PERFORMANCE OF MRC FREEZER BOX WITH CFC REFRIGERANTS

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ABSTRACT

A single-stage Mixed Refrigerant Cascade (MRC) system with freezer box is designed and developed to maintain low temperatures within the range of 183K to 200K. A traditional multi-stage cascade refrigeration system has been replaced by the use of mixtures of available hydrocarbon refrigerants.

A minimum refrigeration temperature of 183.8 K was achieved inside the freezer box at approximately 180 minutes under no-load conditions, and other performance parameters of the refrigeration systems like heat load, pressure, exergy efficiency and compression ratio have been presented in this paper.

Keywords: MRC Freezer Box, Cool down, Hydrocarbon refrigerant mixture, Heat load

Nomenclature		**Abbreviations**	
$\dot{m}$	Mass flow rate through the compressor (Kg/s)	HX	Heat exchanger
$\dot{Q}$	Heat load, (W)	J–T	Joule Thomson
$\dot{Q}_o$	Heat rejection, (W)	Ts	Temperature sensors (ºC)
$\dot{W}_{comp}$	Compressor power (W)	Ps	Pressure sensors (bar)

INTRODUCTION

Conventional multi stage cascade vapor compression refrigerators are typically employed for providing refrigeration below 230K. Normally, two cascade stages are required for temperatures down to 200K, and three stages for temperatures down to 173K. Achieving even lower temperatures necessitates additional stages, leading to increased system complexity, the number of heat exchangers, compressors, and ultimately, costs. To enhance performance, a single-stage compressor with a lower pressure ratio (15-20 bar) can be utilized along with mixtures of different hydrocarbon refrigerants. Such systems are referred to as Joule Thomson refrigeration systems or Mixed Refrigerant Cascade refrigerators (MRC) [1].

Boiarski et al. [2] developed a mixed gas refrigerator for use in the cryogenic range of temperatures between 80K and 100 K. The system incorporates a single-stage compressor that provides a discharge pressure up to 30 atm. The refrigerant composition includes nitrogen between 30% and 50% molar, methane less than 20% molar, propane more than 30% molar, and ethane comprising the remaining balance.

Babu et al. [3] presented the first results with a binary mixture of ethylene-propylene on a simple test stand, which included a fully hermetic oil-lubricated compressor. The analysis was conducted using the ASPEN PLUS process simulator. Their results show that the exergy loss in the internal heat exchanger is much larger than in other components, and the choice of the compressor plays an important role, similar to the selection of an optimum mixture, in the design of efficient MRC systems.

Senthil Kumar, P., and Venkatarathnam [4] have fabricated and tested various types of heat exchangers for a mixed refrigerant cascade refrigerator using a mixture of nitrogen and hydrocarbons. An exergy efficiency greater than 6% was achieved at temperatures exceeding 100K.

Laxshmi Narasimhan and Venkatarathnam [5] experimentally studied the relationship between the composition of the mixture charged and that in circulation during steady state in a J- T refrigerator operating with mixtures of nitrogen, neon, methane, ethane and propane.

Rajesh Reddy et al. [6] suggested in his experimental studies that the deficiency of a particular component of the mixture can be identified from the inflection points in the cooldown characteristics, replotted in the form of temperature difference across the J-T valve versus J-T inlet temperature curves.

Rajesh Reddy et al. [7] developed a fast cooldown mixed refrigerant cascade refrigerator and tested it with both flammable and non-flammable mixtures, such as Nitrogen-Hydrocarbon and Argon-Hydrocarbon. They achieved cooldown times of 30 to 45 minutes for flammable and 50 to 65 minutes for non-flammable mixtures. The maximum exergy efficiency attained was 6.93% at 136.4K with a reciprocating compressor and at 137.7K with a rotary compressor for flammable mixtures. For non-flammable mixtures, an external exergy efficiency of 4.09% at a temperature of 152.2K and an internal exergy efficiency of 4.23% at a temperature of 149.5K were achieved.

Bura Sreenivas et al. [8] developed a fast cooldown mixed refrigerant cascade refrigerator for cooling a space simulation chamber with HFC-FC-HC mixtures. Cool down to a temperature of 193K is achieved in 16 min, a maximum exergy efficiency of 5.6% could be obtained with a fluorocarbon-hydrocarbon mixtures.

The developed MRC freezer box was subjected to comprehensive testing to assess its cooldown characteristics and performance under various operating heat loads. Different compositions of hydrocarbon refrigerants were utilized by trial and error method to study their impact on the system's performance parameters within the specified temperature range of 183K to 200K.

The selection of first hydrocarbon refrigerant mixture in this work is based on the experimental analysis done by *Rajesh Reddy et al*. [7] in single stage mixed refrigerant refrigerator with rotary compressor.

EXPERIMENTAL SETUP AND PROCEDURE

The schematics of experimental setup of the mixed refrigerant cascade system and cold section (Freezer Box) are shown in figure 1 and figure 2.

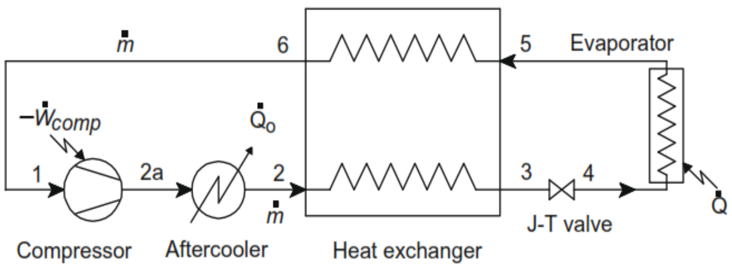

Figure 1.Schematic of MRC refrigerators

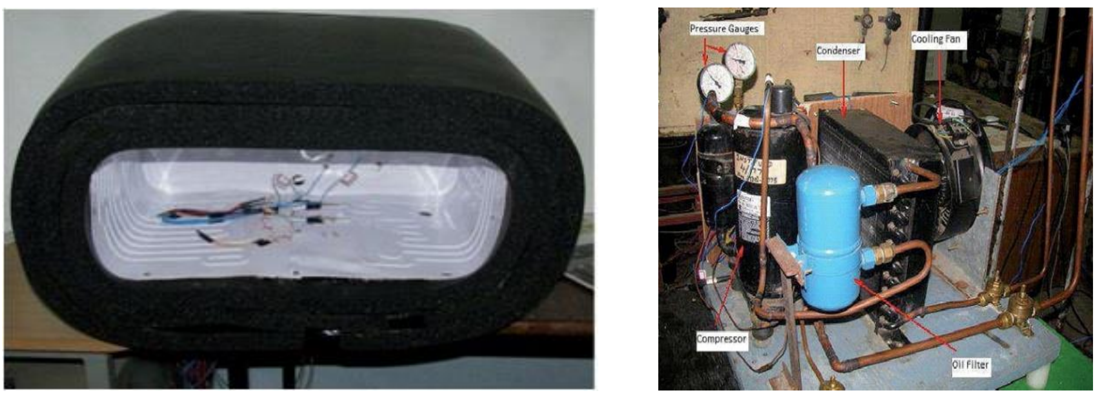

Figure 2.Cold Section and Hot Section of experimental setup

The experimental setup can be essentially divided into two sections: (a) the hot section, which includes the compressor, oil separator, and after cooler, and (b) the cold section, which consists of the counter-flow heat exchanger. The heat exchanger is placed inside the cryostat.

The single stage oil-lubricated rolling piston-type compressor (1-2a) compresses the mixture of refrigerants from ambient temperature and system filling pressure to high pressure, approximately 15 to 25 bar, and high temperature.

The discharge pressure is dependent upon the initial filling pressure of the system with the refrigerant mixture. Approximately 80 to 90% of the compressor lubricating oil carried by the refrigerant is separated in the oil separator and returned to the compressor via the compressor suction line. The heat of compression is then rejected in the condenser (2a-2). The partially condensed high-pressure refrigerant system, at nearly ambient temperature, undergoes further condensation and sub-cooling using the low-pressure refrigerant from the evaporator. This process occurs in a counterflow heat exchanger (2-3) situated inside the cryostat.

The cryostat is maintained at a vacuum of $1x10^{-5}$ mbar. The sub-cooled high-pressure refrigerant undergoes expansion through a J-T valve (3-4), providing cooling in the evaporator (4-5). Only a small portion of the latent heat of the low-pressure refrigerant is utilized in the evaporator (Freezer Box). The majority of the latent heat of the low-pressure refrigerant is employed to cool and condense the high-pressure refrigerant in the heat exchanger (5-6).

A heater, consisting of Nichrome wires sandwiched between parallel copper plates and supplied with DC power, is utilized to provide the heat load. The temperatures are measured using T-type thermocouples with a measurement range from -200ºC to 400ºC. Pressure measurements are conducted using piezoresistive transmitters with a measurement uncertainty of ±0.125 bar in the range of 0 to 25 bar. Both pressure and temperature readings are acquired by a data acquisition system connected to a computer.

RESULTS AND DISCUSSIONS

Experiments have been carried out to study the transient and steady state performance with hydrocarbon refrigerant mixtures (Table 1) in this work.

Table 1. Charge composition of refrigerant mixture tested

Mixtures	Refrigerant composition (mol %)					
	Methane	Ethane	Propane	n- Pentane	Iso – Butane	R23
Mix– 1	14.40	20.16	65.44	-	-	-
Mix – 2	12.98	17.97	60.45	8.60	-	-
Mix – 3	17.08	19.84	53.70	9.38	-	-
Mix – 4	19.84	22.33	47.43	10.4	-	-
Mix – 5	18.73	26.65	44.78	9.84	-	-
Mix – 6	18.18	25.87	43.53	9.54	2.88	-
Mix – 7	17.94	25.52	42.88	9.40	2.84	1.42

Figure 4 illustrates the cooldown characteristics of a single-stage cascade freezer system operating with Mix – 7. The system achieved the lowest temperature of 189.3K at approximately 180 minutes.

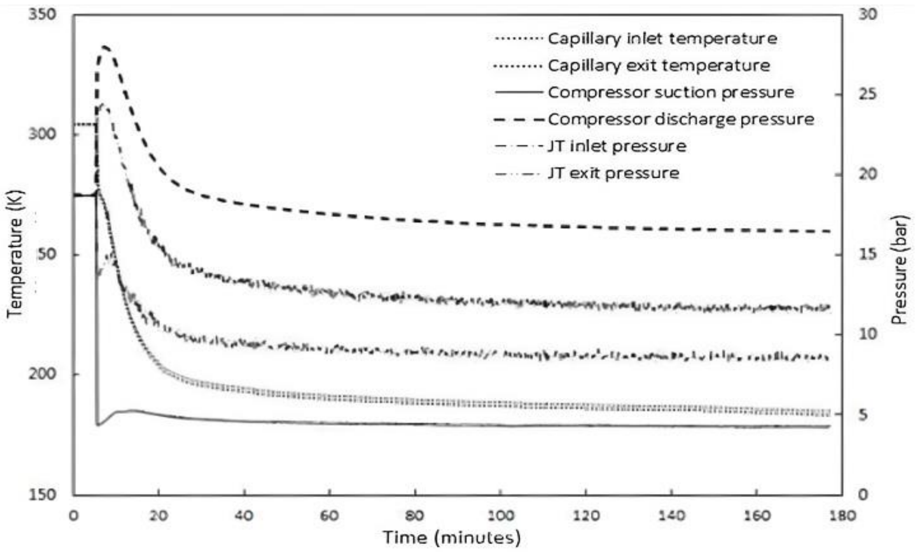

Figure 4.Cooldown characteristics of MRC freezer operating with mixture Mix-7

Figure 5 shows variation of the temperature of refrigerant leaving the evaporator at different applied heat loads. Mix – 7 shows more refrigeration capacity because in presence of high boilers refrigerants. Maximum heat load 158W could be attained.

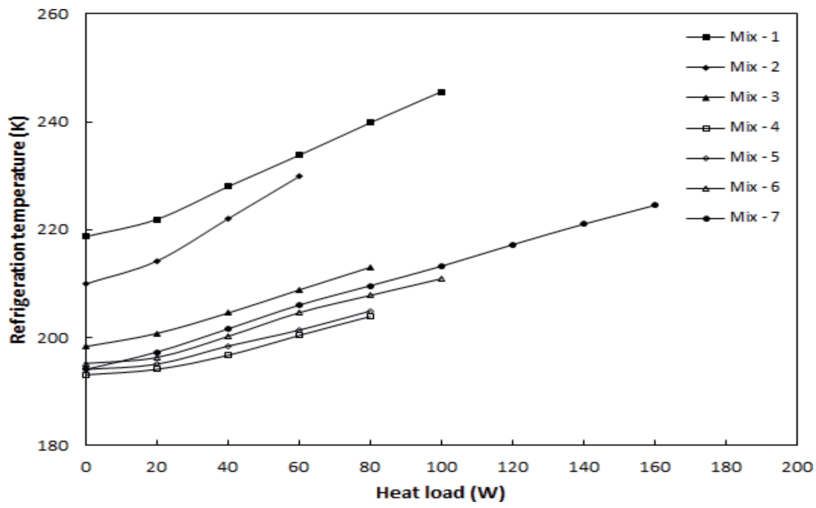

Figure 5.Variation of refrigeration temperature with heat load

Figure 6 shows the variation of internal exergy efficiency with refrigeration temperature of MRC freezer with different refrigerant mixtures. With Mix – 7 the maximum internal efficiency 2.07 % is obtained.

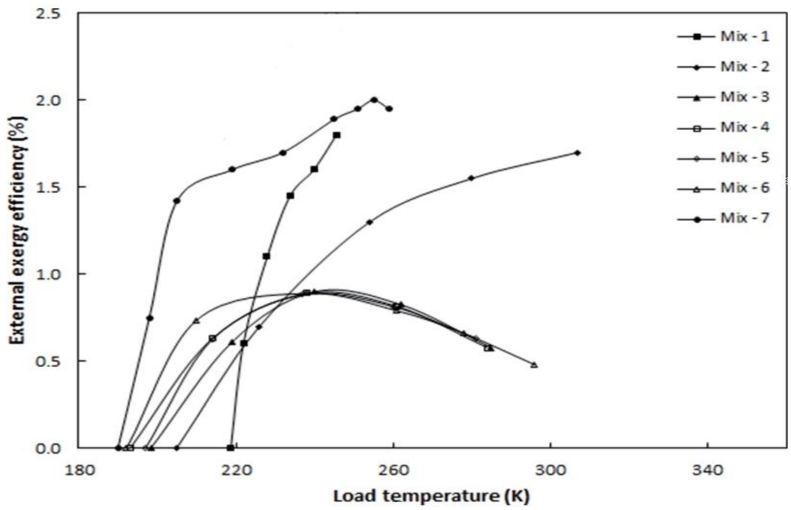

Figure 6.Variation of external exergy efficiency with refrigeration temperature

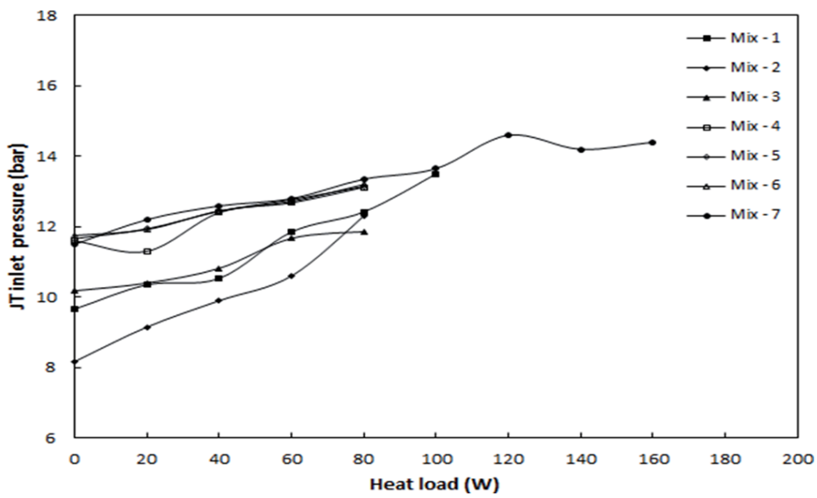

Figure 7.Variation of external exergy efficiency with refrigeration temperature

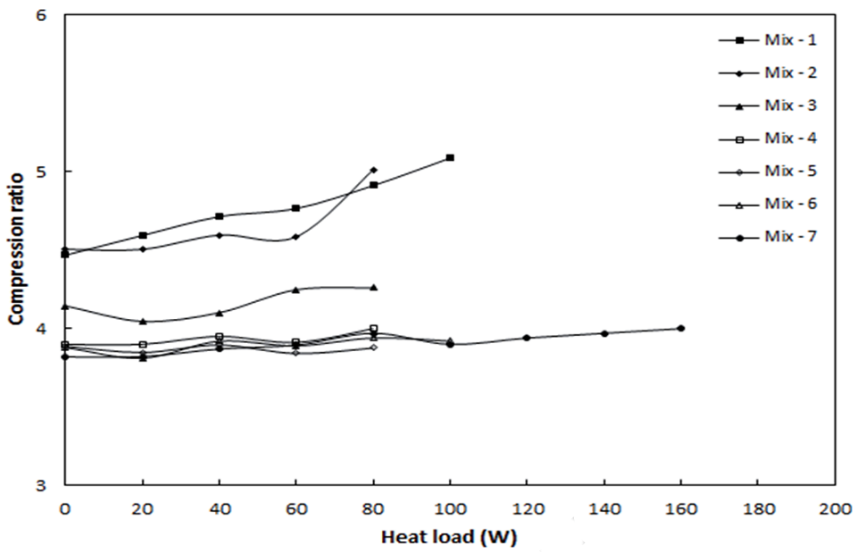

Figure 8.Variation of external exergy efficiency with refrigeration temperature

CONCLUSIONS

1. The best performance was obtained was obtained with a six components mixture (Mix-7). The maximum exergy efficiency of 2.07% is achieved.
2. A minimum refrigeration temperature of 183.8 K was achieved inside the freezer box at no-load conditions. A maximum refrigeration capacity of 158W could be met at operating temperature range.
3. Pressure increases with increase in heat load. Exergy efficiency could be increased by not using an additional compressor cooling fan, as in the present case.

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