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Development of a −186 °C cryogenic preservation chamber based on a dual mixed-gases Joule–Thomson refrigeration cycle

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ABSTRACT

First of all, a dual mixed-gases Joule–Thomson refrigeration system was designed, constructed and tested in this work. A minimum no-load temperature of −197.7 °C (about 75.5 K) was reached and about 110 W cooling capacities at −174 °C (about 99 K) was obtained with the mixed-gases refrigeration prototype. Secondly, a cryogenic chamber for biomaterials preservation was built and tested with the similar cycle configuration, which has reached the lowest temperature of −192 °C (about 81 K) with an effective preservation volume of 80 L. A relatively fast cooling-down rate for this cryogenic chamber was obtained. Specifically, it took 2.5 h to reach −180 °C, and about 5 h to reach −190 °C. The cryogenic chamber shows a good perspective as a substitute for traditionally used liquid nitrogen preservation vessels.

1. Introduction

The Joule–Thomson refrigeration based on the real gas Joule–Thomson effect is one of the oldest refrigeration methods, and gets its revival by using multicomponent mixed-gases in recent several decades. Numerous refrigeration cycle configurations have been proposed for various applications. Some applications based on the mixed-gases Joule–Thomson refrigeration technology have already been commercialized, such as low-temperature cryogenic preservation chambers, cryogenic water traps for high vacuum applications, and natural gas liquefiers. Most of the above applications are at temperatures around 120 K. There are numerous requirements for refrigeration at temperatures around 80–100 K, for instance, air liquefaction and separation, high-temperature superconductivity, electronic and infrared apparatus cooling, etc. The mixed-refrigerant refrigerator with single-stage configuration was proved to be able to reach temperatures as low as 70–80 K [1,2]. However, so large temperature span makes it much complicated to get the optimal mixture refrigerant. Generally, there are up to seven components with different boiling temperatures from near ambient temperature to the cryogenic temperature needed to obtain the required mixed-refrigerant. So many components with various boiling temperatures bring about several crucial problems such as circulating composition shift from the original charged mixture, the risk of component freezing out of those with high triple-point temperatures, heat transfer deterioration, etc.

Using two mixed-refrigerant refrigerators based on a cascade cycle configuration is a good way to solve those problems above. With the precooling provided by the high-temperature mixed-refrigerant cooling stage, there are several merits for the low-temperature mixed-refrigerant refrigeration stage. One obvious merit is that high boiling point components such as isopentane and butane need not be used at all. The possibility of freezing those high boiling components is therefore much less likely in the refrigeration processes. Another advantage is that the effect of the variation of ambient temperature on the cooling performance can be minimized, especially in the case of high ambient temperature.

Some analyses and researches have already been done on the cascade mixed-refrigerant refrigerator for temperatures around 80–100 K by many researchers [3–8]. Among those, Alexeev [3] has achieved a high cooling performance by using a typical single-stage vapor compression cycle to precool a single-stage mixed-refrigerant cryocooler. In his work, the high-temperature stage is a traditional single-stage vapor compression system by using R507 as the refrigerant. Skye et al. [4,5] reported their analysis and experimental study on a mixed-refrigerant cryosurgical probe precooled by a typical R22 single-stage vapor compression cycle. Obviously, the precooling stage can also be a mixed-refrigerant refrigeration system. Such a system in which the main mixed-refrigerant system is precooled by another mixed-refrigerant cycle has already been disclosed in some natural gas liquefaction

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