Contribution ID: **158**   Type: **Contributed Oral Presentation**

Performance analysis of a miniature Joule-Thomson cryocooler with and without the distributed J-T effect

Wednesday 1 July 2015 16:30 (15 minutes)

Cryogenic temperatures are required for proper functioning of infrared sensors and thermal cameras, space chamber simulations, preservation of biological samples, etc. Such temperatures can be produced by expanding a high pressure gas in a relatively easier way. This is popularly known as the Joule-Thomson (J-T) effect. A typical miniature J-T cryocooler consists of a storage reservoir/compressor providing the high pressure gas, a finned tube recuperative heat exchanger, an expansion valve/orifice, and the cold end heat exchanger. The recuperative heat exchanger is indispensable for attaining cryogenic temperatures. The geometrical parameters and the operating conditions of the heat exchanger drastically affect the cryocooler performance in terms of cool down time and cooling effect.
In the literature, the numerical models for the finned tube recuperative heat exchanger have neglected the distributed J-T effect. The distributed J-T effect accounts for the changes in enthalpy of the fluid due to changes of pressure in addition to those due to changes of temperature. As the pressure drop of the high pressure fluid in the finned tube is large (of the order of 80-100 bar), contribution of pressure variation to changes in enthalpy cannot be neglected. The objective of this work is to study the performance of a miniature J-T cryocooler with and without the distributed J-T effect to highlight its importance. A one dimensional transient model is employed for the numerical analysis of the cryocooler. Cases with different operating conditions and geometrical parameters are worked out with Argon and Nitrogen as working fluids. J-T expansion at the end of the finned tube is also considered to complete the cryogenic cycle. The mathematical model, method of resolution, and results of the study are presented in this paper.

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Session Classification: C3OrK - Special Session: JT Coolers

Track Classification: CEC-03 - Cryocoolers (Non-Aerospace)