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C1Po1D-06: Development of a heat exchanger with distributed Joule–Thomson effect for a closed-cycle cryocooler

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In this study, a counterflow heat exchanger for a Joule–Thomson (JT) cryocooler was developed and integrated into a closed-cycle cryocooler. The cryocooler uses a two-stage Gifford–McMahon refrigerator as the precooler and helium-4 as the working fluid for the JT cooling circuit. The cryocooler achieved temperature below 2 K, with the cooling power dependent on its operational settings. A typical cooling power of 0.2 mW was measured at 2.3 K with a circulation rate of 57 micromol/s. The developed heat exchanger has a helical-in-tube-type construction, consisting of a helically coiled capillary tube installed inside a straight outer tube. High-temperature and heigh-pressure fluid flowed through the helically coiled capillary, while low-temperature and low-pressure fluid flowed through the space between the outer surface of the capillary and the inner wall of the outer tube. The current in the high temperature side is cooled by that in the low temperature side. The flow impedance on the high-temperature side of the heat exchanger was designed to be significantly higher than that of conventional counterflow heat exchangers. This high impedance induced a substantial frictional pressure drop and a continuous temperature reduction in the fluid along the capillary in the flow condition of the present study. That is called distributed Joule–Thomson effect.
The distributed JT effect has been studied theoretically, numerically and experimentally by many researchers. Previous research has demonstrated that a counterflow heat exchanger incorporating the distributed JT effect can eliminate the need for flow restriction components, such as an orifice and needle valves, at the outlet of the high-temperature side of the heat exchanger. The flow restriction is one of the main components of a conventional JT cryocooler. Eliminating the independent flow restriction simplifies the JT cryocooler structure. However, experimental investigations into the characteristics of the distributed JT effect remain limited, especially at the liquid helium temperature range. Most prior studies used mixed refrigerants or operated above liquid helium temperatures, often involving experiments within a liquid helium dewar.
In this study, an experiment was conducted with helium-4 as a single-component working fluid and mechanical refrigerator as a precooler for the JT cooling circuit.
Estimating the pressure drops in a helically coiled capillary is crucial for designing a heat exchanger leveraging the distributed JT effect. To this end, pressure drops in helically coiled capillaries of varying inner diameters were measured at room temperature and liquid nitrogen temperature of 77 K prior to designing the heat exchanger. This study presents a detailed discussion of the characteristics of the developed counterflow heat exchanger and closed-cycle cryocooler.

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