Contribution ID: **23** Type: **Poster Presentation (120m)**

Design methodology of a Mixed Refrigerant Joule-Thomson (MRJT) cryocooler

Tuesday 23 July 2024 14:00 (2 hours)

Joule Thomson (JT) cryocoolers are emerging as an alternative choice for cooling temperatures upto 100 K. This is enabled by using refrigerants instead of single/pure refrigerant as a working fluid. Such cryocoolers are also referred to as Mixed Refrigerants Joule-Thomson (MRJT) cryocoolers. By using mixed refrigerants, the pressure ratio in the cryocooler is reduced from an order of 100s to around 8-10. As a result, off the shelf air conditioning compressors can be used for MRJT cryocoolers. In addition to this, the MRJT cryocoolers also have an efficiency that is of order magnitude higher than that of a JT cryocooler operating with a single refrigerant. However, a clear and systematic methodology for designing an MRJT cryocooler for a given evaporator temperature and refrigeration load is not available. The present work focuses on a detailed design methodology for designing an MRJT cryocooler for a given capacity and cooling temperature. Major components that need to be designed for an MRJT cryocooler are compressor, aftercooler, recuperative heat exchanger, expansion device and evaporator.

Before going into the detailed design of the individual components, it is essential to carry out the theoretical design of the MRJT cryocooler cycle. The first step in designing an MRJT cryocooler is the identification of the cryocooler operating parameters. In the present work, the operating parameters are determined by carrying out theoretical optimization of the MRJT cycle. Commercial softwares are available for optimization; however, an inhouse solver is also developed to determine the cryocooler theoretical performance. For optimum results, it is recommended that the exergy efficiency of the cryocooler be used as the objective function.

As described earlier, air conditioning compressors are used in MRJT cryocoolers. The selection of the compressors is carried out by matching its swept volume with the volume flow rate required at the suction side of the compressor. For cases where two stage compression process is required, a mathematical model is developed to select the compressors of the subsequent stages. The aftercooler of the compressor is similar to the condenser of a conventional air conditioning unit. The aftercooler is designed based on the heat generation during the compression process. The recuperative heat exchanger is the most critical component of the MRJT cryocooler. In the present work, a numerical model is developed in order to determine the heat transfer area leading to the heat exchanger dimensions.

Capillary tubes are used as an expansion device for MRJT cryocoolers as they do not contain any moving parts and, hence, do not require sealing arrangements at low temperatures. A one dimensional mathematical model, already published by authors, is used to select the capillary tube size (diameter and length). In MRJT cryocoolers, the heat load may range from a few watts to several kilo watts, thus, an evaporator based on the refrigeration effect and the end application may be designed. The design of individual components is combined to form an MRJT design methodology. The design methodology, so developed, is validated by comparing the results with experimental results obtained in our laboratory.

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Session Classification: Tue-Po-1.2

Track Classification: Tracks ICEC 29 Geneva 2024: ICEC 02: Cryocoolers, magnetic coolers and other coolers