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C3Or2D-02: Design and optimization of the sintered heat exchanger in the cryogen-free dilution refrigerator

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The cryogen-free dilution refrigerator operating at around 10 mK or even below provides the indispensable cryogenic environment for the superconducting quantum computing, low-temperature transport property measurement and space exploration, etc. However, at extremely low temperatures, the Kapitza resistance often leads to a sharp deterioration of heat transfer in the heat exchanger and thus the sintered heat exchanger is necessary to optimize the interface heat transfer, which proves to be a crucial component of the cryogen-free dilution refrigerator. The design of the heat exchanger becomes particularly critical because its flow and heat transfer characteristics directly impact the cooling performance.

In this paper, a numerical model of the sintered heat exchanger is established to study the effects of particle size, porosity, and specific surface area of the powder on the heat transfer characteristics and the flow resistance under various working conditions as well. Based on the theoretical analysis, the structural and dimensional parameters of the sintered heat exchanger are optimized to meet the requirements of achieving cooling temperature below 10 mK for a He-3 flow rate of 100-300μmol/s. An improved sintered heat exchanger is then designed and integrated into the cryogen-free dilution refrigerator. The verification experiments are conducted and the results show a good agreement between simulations and experiments. The model can accurately predict the performance of the sintered heat exchanger and provide a helpful guidance for the optimization of the cryogen-free dilution refrigerator.

The theoretical analyses and experimental studies are described in detail, and the flow and heat transfer characteristics of the sintered heat exchanger are presented and discussed.

Keywords：Cryogen-free dilution refrigerator; Sintered heat exchanger; Heat transfer performance; Numerical analysis model; Experimental verification

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