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EFFECTS OF COOLANTS ON THE PROPERTIES OF IGBT LIQUID COOLED PLATES UNDER DIFFERENT MATERIALS - A REVIEW

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The thermal performance of Liquid-cooled plate (LCP) can be improved by using different kinds of materials and coolants. Suitable and effective coolant can bring better cooling capacity to cope with the impact of high temperature on IGBT chips, and improve the safety and service life of new energy metallurgical loaders. In this context, the recent progress of the effects of traditional coolants, nano-fluids, ethylene glycol and oil on the heat transfer capacity of the liquid cooling plate is reviewed in detail. Nanofluids have been identified as the most prominent cooling method at present because of their good thermal conductivity. In addition, the considerations and advantages and disadvantages of using different coolants are discussed in depth.

Keywords: traditional coolant, thermal performance, nano-fluids, thermal conductivity; consideration

INTRODUCTION

Currently, the predominant reliance on fossil fuels for global energy supply is increasingly viewed as problematic due to severe environmental concerns. Consequently, new energy sources have emerged as significant areas of focus. In the context of new energy vehicles, thermal management remains a critical challenge, particularly the issue of IGBT chip overheating. Research indicates that a 10 °C increase in IGBT temperature can halve the reliability of electronic components [1], the working reliability of electronic components will be reduced by 50 %, and there are many problems in practical applications due to heat dissipation, which makes heat dissipation become a bottleneck restricting the development of new energy technology. The traditional air cooling and liquid cooling technology obviously can not meet the heat dissipation requirements of electronic modules at this stage [2]. In order to solve this problem, new types of coolants are starting to gradually come onto the stage and play a role in more liquid cooling plates. The liquid-cooled plate (LCP) is the principal device used for this purpose. The detailed physical model is shown in Figure 1.

Figure 1 Physical drawing of LCP

In this paper, the effects of different coolants such as nanofluids, liquid metals, traditional coolant on the performance of liquid cooled plates are analyzed, and the future development trend and direction of liquid cooled plates are further clarified, which provides a certain reference for researchers interested in liquid cooled plates.

TRADITIONAL COOLANT

Water is the most widely used liquid in the world, due to its good thermal conductivity, viscosity, specific heat capacity and density, ensure that water can transfer heat more efficiently while producing less pressure loss. Therefore, water is often used as a cheap coolant for liquid cooling plates. Monika et al. [3] used water as the coolant to explore the influence of water on the thermal performance of the rectangular channel liquid cooling plate. Detailed values show that a flow rate of 0,003 kg/s and an ambient temperature of 25 °C are ideal results for liquid-cooled plate performance. The U-shaped cold plate structure designed by Su et al. [4] reduces the maximum temperature rise of the battery by 0,03 K and the pressure drop by 585,67 Pa through water cooling. Qian and Wang [5, 6] suggest that the use of water as a coolant can significantly improve the cooling capacity of the cooling system. The results show that the cooling performance of the liquid cooling plate is obviously enhanced with the increase of water flow.

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NANOFLUID

Compared to traditional coolants, the metal has a better thermal conductivity. Adding metal particles to the fluid can improve the heat transfer performance of the liquid. This new coolant, which adds nanoparticles to a conventional liquid, is defined as a nanofluid [7]. The most widely used nanoparticle coolants include metals such as Cu, Ni, Ag, Al, Al_2O_3, CuO, Fe_3O_4 or metal oxides.

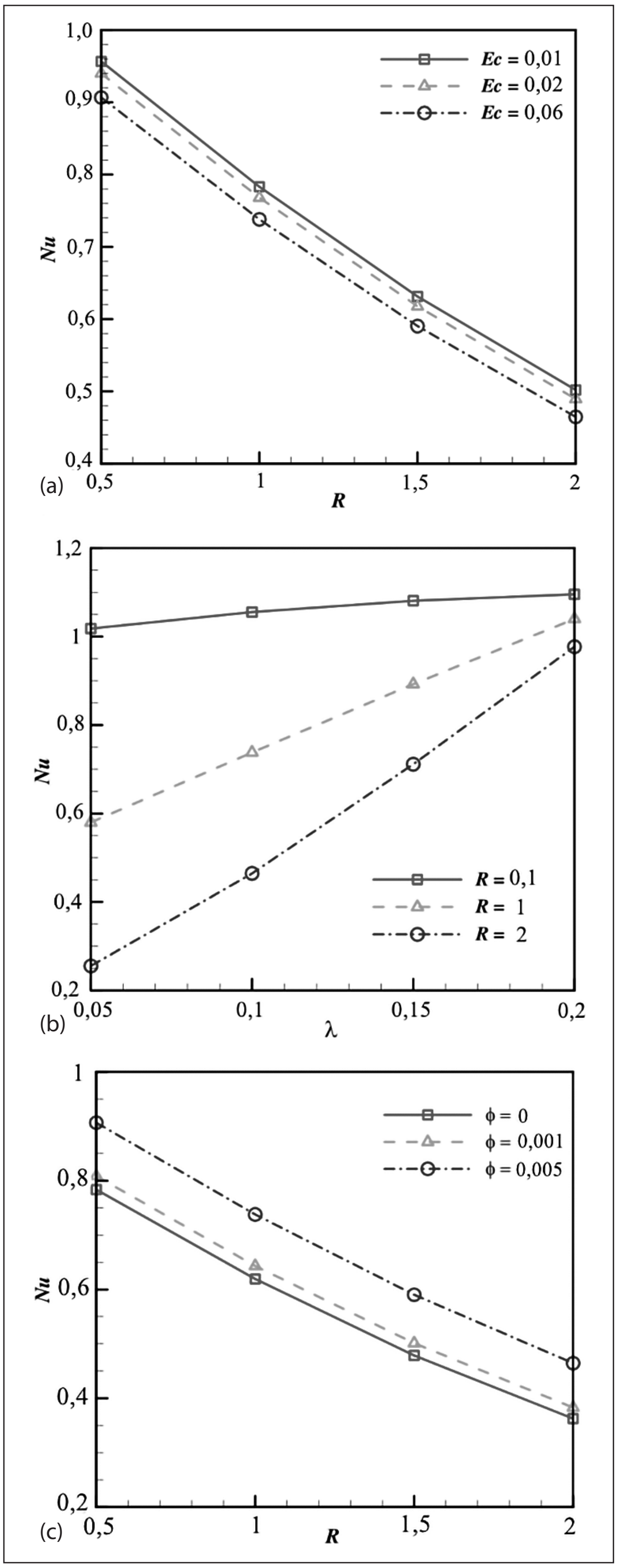

Figure 2 Effects of viscosity parameter, suction parameter, nanoparticle volume fraction on Nusselt number when P=21,976
(a) Viscosity parameter; (b) suction parameter; (c) Viscosity parameter

In the realm of nanofluid research for IGBT liquid cooled plates, several studies have contributed to understanding the effects of nanofluids on thermal and hydraulic performance. Mahmoodi and Kandelousi [8] conducted a semi-analytical investigation of kerosene-alumina nanofluid between two parallel plates, discussing the effects of parameters such as nanofluid volume fraction, suction parameter, viscosity parameter, and Eckert number on flow and heat transfer characteristics. See Figure 2 for details.

Yakhshi-Tafti, Tamanna, and Pearlman [9] experimentally investigated the thermal and hydraulic performance of alumina-water nanofluids in single-phase liquid-cooled cold plates, finding that heat transfer coefficient increased with particle loading, but no significant enhancements in pressure drop, pumping power, or thermal performance were observed with dilute alumina-water nanofluids. Ma et al. [10] numerically investigated the flow characteristics of Al_2O_3-water nanofluid in microchannel plate fin heat sinks, examining the effects of Reynolds number, channel aspect ratio, and nanoparticle volume fraction on pressure drop and entropy generation. Sarchami, Tousi, Kiani, et al. [11] numerically analyzed a novel nanofluid cooling system with stair and wavy channels for modular lithium-ion battery thermal management, demonstrating that the addition of coolant alumina nanofluid with a 2 % volume fraction significantly reduced the highest temperature and temperature nonuniformity across the battery module. Santra, Sen, and Chakraborty [12] studied the heat transfer due to laminar flow of copper-water nanofluid through two isothermally heated parallel plates, observing heat transfer augmentation using nanofluid compared to conventional fluids. These studies collectively advance the understanding of nanofluids in IGBT liquid cooling applications.

Srchami, Kiani, Najafi, et al. [13] conducted an experimental investigation on an innovative indirect-cooling system for Li-ion battery packs during fast charging and discharging. The study utilized an AgO nanofluid and copper mold in the cooling system. The use of AgO nanofluid with volume fractions of 1 %, 2 %, and 4 % decreased the maximum temperature of the LIB pack by 7,3 %, 11,1 %, and 12,4 %, respectively, compared to a water-cooled system during fast discharging.

ETHYLENE GLYCOL

In the context of ethylene glycol as a coolant in thermal management systems, particularly for IGBT liquid cooled plates, several studies have contributed to understanding its effects and optimizing its use. Liu, Wang, Chen et al. [14] studied the double-layer liquid cooling plate with circular curved flow path. They used different mass concentrations of water and glycol solutions as

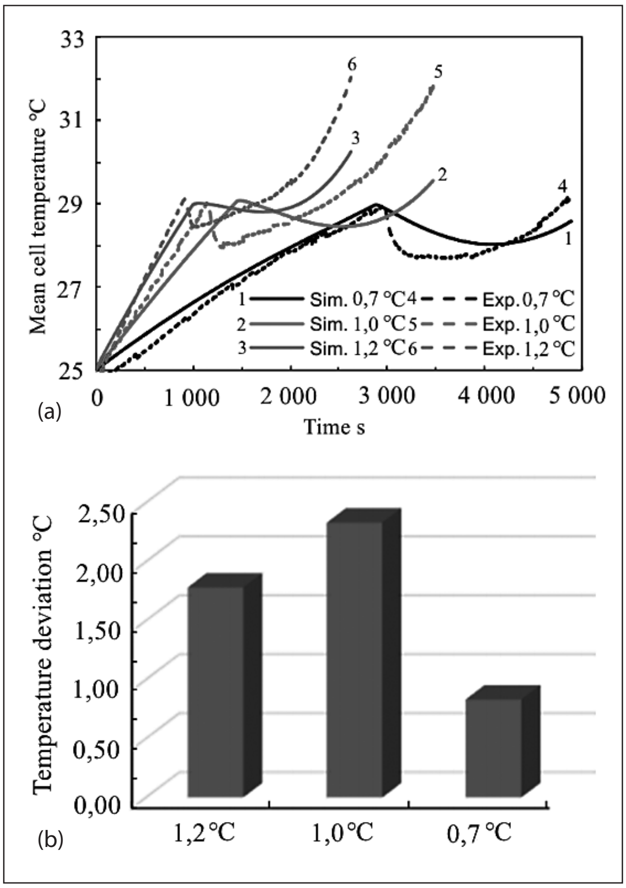

Figure 3 Temperature history comparison between experiment and simulation
(a) Mean cell temperature; (b) Temperature deviation

working fluids. The results show that the flow characteristics and cooling capacity of the proposed liquid cooling plate are effective, and the LED chip pin temperature is kept below 50 °C after cooling, and the luminous intensity increases significantly with the increase of flow rate.

Zhang, Fu, Sheng, et al. [15] focused on liquid-cooled thermal control for large-scale pouch lithium-ion batteries. Their study analyzed the influences of mass flow rates, cooling trigger-time, and glycol solution concentration on the cell thermal distribution. The results show that increasing the mass flow rate has a positive effect on controlling the temperature rise and temperature difference of the battery. The specific change trend is shown in Figure 3.

These studies collectively advance the understanding of ethylene glycol as a coolant in various thermal management systems, including IGBT liquid cooled plates, and highlight the importance of optimizing coolant choice and system design for enhanced performance and safety.

OIL

The thermal conductivity and specific heat capacity of mineral oil and silicone oil are between water and air, but the viscosity of oil is the highest. Therefore, when choosing oil as the coolant for the liquid cooling plate, it is necessary to consider the fluidity of the oil. Chen et al. [16] compared various cooling methods, such as air cooling, water cooling and oil cooling, and believed that mineral oil cooling was a more effective cooling method than air cooling.

In the realm of oil-based cooling solutions for data center servers, Wang et al. [17] conducted a comprehensive performance evaluation and optimization study of single-phase immersion cooling (SPIC) systems. Their research involved constructing a three-dimensional model of blade servers with different cooling methods and numerically solving it to compare thermal transport performance, flow characteristics, and energy consumption performance. The study revealed that SPIC schemes offer significant advantages in terms of heat transfer capability, heat transfer uniformity, and flow resistance loss. Additionally, the power usage effectiveness (PUE) of SPIC systems was found to be 20,8 % and 17,6 % lower than forced air cooling and water cooling plate solutions, respectively.

CONCLUSION

In conclusion, the exploration of various coolants for IGBT liquid cooled plates has yielded valuable insights into the complexities and potential of thermal management systems. Nanofluids, with their enhanced thermal properties, have emerged as a promising option for improving heat transfer in microchannel plate fin heat sinks and liquid-cooled cold plates.Ethylene glycol, a commonly used coolant, has shown its effectiveness in diverse applications, from high-power LED cooling plates to large-scale pouch lithium-ion batteries. Single-phase immersion cooling, particularly with oil-based coolants, has demonstrated remarkable potential in data center server cooling.

The findings from these studies underscore the importance of considering the specific requirements of each application when selecting a coolant and cooling technique. Moreover, ongoing research and development in this field are essential to address the evolving thermal challenges in various industries and to further improve the performance and sustainability of thermal management systems.

REFERENCE

[1] I. Aranzabal, I. M. D. Alegria, N. Delmonte, et al. Comparison of the Heat Transfer Capabilities of Conventional Single- and Two-Phase Cooling Systems for an Electric Vehicle IGBT Power Module[J]. IEEE, 34(2019)5.

[2] A. K. Thakur, R. Prabakaran, M. R. Elkadeem, et al. A state of art review and future viewpoint on advance cooling techniques for Lithium–ion battery system of electric vehicles[J]. The Journal of Energy Storage, 32(2020), 101771.

[3] K. Monika, C. Chakraborty, S. Roy, et al. An improved mini-channel based liquid cooling strategy of prismatic LiFePO4 batteries for electric or hybrid vehicles[J]. The Journal of Energy Storage, (2021)35, 102301.

[4] S. Su, W. Li, Y. Li, et al. Multi-objective design optimization of battery thermal management system for electric vehicles[J]. Applied Thermal Engineering, (2021)196, 117235.

[5] Z. Qian, Y. M. Li, Z. H. Rao. Thermal performance of lithium-ion battery thermal management system by using mini-channel cooling[J]. Energy Conversion and Management, (2016)126, 622-631.

[6] G. Wang, N. Qian, G. Ding. "Heat transfer enhancement in microchannel heat sink with bidirectional rib[J]. International Journal of Heat and Mass Transfer, (2019)136, 597-609.

[7] S. U. Choi, J. Eastman. Enhancing thermal conductivity of fluids with nanoparticles[J]. ASME Publ. Fed 231(1995), 99–105.

[8] M. Mahmoodi, S. Kandelousi. Semi-analytical investigation of kerosene-alumina nanofluid between two parallel plates[J]. Journal of Aerospace Engineering, 29(2016)4.

[9] E. Yakhshi-Tafti, S. Tamanna, H. Pearlman. Experimental Investigation on the Thermal and Hydraulic Performance of Alumina–Water Nanofluids in Single-Phase Liquid-Cooled Cold Plates[J]. Journal of Heat Transfer, 137(2015)7, 071703.

[10] H. Ma, Z. Duan, L. Su, et al. Fluid flow and entropy generation analysis of Al2O3–water nanofluid in microchannel plate fin heat sinks[J]. Entropy, 21(2019)8, 739.

[11] A. Sarchami, M. Tousi, M. Kiani, et al. A novel nanofluid cooling system for modular lithium-ion battery thermal management based on wavy/stair channels[J]. International Journal of Thermal Sciences, 182(2022), 107823.

[12] A. K. Santra, S. Sen, N. Chakraborty. Study of heat transfer due to laminar flow of copper–water nanofluid through two isothermally heated parallel plates[J]. International journal of thermal sciences, 48(2009)2, 391-400.

[13] A. Sarchami, M. Kiani, M. Najafi, et al. Experimental investigation of the innovated indirect-cooling system for Li-ion battery packs under fast charging and discharging[J]. Journal of Energy Storage, 61(2023), 106730.

[14] G. Liu, J. Wang, Y. Chen, et al. Investigation of the cooling performance of a double-layer liquid-cooled plate with circular arc-shaped flow channels for thermal management of light-emitting diodes[J]. International Journal of Thermal Sciences, 197(2024), 108756.

[15] F. Zhang, B. Liang, Y. He, et al. Study on flow and heat transfer characteristics of phase change synergistic combination finned liquid cooling plate[J]. International Communications in Heat and Mass Transfer, 138(2022), 106377.

[16] D. Chen, J. Jiang, G. Kim, C. Yang. Pesaran, Comparison of different cooling methods for lithium ion battery cells[J]. Appl. Therm. Eng. 94(2016), 846–854.

[17] H. Wang, X. Yuan, K. Zhang, et al. Performance evaluation and optimization of data center servers using single-phase immersion cooling[J]. International Journal of Heat and Mass Transfer, 221(2024), 125057.

Note: The responsible translator for English language is B. Z. Wang - North China University of Science and Technology, China.