A Review Paper on Performance Analysis of N20 Trans-Critical Refrigeration Cycle with Ejector Expansion System (EETRC)

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Abstract-Performance analysis of Trans-critical N2O ejector expansion refrigeration cycle is analyzed. Two phase ejector, an expansion device is used instead of conventional expansion device. Performance analysis is carried out on basis of three thermodynamic parameters mainly 'COP, Refrigerating effect (R.E.) and compressor work 'and two main performance parameters called 'Entrainment Ratio and Pressure Recovery Ratio'. The resulting parameters of N2O cycles are compared with that of CO2 cycle performance parameters. The N20 ejector expansion system is found to have higher COP, lower compressor discharge pressure and higher Entrainment ratio but lower volumetric cooling capacity.

Keywords — Trans-critical, N2O, Ejector, refrigeration, entrainment ratio, pressure recovery

I. INTRODUCTION

Refrigeration has become one of the most important essentials of modern life. It requires maintenance in which energy plays very important role in it. Refrigeration systems we use mostly work on power absorbing cycles like vapor compression cycle and vapor absorption cycles. However due to increase in population, demand of refrigeration is increasing day by day. This increase in demand and high production cost has made the current scenario worst, further affects of pollution on Global environmental is irreparable .Due to this situation, researchers have been focusing on the renewable energy alternatives in refrigeration. A number of natural refrigerants are available for their use in Refrigeration and Air Conditioning. Refrigerants like water, ammonia, carbon dioxide, isobutene, propane and nitrous oxide are available. The main advantage of these refrigerants is their zero ozone layer depletion potential and low Global Warming Potential.CO2 has already been studied and has gained important acceptance in RAC and heat pump applications, but N2O has still remained untouched. Researchers are also working on many alternative methods to reduce power consumption of refrigeration. EERC (ejector expansion refrigeration cycle) is one which is most appropriate one and which is not so popularly used. In this paper EERC is used.

Thermodynamic analysis of N2O transcritical refrigeration cycle using dedicated mechanical subcooling cycle has been carried out in the present work. The transcritical cycle with the mechanical subcooling is evaluated for three different evaporator temperatures 5, -5 and -30 ºC with different degrees of subcooling and for the environment temperatures range from 30 to 40 ºC using propane as refrigerant for the subcooling cycle. Performance of N2O transcritical cycle has been compared with CO2transcritical cycle. The results show that N2O transcritical cycle is better than CO2 cycle for environment temperature above 30 °C, which is an important fact for countries having tropical climate. In this paper performance of N_2O as a refrigerant in EERC is compared with that of the CO_2.However, CO_2 can be used below evaporation temperature of -55˚c only as triple point of CO_2 is 56.56˚C. But on the other hand N_2O can be used below this temperature as its Triple point temperature is -88.47˚C. The main reason of comparing CO_2 and N_2O is the similarity in many important characteristics which are shown in the table below.

Properties	CO_2	N_2O
Critical pressure (MPa)	7.37	7.245
Critical temperature (˚C)	31.3	36.4
Boiling point (˚C)	-78.4	-88.47
ODP	0	0
Triple point temperature (˚C)	-56.55	-90.82
Molecular weight (kg/KMol)	44.01	44.013
Toxicity (ppm)	5000	1000

Table 1- Properties of $CO_2$and N_2O

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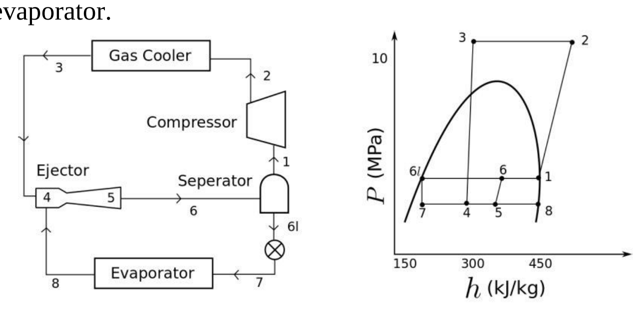
I. NOMENCLATURE

amb	= ambient
c	= compressor
COP	= coefficient of performance (KJ/Kg)
d	= diffuser
h	= specific enthalpy (KJ/Kg)
eje	= ejector
I	= specific energy (KJ/Kg)
evap	= evaporator
P	= pressure
gc	= gas cooler outlet
Q	= specific heat transfer rate (KJ/Kg)
gen	= generation
S	= specific entropy (KJ/KgK)
mix	= mixing chamber
T	= temperature
U	= entrainment ratio
η	= efficiency (%)
V	= velocity (m/s)
Subscript	
0	= reference environment
1,2,3	= cycle locations

Ejector Expansion cycle

An ejector expansion trans-critical refrigeration cycle (EETRC) consists of compressor, a gas cooler, a two phase ejector,

a liquid vapor separator, a control valve and an evaporator as shown in Fig 1(a). Ejector mainly consist of motive nozzle, a mixing chamber , a constant area throat and a diffuser.Fig2(b) shows schematic and P-h chart of ejector expansion transcritical refrigeration cycle. The liquid refrigerant coming out of the evaporator is compressed by compressor in the process 1-2, and then it is cooled in gas cooler. The working fluid then passes through two phase ejector .At the following stage, it is expanded to stage 4 which is subcritical condition at P_e, and the saturated secondary vapor enters the ejector. These two vapor steams mix at constant pressure and final state of mixture is 5.This mixture goes through the ejector diffuser as it then recovers to state 6.After that mixture enters the vapor-liquid separator,out of which vapor enters the compressor and liquid enters the expansion valve and then it goes to evaporator.



(a) Schematic   (b) P-h diagram

Fig. 1 - (a) first picture;   (b) second picture.

For ejector two performance parameters are considered and these are –

1) Entrainment ratio (U) =(suction mass flow rate)/(motive mass flow rate)
2) Pressure recovery ratio = (pressure at the exit of ejector)/(evaporator pressure)

II. THERMODYNAMIC MODELLING

Thermodynamic model of ejector expansion transcritical refrigeration cycle is developed using basic energy relations as tabulated in Table 2.

Subsystems	**Energy relations**
Compressor	$W_c = (h_2-h_1)(1/(1+U))$, $\eta c = (h_{2s}-h_1)/(h_2-h_1)$
Gas cooler	$Q_{gc} = (h2-h3)/(1+U)$
Ejector	$\eta_m = \frac{h3-h4}{h3-h4s}$, $h_3-h_4 = \frac{v4^2}{2}$ V5=V4/(1+U), $h_6 = h_3/(1+U)+h_8U/(1+U)$ $h_6-h_5 = \frac{v5^2}{2}$, $\eta_d = \frac{h6s-h5}{h6-h5}$, $x_6 = 1/(1+U)$
Control Valve	$h_7 = h_{6l}$
Evaporator	$Q_{evap} = (h_8-h_7)U/(1+U)$, VCC= $(h_8-h_7)* D_7$

In above thermodynamic relations:
1/(1+U) = motive mass flow rate
U/(1+U) = suction mass flow rate

III. RESULT AND DISCUSSION

Variation of COP with environment temperature at three different evaporator temperatures 5, -5 and -30 °C has been shown in Fig. 3. Here the gas-cooler exit temperature is fixed at 5 °C greater than the environment temperature. It has been observed that for evaporator temperatures of 5 and – 5 °C the COP of the N2O transcritical cycle is greater than that of CO2transcritical cycle if the environment temperature is more than 26 °C or the gas-cooler exit temperature is more than 31 °C. For evaporator temperature below -30 °C, the COP of N2O transcritical cycle is more than that of CO2transcritical cycle even at environment temperature below 25 °C. The reason of this variation is optimum heat rejection pressure, at the environment temperature of 20 °C, both refrigerants have same value of optimum heat rejection pressure, but if environment temperature increases, the optimum heat rejection pressure will increase. The increment in optimum heat rejection pressure with environment temperature is higher in case of CO2 than N2O. Hence, the pressure ratio for CO2 will be higher than N2O, which increases the compressor work and decreases the COP of CO2transcritical cycle.

Variation of COP with environment temperature for different degrees of subcooling and for three different evaporator temperatures 5, -5 and -30 °C. It has been observed that the COP of the N2O cycle decreases as environment temperature increases for all evaporator temperatures, and also the COP of the cycle decreases as evaporator temperature decreases. Using dedicated mechanical subcooling it is clearly seen that for all environment temperatures, the COP of the cycle improves at all evaporator temperatures because of the increment in specific cooling capacity.

IV. CONCLUSION

- $(COP)_{N2O} > (COP)_{CO2}$ for fixed Evaporative pressure
- COP of N_2O is greater than that of CO_2 at lower gas cooler exit pressure
- COP of CO_2 is greater than that of N_2O at higher gas cooler exit pressure.
- $(COP)_{N2O}$ EETRC > $(COP)_{CO2}$ at gas cooler exit pressure below 10.5Mpa.
- Volumetric cooling capacity of N_2O is less than that of CO_2.
- Two stage N_2O EETRC shows higher performance at lower optimum discharge pressure than two stage CO_2 EETRC.
- Max COP of N_2O is 10.13% higher than max COP of CO_2 for fixed evaporator temperature.
- N_2O ejector cycle gives comparatively better performance at gas cooler pressure below 8.5, 9.5, 10.5Mpa.
- N_2O cycle will require more mass of refrigerant than that of CO_2 cycle.
- Max cooling capacity of N_2O is 20.07 MJ/m^3 and that of CO_2 is 22.26 MJ/m^3.

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