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Experimental investigation on mixed refrigerant cryocooler operating at 70 K for cooling high temperature superconductors

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Abstract. The paper deals with a Mixed Refrigerant Cascade refrigerator operating at 70 K. A mixture of nitrogen, neon and hydrocarbons has been used as the refrigerant. A lowest temperature of 64 K was achieved on no load, 70 K at 2 watts and 75 K at 5 watts. The details of the study are presented in this paper.

1. Introduction

Many large applications of High Temperature Superconductors such as superconducting transformers, motors etc. are currently being developed. In some of the applications such as superconducting transformers, the system is placed in a subcooled liquid nitrogen bath [1], typically at a temperature close to 70 K. A single cylinder Stirling/ GM refrigerator can be used to meet the heating load due to (a) heat inleak (b) heat generation within the system [2], when the total heat load is typically less than 1 kW. Multiple refrigerators (cylinders) need to be used in parallel to meet heat loads larger than about 0.7-1kW. The mixed refrigerant cycle refrigerators are an ideal for meeting heat loads that are several kW or tens of kW [3].

The lowest temperature in MRC refrigerators for the above applications can reach close to 63 K. Commonly used high boilers of the mixture such as propane, iso butane etc. freezeout at this temperature. The triple point temperatures of some of the components commonly used in the MRC cryocoolers are shown in Table 1 [4]. The freezing temperatures are normally lower than the individual triple point temperature, due to the presence of other low boilers in the mixture. However, the freezing point depression is normally limited and most hydrocarbons (other than methane) freezeout below 68 K.

Table 1 Triple points of different components of the typical Mixed Refrigerant Cascade cycles

Components	Triple point (K)
Neon	24.556
Nitrogen	63.151
Propane	85.525
Ethane	90.368
Methane	90.694
iso Butane	113.73

The problem that arises due to the freezeout of high boilers can be avoided by employing a phase separator cycle. The result of our studies on a small prototype refrigerator operating at a temperature below 70 K on a phase separator based cycle built in our lab is presented in this paper.

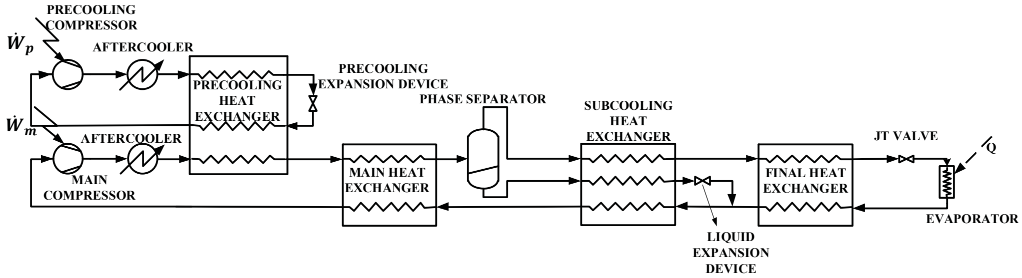

Figure 1 Schematic of Mixed Refrigerant Cascade Cycle with phase separator for low temperature applications

2. Experimental setup

Figure 1 shows the schematic of the process investigated in this work. The refrigerant in this process is compressed in a rolling piston compressor, from a pressure of about 2 to 3 bar to about 18 to 20 bar. The heat of compression is rejected in the aftercooler, which is cooled by the ambient air. The lubrication oil carried over from the compressor is removed in a three stage oil separation system to prevent the freezing of oil at low temperatures. The high pressure refrigerant enters into the cryostat at a temperature close to the ambient. The cryostat is maintained at a pressure of 10^{-5} mbar for minimising the heat inleak to the system. To minimise the radiation to the system, the entire cold section shown in Fig. 2 is covered with galvanized mylar multilayer insulation. The precooling cycle is operated with a mixture of propane and ethane. The heat exchangers used in the setup are coiled tubes-in-tube type. Cryogenic needle valves are used as throttling devices. The evaporator is a multiple channel type with a cross section of 2 mm x 2 mm and a length of 40 mm for each channel. Heat load is applied using a cryogenic cartridge heater. Class A Pt 100s were used for temperature measurements and piezoresistive transmitters were used for pressure measurements.

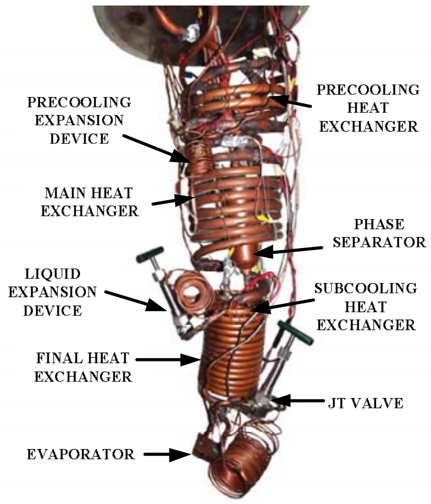

Figure 2 Pictorial view of cold section

3. Results and Discussion

Experiments were performed with mixtures of nitrogen, neon, methane, ethane and propane as the main refrigerant and a mixture of propane and ethane as the precooling refrigerant. The main refrigerant is precooled to a temperature of 259 K in the precooler and to a temperature of about 113 K at the entry of the phase separator. The vapour fraction of the refrigerant is of the order of 70 % at the entry of the phase separator. Most of the high boilers of the main refrigerant namely propane, ethane and methane are removed almost completely in the phase separator in the liquid phase. The vapour phase consists of nitrogen, neon and a small fraction of methane (typically less than 4%). The liquid separated in the phase separator is subcooled in the subcooling heat exchanger before it is throttled and mixed with the returning stream to the compressor suction. The vapour separated in the phase separator is cooled in both the subcooling heat exchanger and the final heat exchangers before it is expanded in the J-T valve for providing the necessary refrigeration in the evaporator. The compressor is operated at a compression ratio of 7 with a discharge pressure of 18 bar during steady state condition.

Figure 3 shows the cooldown characteristics of the refrigerator tested in this work. The phase separator cools to a temperature of 113 K in about 90 minutes and remains about the same, thereafter. The vapour phase separated in the phase separator enters the JT valve before the evaporator in vapour phase till its temperature reduces to about 113 K. It can be seen from Fig. 3 that this cooldown to two phase state at the entry of the JT valve takes about 300 minutes. The main refrigerant cools to steady state temperature of 64 K at the exit of the JT valve in about 550 minutes.

It is possible to reduce the cooldown time substantially by allowing a part of the high boilers separated in the phase separator to pass through the final heat exchanger till the temperature of the order of 100 K reaches at the entry of the JT valve. From Fig. 4 it can be seen that the temperature of the refrigerator at the entry and exit of the evaporator are 66.1 and 69.8 K at an applied heat load of 2 watts and, 71.5 and 75.3 K at an applied heat load of 5 watts. No freezing of refrigerant was observed during the operation of the system with the above refrigerant as well as with refrigerants containing nitrogen, neon and hydrocarbons, even under zero load conditions.

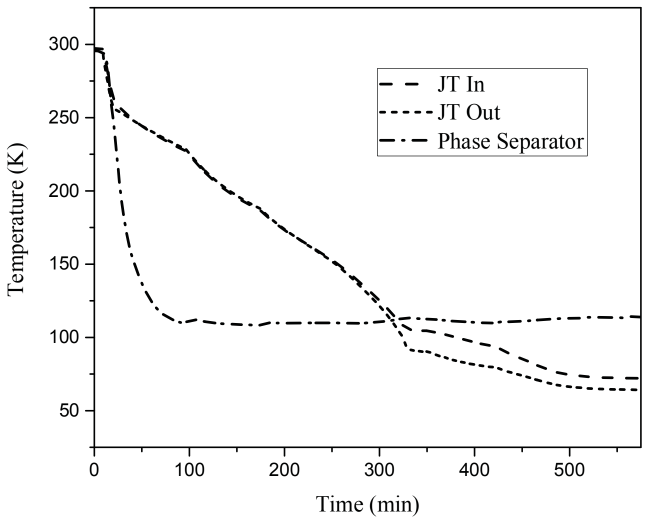

Figure 3 Cooldown characteristic

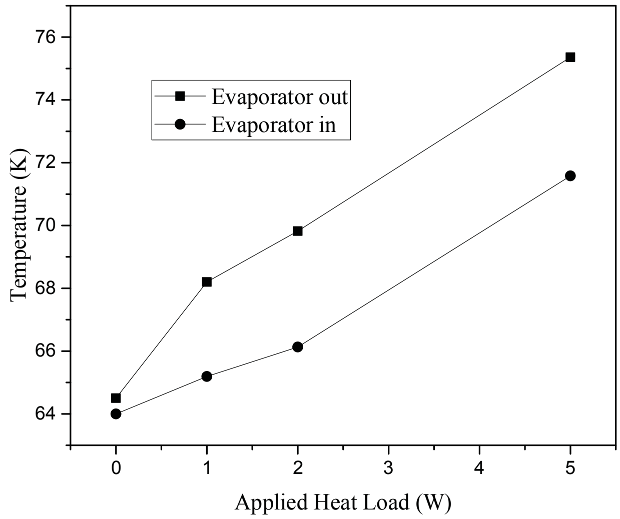

Figure 4 Load characteristics

4. Conclusions

A minimum temperature of 64 K has been achieved at the exit of the JT valve at a pressure of 4.3 bar at the JT exit, with the mixture of nitrogen, neon and hydrocarbons in the process shown in Fig. 1.

Experiments are currently underway to reduce the cooldown time as well as to improve the performance of the system considerably.

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