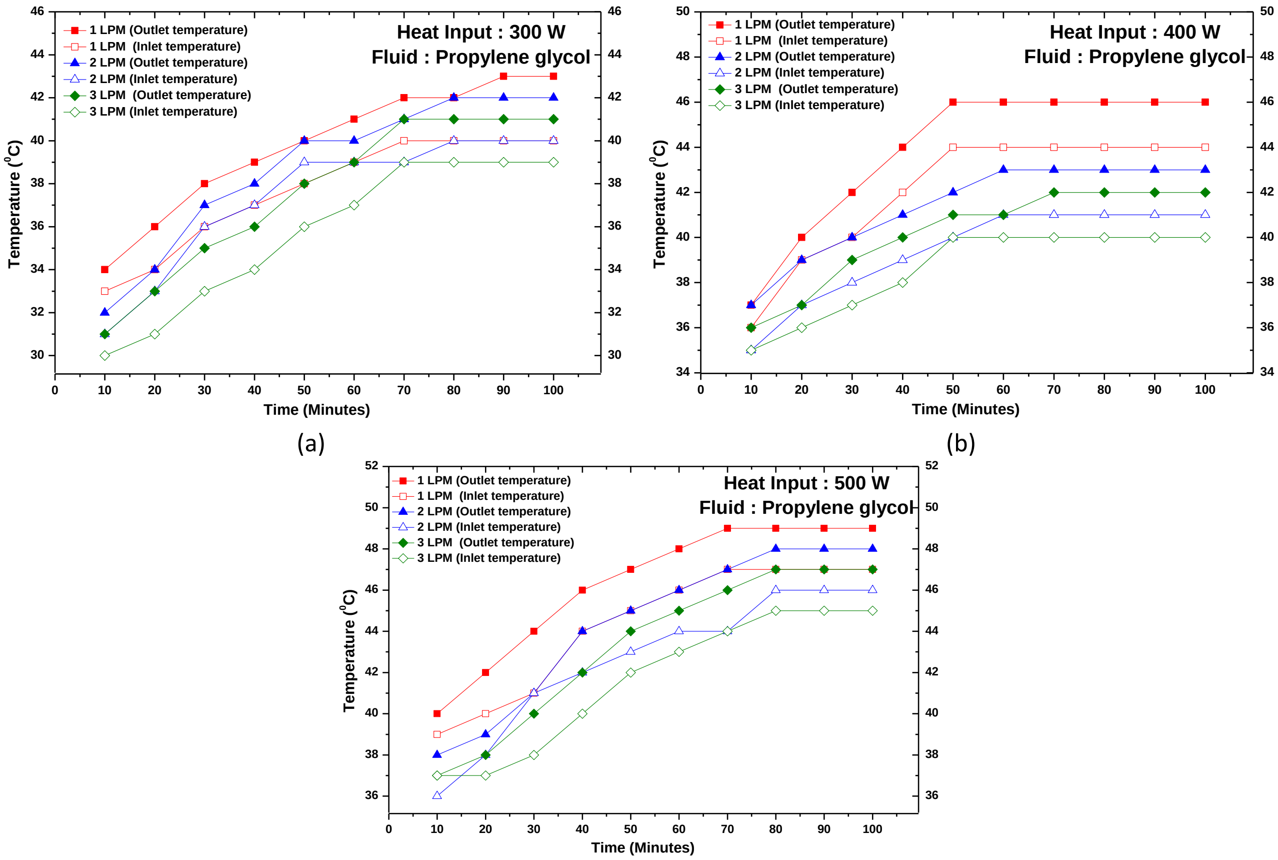
Fig. 8. Temperature variation of mineral oil with varying flow rate and heat input of (a) 300 W (b) 400 W (c) 500 W



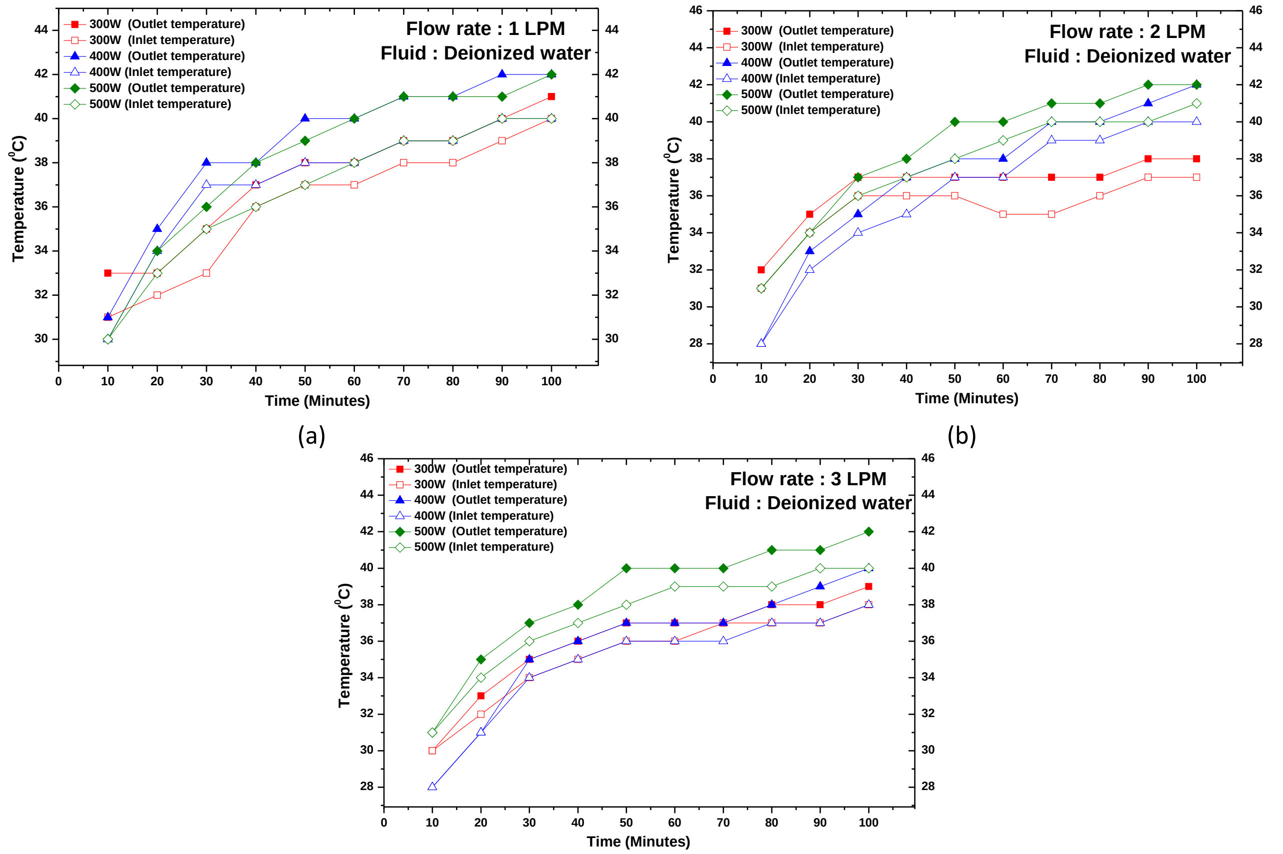
(a) (b)

(c)

Fig. 9. Temperature variation of propylene glycol with varying flow rate and heat input of (a) 300 W (b) 400 W (c) 500 W

4.3 Effect of Varying Flow Rate and Fluid on Temperature at Various Heat Input

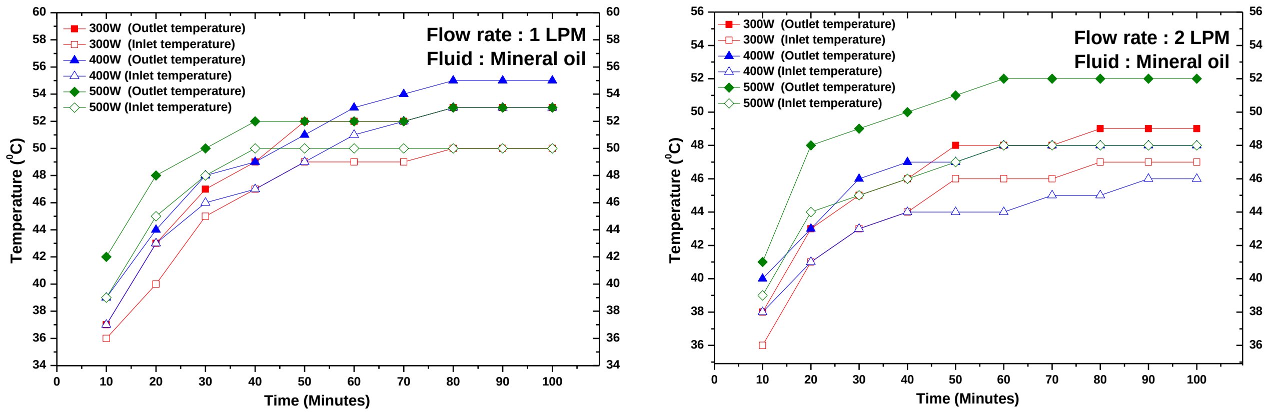
Figure 10, 11 and 12 show the effect of heat input for three levels: 300 W, 400 W, and 500 W. This variation in heat input helped in assessing the influence of different heat levels on the heat transfer process. For all the fluids considered increasing heat input has increased outlet temperature. At 300 W of heat input, the highest outlet temperature of 53°C is observed at 1 LPM in mineral oil whereas the lowest temperature recorded was deionized water at 39°C and 3 LPM and propylene glycol's temperature was very close to the temperature of deionized water. At 400 W of heat input, the highest outlet temperature of 55°C was observed at 1 LPM in mineral oil whereas the lowest temperature of 40°C recorded was deionized water at 3 LPM and propylene glycol's temperature was very close to the temperature of deionized water. At 500 W of heat input, the highest outlet temperature of 53°C was observed at 1 LPM in mineral oil whereas the lowest temperature of 42°C recorded was deionized water at 3 LPM and propylene glycol's temperature was very close to the temperature of deionized water. It is important to note the volume of fluid in which the heater is immersed also plays a significant role in the temperature.



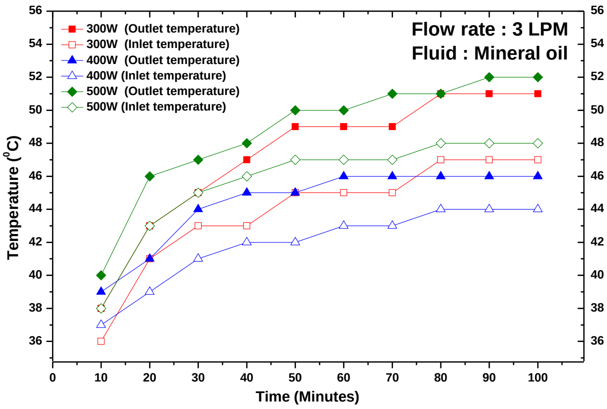
(a) (b)

(c)

Fig. 10. Temperature variation of deionized water at varying heat input and flow rate (a) 1 LPM (b) 2 LPM (c) 3 LPM

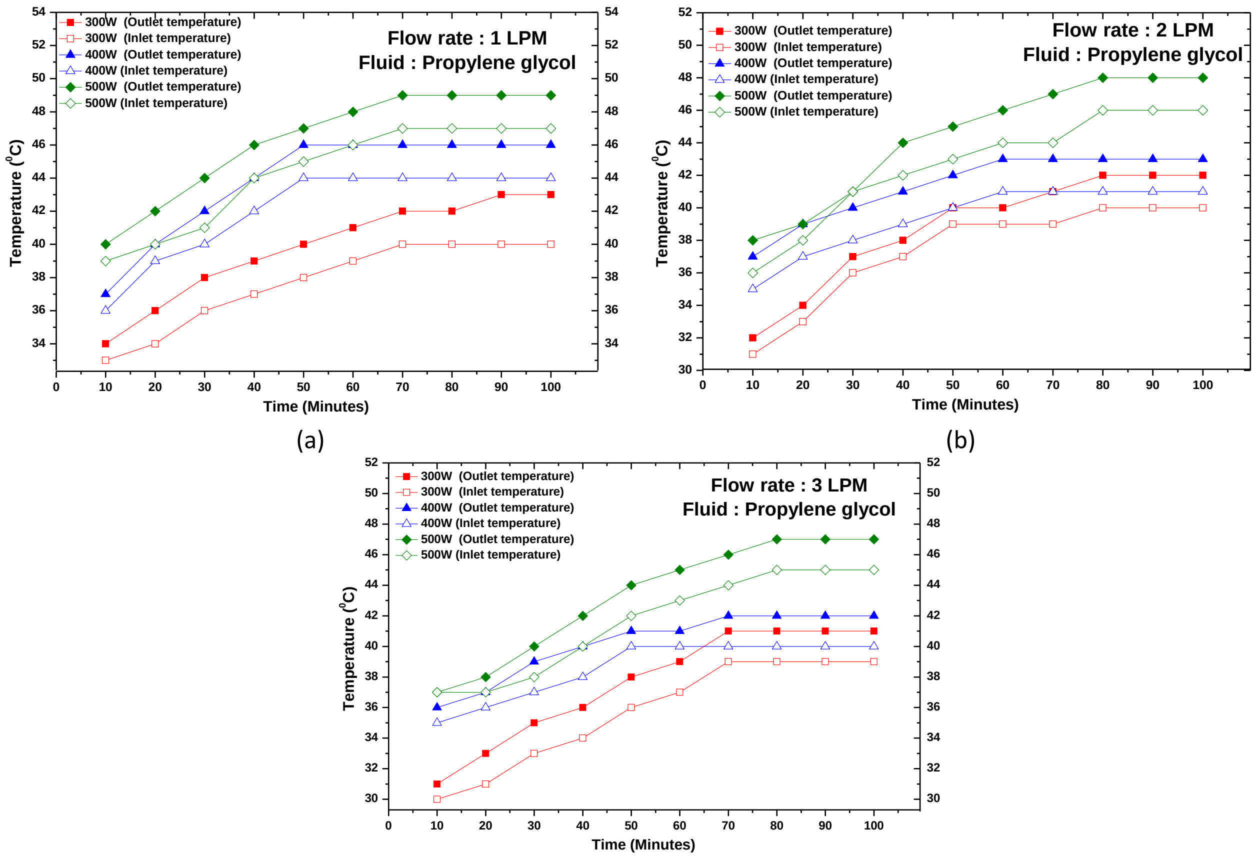


(a) (b)



(c)

Fig. 11. Temperature variation of mineral oil at varying heat input and flow rate (a) 1 LPM (b) 2 LPM (c) 3 LPM



(c)

Fig. 12. Temperature variation of propylene glycol at varying heat input and flow rate (a) 1 LPM (b) 2 LPM (c) 3 LPM

5. Conclusions

After collecting the data, detailed analysis and comparisons were conducted to determine how the choice of fluid, flow rate, and heat input influenced the heat transfer performance in the experimental setup. This investigation gave vital insights into their heat transfer behaviour and performance. It is worth emphasizing that the volume of fluid surrounding the heater has a substantial impact on temperature regulation. Furthermore, it's evident that augmenting the flow rate consistently led to a reduction in exit temperature for all fluids at all heat inputs. This observation highlights how varying heat input levels can aid in evaluating their influence on the heat transfer process. For all the fluids examined, it's evident that increasing heat input invariably resulted in higher outlet temperatures. Deionized water consistently outperformed the other two fluids by maintaining the lowest outlet temperature across various heat inputs and flow rates, primarily due to its higher thermal conductivity and specific heat. The average heat transfer coefficient for deionized water was calculated as the highest, with a value of 349.29 W/m^2·K. Propylene glycol had an intermediate heat transfer coefficient, which was 194.69 W/m^2·K, and mineral oil exhibited the lowest heat transfer coefficient at 74.44 W/m^2·K. Based on the heat transfer coefficient values, it is clear that deionized water has the lowest temperature due to its significantly higher heat transfer coefficient, and the same trend applies to the other fluids.

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References

[1] Wang, Siqi, Rang Tu, Xianzhong Chen, Xu Yang, and Kun Jia. "Thermal performance analyses and optimization of data center centralized-cooling system." *Applied Thermal Engineering* 222 (2023): 119817. https://doi.org/10.1016/j.applthermaleng.2022.119817

[2] Abbas, A. M., A. S. Huzayyin, T. A. Mouneer, and S. A. Nada. "Thermal management and performance enhancement of data centers architectures using aligned/staggered in-row cooling arrangements." *Case Studies in Thermal Engineering* 24 (2021): 100884. https://doi.org/10.1016/j.csite.2021.100884

[3] Murshed, S. M. Sohel, and C. A. Nieto De Castro. "A critical review of traditional and emerging techniques and fluids for electronics cooling." *Renewable and Sustainable Energy Reviews* 78 (2017): 821-833. https://doi.org/10.1016/j.rser.2017.04.112

[4] Fulpagare, Yogesh, and Atul Bhargav. "Advances in data center thermal management." *Renewable and Sustainable Energy Reviews* 43 (2015): 981-996. https://doi.org/10.1016/j.rser.2014.11.056

[5] Grishina, Anastasiia, Marta Chinnici, A-L. Kor, Davide De Chiara, Guido Guarnieri, Eric Rondeau, and J-P. Georges. "Thermal awareness to enhance data center energy efficiency." *Cleaner Engineering and Technology* 6 (2022): 100409. https://doi.org/10.1016/j.clet.2022.100409

[6] Andrae, Anders S. G., and Tomas Edler. "On global electricity usage of communication technology: trends to 2030." *Challenges* 6, no. 1 (2015): 117-157. https://doi.org/10.3390/challe6010117

[7] Bureau of Energy Efficiency (BEE). "Energy Efficiency Guidelines & Best Practices in Indian Datacenters." *Bureau of Energy Efficiency (BEE), Ministry of Power, Government of India* (2007).

[8] Abbas, A. M., A. S. Huzayyin, T. A. Mouneer, and S. A. Nada. "Effect of data center servers' power density on the decision of using in-row cooling or perimeter cooling." *Alexandria Engineering Journal* 60, no. 4 (2021): 3855-3867. https://doi.org/10.1016/j.aej.2021.02.051

[9] Liu, Wei, Song Lian, Xin Fang, Zhenyu Shang, Hao Wu, Hao Zhu, and Simon Hu. "An open-source and experimentally guided CFD strategy for predicting air distribution in data centers with air-cooling." *Building and Environment* 242 (2023): 110542. https://doi.org/10.1016/j.buildenv.2023.110542

[10] Ebrahimi, Khosrow, Gerard F. Jones, and Amy S. Fleischer. "A review of data center cooling technology, operating conditions and the corresponding low-grade waste heat recovery opportunities." *Renewable and Sustainable Energy Reviews* 31 (2014): 622-638. https://doi.org/10.1016/j.rser.2013.12.007

[11] Ozer, Rahim Aytug, Bayram Sahin, and Ibrahim Ates. "Effect of the acoustic manipulation on single phase immersion cooling performance of discretely heated vertical plate." *International Journal of Heat and Mass Transfer* 217 (2023): 124649. https://doi.org/10.1016/j.ijheatmasstransfer.2023.124649

[12] Kuncoro, I. W., N. A. Pambudi, M. K. Biddinika, I. Widiastuti, M. Hijriawan, and K. M. Wibowo. "Immersion cooling as the next technology for data center cooling: A review." In *Journal of Physics: Conference Series*, vol. 1402, no. 4, p. 044057. IOP Publishing, 2019. https://doi.org/10.1088/1742-6596/1402/4/044057

[13] Han, Jeong-Woo, Kunal Sandip Garud, Seong-Guk Hwang, and Moo-Yeon Lee. "Experimental Study on Dielectric Fluid Immersion Cooling for Thermal Management of Lithium-Ion Battery." *Symmetry* 14, no. 10 (2022): 2126. https://doi.org/10.3390/sym14102126

[14] Luo, Qingyi, Changhong Wang, Haiping Wen, and Liangde Liu. "Research and optimization of thermophysical properties of sic oil-based nanofluids for data center immersion cooling." *International Communications in Heat and Mass Transfer* 131 (2022): 105863. https://doi.org/10.1016/j.icheatmasstransfer.2021.105863

[15] Chen, Hongwei, and Dong Li. "Current Status and Challenges for Liquid-Cooled Data Centers." *Frontiers in Energy Research* 10 (2022): 952680. https://doi.org/10.3389/fenrg.2022.952680

[16] Watson, Bryony, and Vinod Kumar Venkiteswaran. "Universal cooling of data centres: a CFD analysis." *Energy Procedia* 142 (2017): 2711-2720. https://doi.org/10.1016/j.egypro.2017.12.215

[17] Carbó, Andreu, Eduard Oró, Jaume Salom, Mauro Canuto, Mario Macías, and Jordi Guitart. "Experimental and numerical analysis for potential heat reuse in liquid cooled data centres." *Energy Conversion and Management* 112 (2016): 135-145. https://doi.org/10.1016/j.enconman.2016.01.003

[18] Birbarah, Patrick, Tarek Gebrael, Thomas Foulkes, Andrew Stillwell, Alexandra Moore, Robert Pilawa-Podgurski, and Nenad Miljkovic. "Water immersion cooling of high power density electronics." *International Journal of Heat and Mass Transfer* 147 (2020): 118918. https://doi.org/10.1016/j.ijheatmasstransfer.2019.118918

[19] Cheng, Chin-Chi, Po-Chun Chang, Hsing-Chieh Li, and Fu-I. Hsu. "Design of a single-phase immersion cooling system through experimental and numerical analysis." *International Journal of Heat and Mass Transfer* 160 (2020): 120203. https://doi.org/10.1016/j.ijheatmasstransfer.2020.120203

[20] Ramdas, Shrinath, Pavan Rajmane, Tushar Chauhan, Abel Misrak, and Dereje Agonafer. "Impact of immersion cooling on thermo-mechanical properties of PCB's and reliability of electronic packages." In *International Electronic Packaging Technical Conference and Exhibition*, vol. 59322, p. V001T02A011. American Society of Mechanical Engineers, 2019. https://doi.org/10.1115/IPACK2019-6568

[21] Taddeo, Paolo, Joaquim Romaní, Jon Summers, Jonas Gustafsson, Ingrid Martorell, and Jaume Salom. "Experimental and numerical analysis of the thermal behaviour of a single-phase immersion-cooled data centre." *Applied Thermal Engineering* 234 (2023): 121260. https://doi.org/10.1016/j.applthermaleng.2023.121260

[22] Shrigondekar, Harshad, Yueh-Cheng Lin, and Chi-Chuan Wang. "Investigations on performance of single-phase immersion cooling system." *International Journal of Heat and Mass Transfer* 206 (2023): 123961. https://doi.org/10.1016/j.ijheatmasstransfer.2023.123961

[23] Pambudi, Nugroho Agung, Awibi Muhamad Yusuf, and Alfan Sarifudin. "The use of single-phase immersion cooling by using two types of dielectric fluid for data center energy savings." *Energy Engineering* 119, no. 1 (2022): 275-286. https://doi.org/10.32604/EE.2022.017356

[24] Shah, Jimil M., Richard Eiland, Ashwin Siddarth, and Dereje Agonafer. "Effects of mineral oil immersion cooling on IT equipment reliability and reliability enhancements to data center operations." In *2016 15th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm)*, pp. 316-325. IEEE, 2016. https://doi.org/10.1109/ITHERM.2016.7517566

[25] Bunger, Robert, and Tony Day. "Comparison of dielectric fluids for immersive liquid cooling of IT equipment." *White Paper 291, Scheider Electric* (2020).