International Journal on Emerging Technologies (Special Issue NCETST-2017) **8**(1): 340-344(2017)
(Published by Research Trend, Website: www.researchtrend.net*)*

ISSN No. (Print) : 0975-8364
ISSN No. (Online) : 2249-3255

Investigations of N_2O Transcritical Refrigeration Cycle Using Dedicated Mechanical Subcooling

Sanjeev Kumar[1] and Dr. D.K. Rao[1]
[1]Assistant Professor, Department of Mechanical Engineering,
Amrapali Group of Institutes, Shiksha Nagar, Lamachaur Road, Haldwani (Uttarakhand), INDIA

ABSTRACT: Thermodynamic analysis of N_2O 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 -30ºC with different degrees of subcooling and for the environment temperatures range from 20 to 40 ºC using propane as refrigerant for the subcooling cycle. Performance of N_2O transcritical cycle has been compared with CO_2 transcritical cycle. The results show that N_2O transcritical cycle is better than CO_2 transcritical cycle for environment temperature above 25°C, which is an important fact for countries having tropical climate.

It has been found that using combined cycle, the maximum increments in COP and in specific cooling capacity are 22% and 30% respectively. It has also been found that using mechanical subcooling cycle, the reduction in optimum heat rejection pressure is higher for lower evaporator temperature i.e. -30 °C and power consumption ratio is higher for higher evaporator temperature i.e. 5 °C. Further, the increment in COP using different refrigerants in mechanical subcooling cycle has been presented, where no significant differences have been found. The increment indicates that this cycle is more efficient for the environment temperatures above 30 °C.

Keywords: N_2O, $CO_{2,}$ transcritical cycle, COP (Co-efficient of pressure), MS cycle, thermodynamic models, refrigeration, refrigerants, Engineering Equation Solver (EES), evaporating temperatures, steady state condition, isenthalpic process.

I. INTRODUCTION

World is facing energy crisis and environmental challenges due to increasing demand of power on account of rapid growth in population and industrial development. Refrigeration and air conditioning sector is also adding to this problem due to high power consumption and environmental issues related to usage of different refrigerants. To solve this issue, the refrigeration sector is undergoing a phase of transition from traditional refrigerants, with high environmental impact, to environmental friendly refrigerants.

Due to the zero ozone layer depletion potential and low global warming potential, several natural refrigerants are considered to be better than synthetic refrigerants. As a result nitrous oxide and carbon dioxide are again being considered as future refrigerants. However, CO_2 can be used down to an evaporator temperature of –55 °C and further lowering of temperature cannot be achieved since the triple point of CO_2 is –56.6 °C. On the other hand, N_2O has a triple point temperature of –90.82 °C with a boiling point temperature of –88.47 °C and hence it can be used in the region below the application range of CO_2. It must be pointed out that N2O exhibits five times lower toxicity than CO_2 but its GWP is significantly higher than CO_2. Still it comes under the consideration of low GWP category which is currently considered to have an upper limit of 300.

II. MATERIALS AND METHODs

Thermodynamic analysis of the refrigerating systems provides valuable information regarding the design of new cycles or for improving the existing cycles. Thermodynamic analysis is used to find out the vital parameters affecting the system performance. Here, thermodynamic analysis of N_2O transcritical refrigeration cycle using dedicated mechanical subcooling is presented.

Engineering Equation Solver (EES) is powerful mathematical programming software similar to Matlab that can numerically solve thousands of coupled non-linear algebraic and differential equations. The program can also be used to solve differential and integral equations, do optimization, provide uncertainty analyses, perform linear and non-linear regression, convert units, check unit consistency, and generate publication-quality plots.

A. Thermodynamic Analysis of the Model

The N_2O transcritical cycle with dedicated mechanical subcooling is shown in Fig. 1

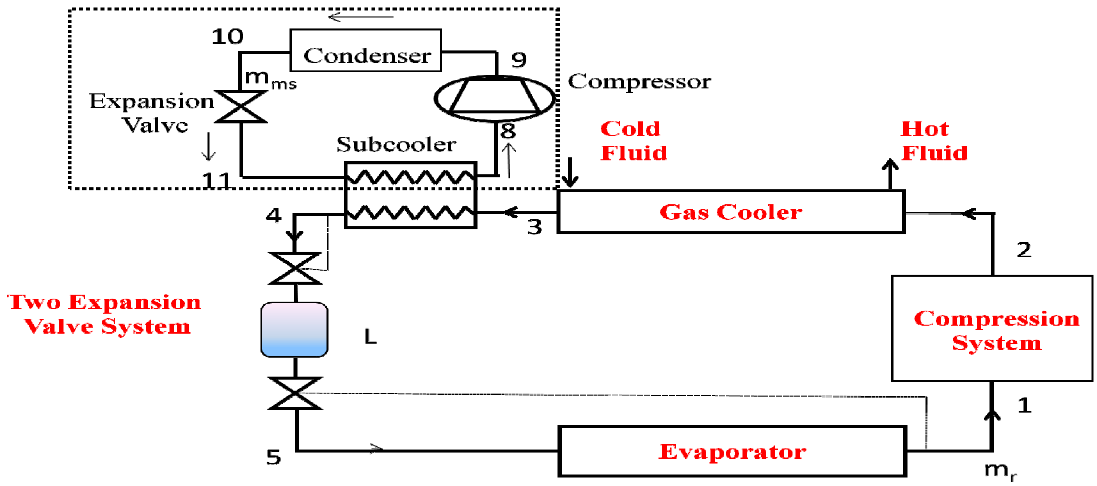

Fig. 1. Schematic representation of transcritical cycle with dedicated mechanical subcooling.

Dedicated mechanical sub-cooling is one of the types of sub-cooling in which both the main cycle and the subcooler cycle has its own condenser. Thornton *et al.* (1994) used a refrigerant property-based thermodynamic model to study the performance of a dedicated mechanical-subcooling system for various values of the sub-cooling saturation temperature.

To analyze the opportunity of enhancing the performance of N_2O transcritical refrigeration cycle using the dedicated mechanical subcooling cycle, the cycle shown in Fig. 1 has been considered. The CO_2 transcritical cycle with a double-stage expansion system (Cabello *et al.*, 2008) with an additional subcooler at the exit of the gas-cooler, where the subcooling is provided by a single-stage compression system is called the MS cycle. The transcritical cycle incorporates a device to regulate the heat rejection pressure and another to control the evaporating process. Here for the evaluation of N_2O transcritical cycle, two compression systems are considered in the main cycle, single-stage for medium and high evaporating temperatures and two-stage with intercooling for low evaporating temperatures. Both cycles perform the heat rejection (in condenser of the MS cycle, in the gas-cooler and in the intercooler of the transcritical cycle) to the same high temperature i.e. the environment temperature.

B. Assumptions

The following assumptions have been taken in the analysis of N_2O transcritical cycle with dedicated mechanical subcooling:

1. The system is at steady state condition. All processes are steady flow processes.
2. Compression process has been assumed to be non-isentropic for all the compressors.
3. Heat losses have been neglected.
4. Pressure losses in the pipelines are neglected for both cycles.
5. The exit temperature of the gas-cooler is 5 °C more than the environment temperature.
6. The evaporator temperature is fixed at a constant degree of superheat in the evaporator i.e. 10 °C for both cycles.
7. Expansion process is isenthalpic process for both cycles.

C. Validation of Present Work

The comparison of results of present work with the previous work has been summarized in Table 1. The maximum variation in the computations is less than 0.91%, which is negligible.

III. RESULTS AND DISCUSSION

Thermodynamic analysis of N_2O 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 °C with different degrees of subcooling and for the environment temperatures range from 20 to 40°C using propane as refrigerant for the subcooling cycle. For the analysis of the cycle, computer codes are developed in EES.

Table 1: Specific cooling capacity variation in validation of result of Rodrigo *et al.* (2015) and present work.

Gas-cooler Pressure (bar)	Rodrigo (2015) q_0 (kJ/kg) Δq_0	Present Work q_0 (kJ/kg)	Difference	Variation (%)
90	171.6	170.4	1.2	0.7
95	174.5	173	1.5	0.86
100	176.7	175.1	1.6	0.91
105	178.6	177	1.6	0.9
110	180	178.5	1.5	0.83
115	181.2	179.9	1.3	0.72
120	182.4	181.2	1.2	0.66

III. RESULTS AND DISCUSSION

Thermodynamic analysis of N_2O 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°C with different degrees of subcooling and for the environment temperatures range from 20 to 40°C using propane as refrigerant for the subcooling cycle. For the analysis of the cycle, computer codes are developed in EES.

A. Effect of Environment Temperature on COP of N_2O and CO_2 Transcritical Cycle

The Variation of COP with environment temperature at three different evaporator temperatures 5, -5 and -30 °C has been shown in Fig. 2. 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 N_2O transcritical cycle is greater than that of CO_2 transcritical 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 N_2O transcritical cycle is more than that of CO_2 transcritical 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 CO_2 than N_2O. Hence, the pressure ratio for CO_2 will be higher than N_2O, which increases the compressor work and decreases the COP of CO_2 transcritical cycle.

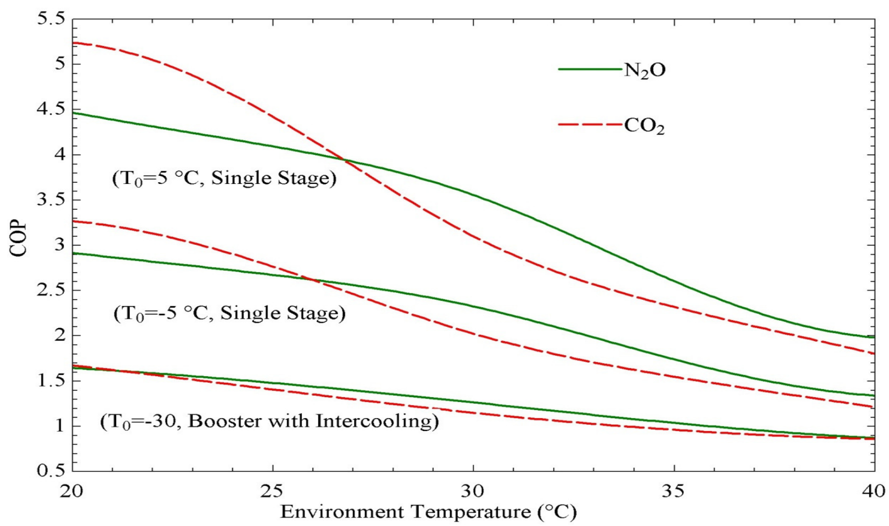

Fig. 2. Variation in COP with environment temperature at different evaporator temperatures.

B. Effect of Environment Temperature on Percentage Improvement in COP for Different Refrigerants

The variation of ΔCOP (%) with environment temperature for different refrigerants using in MS cycle with a subcooling degree of 5°C. This variation has been studied for three different evaporator temperatures 5, -5, and -30 °C. It is observed that the improvements in COP are similar for all the refrigerants. An environment temperature of 25 °C for all the evaporator temperatures, the improvements in COP are similar but for environment above 25 °C.

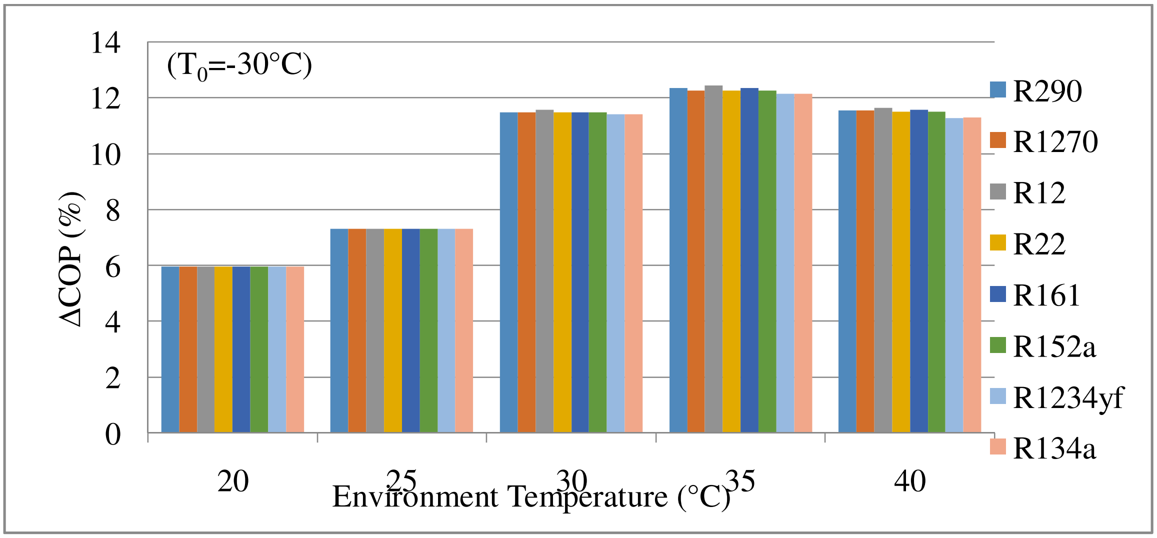

Fig. 3. Variation in COP increments with environment temperature for different refrigerants at 5 °C of subcooling (T_0=-30 °C, booster with intercooling).

IV. SUMMARY AND CONCLUSIONS

The thermodynamic analysis for the performance improvements of N_2O transcritical refrigeration cycle using dedicated mechanical subcooling cycle has been carried out in this work. The performance improvements of transcritical cycle have been studied for three different evaporator temperatures over a wide range of environment temperatures for different degrees of subcooling. Finally, percentage improvement in COP has been determined using different refrigerants in the MS cycle. For this analysis single stage compression system has been used for the evaporator temperatures of 5 °C and -5 °C, and double stage compression system has been used for the evaporator temperature of -30 °C. For this study, thermodynamic models have been developed in Engineering Equation Solver software. Following conclusions have been drawn from the present study:

1. It has been observed that the COP of N_2O transcritical cycle is more than that of CO_2 transcritical cycle for the environment temperature above 26 °C and the evaporator temperatures of 5 °C and -5 °C.
2. It has also been observed that for the evaporator temperature of -30 °C, the N_2O transcritical cycle is better than the CO_2 transcritical cycle even at the environment temperature below 25 °C.
3. While using MS cycle the optimum pressure of the transcritical cycle can be reduced. Use of MS cycle allows an increment in the COP and the specific cooling capacity of the system for all operating conditions considered in this work.
4. It is observed that the value of power consumption required for MS cycle is less than 15% of the power consumption of main cycle at the optimum conditions, but it increases significantly for pressures below the optimum value.

Finally, based on the conclusion of the results, the use of dedicated mechanical subcooling cycle is an efficient way of improving the performance of N_2O transcritical refrigeration cycle especially for tropical countries.

V. FUTURE SCOPE OF PRESENT WORK

This analysis can be extended to study the performance of other natural refrigerants in transcritical cycle with dedicated mechanical subcooling.

REFERENCES

She, X., 2014. A proposed subcooling method for vapor compression refrigeration cycle *IJR* **43**, 50 -61.
Sarkar, J., Bhattacharyya, S., Agrawal, N., 2011. Thermodynamic analyses and optimization of a novel two stage N_2O transcritical cycle. *IJR* **34**: 991-999.
Cabello, R., Sánchez, D., Patiño, J., Llopis, R., Torrella, E., 2012. Experimental analysis of energy performance of modified single-stage CO_2 transcritical vapour compression cycles based on vapour injection in the suction line. *Applied Thermal Engineering* **47**, 86-94.
Aprea, C., Maiorino, A., Greco, A., 2015. The application of a desiccant wheel to increase the energetic performances of a transcritical cycle. *Energy Conversion and Management* **89**, 222-230
Yu, J., Yan, G., 2010. A thermodynamic analysis of a transcritical cycle with refrigerant mixture *Energy and Buildings* **42**, 2431–2436.
Thornton, J.W., Klein, S.A., Mitchell, J.W., 1994. Dedicated mechanical-subcooling design strategies for supermarket applications. *Int. J. of Refrigeration*. **17**(8), 508-515.
Rodrigo Llopis, Ramón Cabello, Daniel Sánchez, Enrique Torrella.,2015. Energy improvements of CO_2 transcritical refrigeration cycles using dedicated mechanical subcooling, International Journal of Refrigeration, JIJR 3004.