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Abstract

Joule-Thomson (J-T) cryocoolers are the simplest devices that can be used to reach cryogenic temperatures. The key advantage is the lack of moving parts in the low-temperature section. On one hand, they are characterized by a simple construction resulting in a high reliability and a low manufacturing cost. On the other hand, the J-T coolers have low thermodynamic efficiency, are sensitive to impurities in the working fluid, and require very high pressure (from several dozen to several hundred bars). Thus, the coolers work mainly in the open cycles, i.e., fed with the gas from the high-pressure cylinder.

The working pressure can be decreased by using a mixture of the gases. This allows reducing the pressure to around 20-30 bar, and there are mass-produced, one-stage refrigeration compressors that are able to reach that pressure. Consequently, it is possible to build a simple and relatively cheap cryocooler, working in closed system, and using mass-produced components made for the refrigeration industry.

There are many research centers around the world working on the J-T cryocoolers. Most of the publications describe J-T coolers fed with gas mixtures providing up to 20 W of cooling power in the temperature between 80 K and 100 K. To the best of our knowledge, there are no one-stage J-T coolers that provide more than 50 W of cooling power in the temperature 80-100 K.

We prove that it is possible to build a one-stage J-T cooler which uses mass-produced components and can provide the cooling power of several dozen W in temperatures less than 100 K. Its exergetic efficiency is comparable with other cryocoolers working in similar parameters, e.g. Gifford-McMahon coolers.

We develop a mixture optimization algorithm based on the maximization of the isothermal J-T effect using the Peng-Robinson equation of state. Using the algorithm, we derive several gas mixtures and compute the exergetic efficiency of corresponding coolers. The efficiency depends on the gas mixture composition, and it is in the range 5-9%. We analyze the energy loss in different parts of the cooler and conclude that it is mainly caused by the processes in the recuperative heat exchanger, the gas cooler, and the compressor. We present experimental results for two coolers with nominal cooling power of 10 W and 50 W in the temperature range 90-100 K. The exergetic efficiency of the tested coolers is 3.8% and 4.8%. They are comparable with the efficiency of other state of the art cryocoolers (e.g., Gifford-McMahon coolers) which shows the potential for the cooler's commercialization. Moreover, we analyze the application of the J-T cooler in the LNG re-condensation system and show that the exergetic efficiency of the J-T cooler is comparable to the efficiency of the four-stage cascade refrigerator.