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The Influence of the Pin-Fin Wake Flow Structure on the Heat Transfer Characteristics of the Microchannels

Zhikun Sun[1], Tiantian Wang[1,2], Bosen Qian[1], Fangcheng Shi[2]
[1]Key Laboratory of Traffic Safety on Track of Ministry of Education, School of Traffic & Transportation Engineering, Central South University
Changsha 410075, Hunan, China
[2]College of Mechanical and Vehicle Engineering
Hunan University
Changsha 410082, Hunan, China
sunzhikun@csu.edu.cn; wangtiantian@csu.edu.cn; bosenqian@csu.edu.cn; shifangcheng@hnu.edu.cn

Extended Abstract

The microchannel heat sink (MCHS) embedded in the circular pin-fin array has a high surface area and volume ratio[1], endowing it with development potential in solving the heat removal problem of high-power devices[2]. However, the relationship between the flow state and heat transfer characteristics of the MCHS circular pin-fin array is unclear[3]. In the present work, a millimeter-scale microchannel circular pin-fin array heat transfer experimental platform was developed, and the evolution of the flow state at the circular pin-fin array wake in different Reynolds numbers was investigated by experimental and numerical simulation methods. The results show that there are two main flow states among the Reynolds number range of 100 to 1000. The flow state at a Reynolds number of 400 can enhance MCHS heat transfer performance by disturbing the boundary layer of the cylindrical wall and reducing the synergy angle of the velocity and temperature gradient. When the Reynolds number is 900, the MCHS pressure loss is significantly increased due to advanced cylindrical wake vortex separation. By combining heat transfer efficiency and energy savings, the microchannel can achieve the best heat transfer efficiency for the Reynolds number of approximately 400. To evaluate the overall heat transfer performance at different ranges Reynolds numbers, an indicator, $\Delta Nu/\Delta P$, is proposed. This parameter defines the ratio of the increase in Nusselt number(ΔNu) to the increase in pressure drop(ΔP) and is based on the efficiency evaluation criterion(EEC)[4] concept, which reflects the heat transfer performance achieved with the same energy consumption. The DEEC of the MCHS is at its maximum when the Reynolds number is approximately 400, and the value is 4.11× 10-2 Pa-1. In terms of high efficiency and energy savings, the MCHS demonstrates superior heat transfer efficiency at a Reynolds number of 400, making it an excellent choice for prioritizing high efficiency and energy savings. In other words, the flow state formed at a Reynolds number of 400 enables the MCHS to obtain the optimal heat transfer performance. This study provides a benchmark for future research on the flow state characteristics in the MCHS.

In this study, the hydrodynamic and thermodynamic response mechanism of the MCHS is explored from the perspective of the topological evolution of the flow state of the cylinder wake. It is revealed that the pressure loss and heat transfer efficiency will be driven by the cylinder wake flow state. It is still possible to further explore the dominant factor of the flow state formation at the cylinder wake and reveal the flow and heat transfer mechanism through theoretical, experimental and numerical simulation analysis.

References

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