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RESEARCH ARTICLE

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EXPERIMENTAL INVESTIGATION OF MIX REFRIGERANT JOULE THOMSON CYCLE LOW TEMPERATURE REFRIGERATOR AS ALTERNATIVE TO THE CASCADE SYSTEM

PRATIK C. PATEL[1], Prof.PRANAV H. PATEL[2]
[1]M.E Thermal, Smt. S. R. Patel Engineering College, Unjha
[2]Government Polytechnic for Girls, Ahmedabad

ABSTRACT

Recent advances in JT cryocooler have been associated with the use of mixed-gases as the working fluid rather than pure gases. Mixed gas Joule Thomson have advantages such as low cost, alternative to cascade system, high reliability , higher cooling effect at 80 k, low vibration and simplicity in design . As a result their use for different application has become threat to conventional cryocooler such as Stirling coolers. [14]This thesis focuses on building a closed cycle Joule Thomson cryocooler operates in the temperature range from 110 K to 190 K, which uses refrigerant mixtures and a single stage oil lubricated compressor. It provides high reliability and no maintenance. This system is compact, has a good thermodynamic efficiency and low levels of vibration and noise. The probable system, its working principle, literature review, summarized parameters, methodology of work of the system is discusses in this project report.

Key Words - Cryocooler, MRJT cycle, Mixed Refrigerant, Cooldown characteristics curves for MRJT.

I. INTRODUCTION

Cryocooler is a device for producing refrigeration at temperature less than 110 K. The main problems associated with cryocooler are: unreliability, inefficiency, size, weight, vibration, cost & cool down time. Recent advances in J-T cryocooler have been associated with the use of mixed refrigerants as working fluid rather than pure gases [8]. Objective of the work is to develop the cryocooler model between 110ºK to 190ºK. This was also to demonstrate the low cost MRJT technology in industry at Pratik Air System, Ahmedabad.

There are several advantages in using refrigerant mixtures in cryocooler[4]:

- The exergy efficiency (figure of merit) of refrigeration systems operating with refrigerant mixtures is many times that of systems operating with pure fluids.
- The operating pressure is much lower when refrigerant mixtures are used, compared to pure fluids.
- Cryocoolers operating with pure fluids operate largely in the superheated vapor region, whereas those operating with refrigerant mixtures operate largely in the two-phase region. Consequently, the heat transfer coefficients in the heat exchangers

are much larger in systems operating with refrigerant mixtures compared to those operating with pure fluids, resulting in smaller heat exchangers.

- The degradation of heat exchanger performance due to longitudinal (axial) heat conduction is much smaller due to higher apparent specific heat of refrigerant mixtures in the two-phase region compared to the specific heat at constant pressure (cp) of pure fluids in the superheated (single-phase) region.

MRJT cryocooler can be used over wide range of temperature from 70K to 150K covering wide applications such as infrared sensor, SQUID and electronic chip cooling, as Cryofreezers, high temperature superconductor cooling, water vapor cryo-trapping etc.

II. DEVELOPMENT OF EXPERIMENTAL SETUP

As shown in Table, MRJT cryocooler consist of two module. Details are shown as below.

TABLE I: UNITS FOR MAGNETIC PROPERTIES

Cryostat module			
Sr.	Components	Dimensions	Materia
1	Recuperative heat exchanger	L = 4.5 m, Mean coil Dia.= 160mm	Copper
2	Capillary tube as expansion device	L = 4m, Dia.= 2.28mm	Copper
3	Evaporator	L = 200mm Dia. = 12.7mm (1/2")	M.S.
4	Cryostat	L= 350mm Dia.= 200mm	M.S.
Compressor module			
5	Commercially available Rotary Compressor for R22 Refrigerant of 1.5 Ton A/C.		
6	Commercially available Condenser of 1.5 Ton A/C as after cooler with filter.		

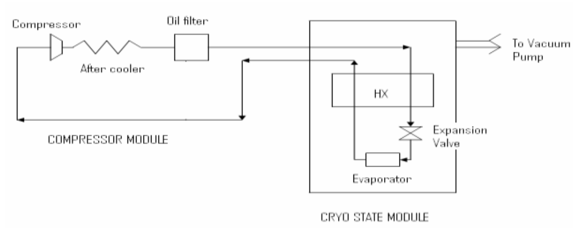


Fig 1: Low cost mixed refrigerant Joule-Thomson cryocooler.

III. SELECTION OF REFRIGERANT MIXTURE

Following method for the selection of mixture component as describe by A. Alexeev is used[3]:

TABLE II: GROUPS OF THE COMPONENT FOR SELECTION OF MIXTURE FOR MRJT CRYOCOOLER

Groups	Components	Boiling Temperature K
Group -1	He, Ne	4.2-27.0
Group -2	N_2, Ar	77.3-87.3
Group -3	CH_4	111.7
Group -4	R_{14}	145.2
Group -5	C_2H_6,C_2H_4,R_{13} ,R_{23}	169.4-194.9
Group -6	C_3H_8,C_3H_6,R_{22} ,R_{12}	225.4-243.4
Group -7	iC_4H_{10},iC_4H_8	261.3-266.9
Group -8	iC_5H_{12},iC_5H_{10}	292.3-303.1

- Following points to be noted for selection of refrigerant:
- Working substance, operating pressure and temperatures decide the mixture.
- Select the components of the mixture and optimize their concentrations.
- Based on thermodynamics, the isothermal effect is directly related to boiling temperature and the liquid- vapor latent heat of the selected components.
- Considering the solubility limit of mixture composition, one can further determine the composition.
- One can choose one component from each group. Group 5, 6 have more components and they can replace each other.
- For oil lubricated compressor, HCs are preferred due to their solubility in oil.
- From 80 K to 300 K, there are large numbers of components.

As per above described method considering the availability it is being decided to used the mixture of Methane(CNG), Ethane, Propane and i-butane.

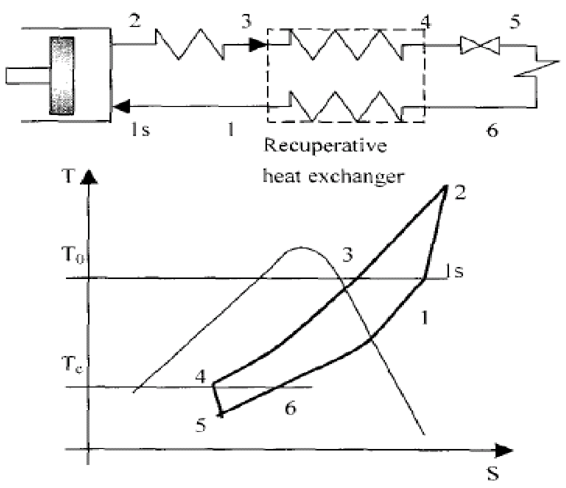
Different properties of following mixtures are derived using COOLPROP and AQUAlibrium between discharge pressure of 18 bars and suction pressure of 2 bars.

TABLE III: DIFFERENT MIXTURE COMPOSITION

Mixture (mol %)	1	2	3	4	5	6
Methane	0.25	0.20	0.15	0.10	0.40	0.45
Ethane	0.17	0.22	0.25	0.30	0.35	0.40
Propane	0.25	0.28	0.35	0.38	0.15	0.10
I-butane	0.33	0.30	0.25	0.22	0.10	0.05

I. THERMODYNAMIC ANALYSIS OF MRJT CYCLE

Figure shows the schematic diagram of a typical single-stage mixed-refrigerant recuperative refrigeration cycle[8] For mixed-refrigerant recuperative cycle, the thermodynamic performance can also be presented as



$$q_c = h_6 - h_5 = h_6 - h_4 = h_1 - h_3$$

$$= \min\left(h(T)_{pl} - h(T)_{ph}\right) - (h_{1s} - h_1)\ \Delta h_t - q_{loss} \quad (1)$$

$$q_{loss} = (h_{1s} - h_1),\ \Delta h_t = \min\left(h(T)_{pl} - h(T)_{ph}\right) \quad (2)$$

$$COP_{MRJT} = \frac{q_c}{h_2 - h_{1s}} \quad (3)$$

$$\eta_{MRJT} = COP_{MRJT} * \frac{T_0 - T_c}{T_c} = \frac{q_c}{h_2 - h_{1s}} * \frac{T_0 - T_c}{T_c} \quad (4)$$

V. SAMPLE CALCULATION FOR MIXTURE 5:

Assuming that MRJT cryocooler operates between temperature range of 300K and 173K and discharge pressure of compressor is 18bar and suction pressure is 2bar. Considering the isothermal compression at 300K and h1s = h1. Different values of enthalpy are as follow:

h1 = 499.30 kJ/kg,

h2 = 669.04 kJ/kg,

h4 = 26.31 kJ/kg,

h6 = 92.64 kJ/kg,

Sp. Refrigerating effect:

$$q_c = h_6 - h_4 = 92.64 - 26.31 = 66.33 KJ / Kg$$

Co-efficient of performance for MRJT cycle:

$$COP_{MRJT} = \frac{q_c}{h_2 - h_{1s}} \quad (5.3)$$

$$COP_{MRJT} = \frac{66.33}{(669.04 - 499.3)} = 0.391$$

Efficiency of MRJT cryocooler:

$$\eta_{MRJT} = COP_{MRJT} * \frac{T_0 - T_c}{T_c} = \frac{q_c}{h_2 - h_{1s}} * \frac{T_0 - T_c}{T_c} \quad (5.4)$$

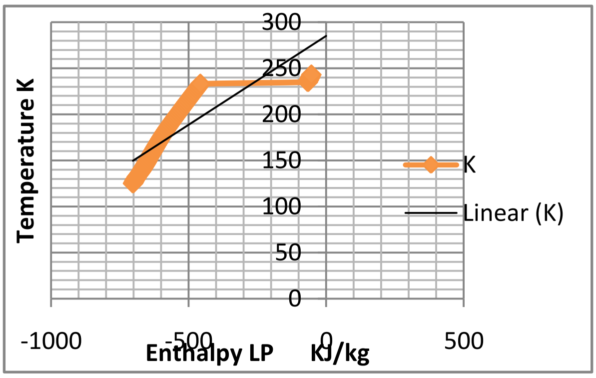
$$\eta_{MRJT} = COP_{MRJT} * \frac{300 - 148}{148} = 40.15\%$$

TABLE IV: CALCULATION TABLE FOR ALL MIXTURE

Mixture	1	2	3	4	5	6
Nitrogen (mol %)	Nil	Nil	Nil	Nil	Nil	0.15
Methane (mol %)	0.17	0.20	0.25	0.35	0.40	0.18
Propane (mol %)	0.50	0.48	0.45	0.37	0.36	0.40
I-butane (mol %)	0.33	0.32	0.30	0.28	0.24	0.27
P_{high} (bar)	18	18	18	18	18	18
P_{low} (bar)	2	2	2	2	2	2
T_0 (K)	300	300	300	300	300	300
T_c (K)	148	148	148	148	148	148
COP	0.038	0.074	0.12	0.212	0.391	0.131
Efficiency (%)	3.6	7.8	13.0	22.36	40.15	14.38
T_{min} achievable (K)	154	146	144	146	134	143

VI. EXPERIMENTAL INVESTIGATION OF MRJT CRYO COOLER

As mixture 5 gives maximum COP and minimum possible temperature can be achieved by this mixture so it is being decided to charge low cost MRJT cooler with this mixture.



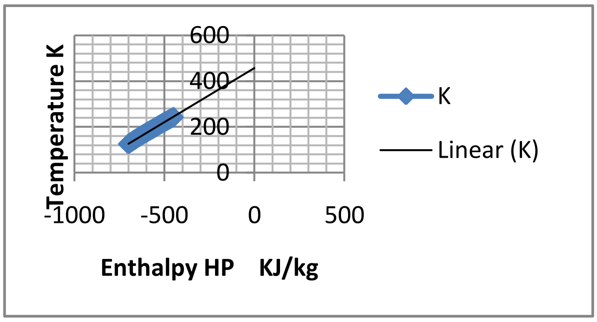


Fig: 3: T-h chart for Mixture 5.

Technical parameters of Low cost MRJT cryocooler.

- Charging pressure: 14 bar
- Compressor discharge pr: 18 bar
- Compressor suction pr: 2.0 bar
- Minimum temperature : 193 K
- Cost: Rs. 28,000

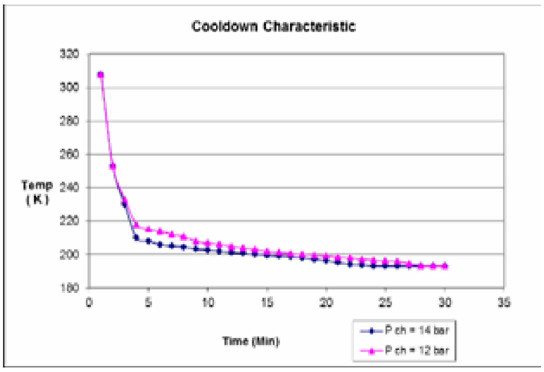


Fig 4: Cooldown curve for mixture 5 with different charging pressure.

Figure shows Cooldown curve for mixture 5 with charging pressure of 14 bars and 12 bar. It can be observed in both cases the lower temperature of 148 K is obtained. Cooldown time for 14 bar is just 25 minutes while it is 30 minutes for 12 bar.

VII. CONCLUSION

A mixed refrigerant Joule Thomson cryocooler has been developed and tested under different parametric condition. Considering the availability of refrigerant it is decided to use the mixture of methane, propane, iso-butane. Different properties of different mixture composition of these refrigerants are derived with the help of COOLPROP. Using these properties COP and efficiency for six different type of mixture composition of MRJT cryocooler is calculated and it observed that as proportion of lower boiling point component (methane and ethane) increase COP and efficiency. A pressure ratio of 6.5, with maximum pressure little less than 17 bar, was obtain under steady state condition. The lowest temperature recorded is 148 K. The experiment was also conducted to study the effect of charging pressures on the cool down characteristics of low cost MRJT cooler. Cool down time decrease with increase in charging pressure.

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