Thermodynamic Performance comparison between Ethylene and Ethane in Transcritical Refrigeration Cycle with Internal Heat Exchanger

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Abstract - *Energy and exergy analysis have been carried out in this paper. In this paper the comparison between the two natural refrigerants have been done. Those two natural refrigerants are Ethane (R170) and Ethylene (R1150).These natural refrigerants have been used in the transcritical vapor compression refrigeration system because they have zero ODP (Ozone Layer Depletion) and GWP (Global Warming Potential) to a smaller extent. Thermodynamic modeling and simulation for each refrigerant have been used to find out the cooling COP, second law efficiency and optimum discharge pressure .Based on the results like COP, second law efficiency and optimum discharge pressure, the comparison between the two refrigerants have been drawn out. In addition to this the internal heat exchanger has also been employed in the basic transcritical refrigeration cycle and its effects on the COP, optimum discharge pressure and second law efficiency has been studied. It is noticed that after using internal heat exchanger in the basic transcritical refrigeration system the COP and second law efficiency increases though optimum discharge pressure decreases which is desirable. It is observed that the use of ethane (R170) in trancritical vapor compression refrigeration system as well as basic transcritical refrigeration system with internal heat exchanger gives more COP, second law efficiency and less optimum discharge pressure as compared to Ethylene (R1150). Therefore the present study reveals that using ethane (R170) in basic transcritical refrigeration system with internal heat exchanger is advisable.*

***Key Words**:* **Cooling COP, Optimum Discharge Pressure, Second Law Efficiency ,Trancritical Vapor Compression system**

1. INTRODUCTION

As far as the population of the world increasing the resources are declining, the resources in the nature are limited so to save the resources from getting extinct, the energy saving technologies are emerging day by day. The aim is to reduce the energy consumption. One way of reducing energy consumption can be achieve by enhancing the refrigeration performance. The vapor compression refrigeration system is being used in the refrigeration and air conditioning process. The transcritical vapor compression refrigeration system consists of mainly four devices such as compressor, gas cooler, expansion valve or throttle valve and evaporator. The synthetic refrigerants used in the vapor compression refrigeration system causes ozone layer depletion and global warming .This problem can be solved by using natural refrigerants in the vapor compression refrigeration system because natural refrigerants have zero ODP and very less GWP. The natural refrigerants have many advantages over synthetic refrigerants as they are non toxic and environmental friendly. Calm et al.[1] studied about the next generation refrigerants which can be used in the vapor compression refrigeration system. Both Ethane and Ethylene are hydrocarbon .Granryd [2] studied about the Hydrocarbons as refrigerants. Manoj et al.[3] studied about the replacement refrigerant for the Freon 22 in the VCRS (Vapor Compression Refrigeration System) and found out that Hydrocarbon have good performance attributes as compare to Freon 22 and can be used in replacement of Freon in VCRS (Vapor Compression Refrigeration System) in future. Henri [4] performed the experiment to liquefy the natural gas for use in the gas industry .In the experiment firstly the natural gas was cooled to temperature less than - 20˚C in the refrigeration cycle by the first coolant comprises of Methane, Ethane, Propane and isobutane. The natural gas get liquefied by the secondary coolant comprises of Nitrogen ,Methane, Ethane ,Ethylene and Propane. The incorporation of Ethylene in the secondary coolant reduced the methane composition in the secondary coolant which in turn reduces the power needed to liquefy the natural gas. Similarly Richard D kuerston et al. [5] did an invention ,serial incremental refrigerant expansion for gas liquefaction. The object of the invention was to develop a method for conserving energy in the liquefaction of the gas and also optimum utilization of each refrigerant in the cascade refrigeration system. The refrigerants used in the invention were Propane ,Ethylene and Methane. . Nasruddin et al.[6] have revealed that Ethane can be used to reach the temperature of around -80˚C. Sun et al.[7] studied that R14 can be replaced by R1150 (Ethylene) in a low temperature cycle in the three stage cascade refrigeration system as well as in the medium temperature cycle R23 can be replaced by the R41 and R170. Arash Nemati et al. [8] did comparison among CO2 ,N2O and ethane as refrigerants for a two stage ejector expansion transcritical refrigeration cycle and observed that for ethane the compressor operating pressure and temperature levels in the cycle are lower than other refrigerants which leads the way to high system safety and lifetime. Towhid Gholizadeh et al.[9] proposed that maximum freshwater can be obtained when a two stage humidification-dehumidification (HDH) desalination system is incorporated with single stage ethane- ejector expander transcritical refrigeration cycle ,moreover for more cooling load the two stage HDH can be incorporate with two stage ethane ejector expander transcritical refrigeration cycle. Kasi [10] used ethane as refrigerant in the cascade refrigeration system to obtain the very low temperature ranges from -70˚C to -50˚C. So the above literature review shows that both ethane and ethylene have their own advantages and can be used in transcritical vapor compression refrigeration cycles. Hence in the present paper the energy and exergy analysis have been carried out for basic transcritical vcrs as well as for transcritical vcrs with internal heat exchanger for both ethane and ethylene as refrigerants individually and comparison of their performances have been drawn out. For finding out the energy and exergy analysis the computer code is generated on the engineering equation solver[11].

2. THERMODYNAMIC MODELLING AND SIMULATION

In figure1 the cyclic layout of basic transcritical VCRS has been shown below for both ethane and ethylene:

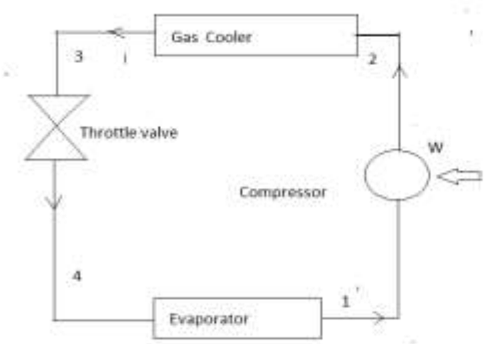

Fig . 1: Cycle layout of a transcritical for both ethane and ethylene refrigeration cycle

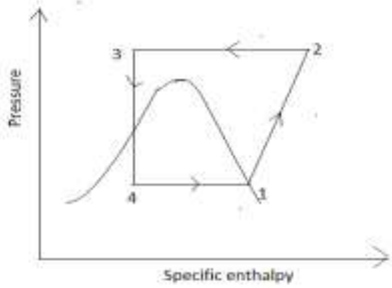

Fig. 2 : Diagram of pressure and enthalpy of a transcritical R170 and R1150 cycle

The basic transcritical R170 vapor compression refrigeration cycle and the basic transcritical R1150 vapor compression refrigeration cycle follow the same cyclic process, the saturated ethane vapor from state 1 is compressed to the superheated state 2 in the compressor and then cooled from (2-3) in a gas cooler by rejecting heat to the atmosphere and then from state 3 ethane is expanded in the throttle valve (3-4) and then from (3-4) passes through the evaporator (4–1) to provide a useful cooling effect similarly the saturated ethylene goes through the same process. When the basic transcritical refrigeration cycle incorporated with internal heat exchanger, the process undergoes both superheating and sub-cooling process.

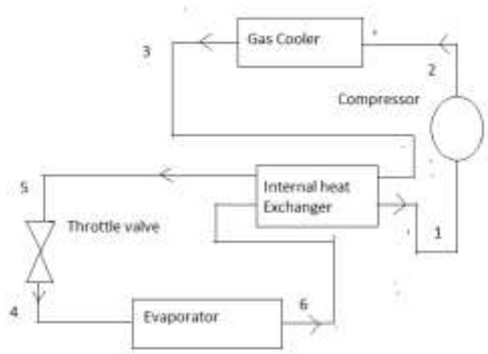

Fig .3: Layout of transcritical R-170 and transcritical R1150 refrigeration cycle with an internal heat exchanger

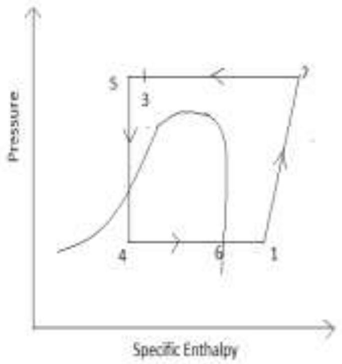

Fig .4: Diagram of pressure and enthalpy of a transcritical R170 and R1150 refrigeration cycle with an internal heat exchanger

The cycle layout and correlating pressure-enthalpy diagram for both basic transcritical R170 cycle and R1150 with an internal heat exchanger shown in Figures 3 & 4 respectively. As shown, the ethane and ethylene saturated vapor from state 6 get superheated to state 1 in the internal heat exchanger, from state 1, they get compressed in the compressor to state 2 for individual cycles and changes to superheated gas. Then the superheated gas from state 2 get cooled in the gas cooler to state 3 by rejecting heat to the atmosphere. The high-pressure gas get sub-cooled from 3 to 5 in the internal heat exchanger for individual cycles and then from there they get expanded in the expansion device to state 4, which is the inlet to the evaporator.

There are some of the assumptions which have been drawn out for the thermodynamic analysis:

1. Only Gas cooler transfers heat with the environment.

2. The process inside the evaporator, gas cooler and internal heat exchanger is isobaric.

3. The compression inside the compressor is irreversible adiabatic.

4. The state of the refrigerant obtained at the evaporator exit is dry saturated.

5. There is isenthalpic expansion inside the throttle valve.

3 EQUATIONS

The specific work input to the compressor for the basic transcritical cycle is given by:

$W_c= (h_2 - h_1)$ (1)

The specific refrigerating effect obtained from the evaporator is given as:

$q=(h_1 - h_4)$ (2)

The cooling COP is expressed by:

$COP=(q/W_c)$ (3)

Volumetric cooling capacity:

$V_c= q\rho$ (4)

For exergetic performance, applying the second law of thermodynamics to each and every component, the following relations can be proposed:

(a)Compressor irreversibility:

$i_c=T_o (s_2 - s_1)$ (5)

(b) Throttling device irreversibility:

$i_{tv}=T_o (s_4 - s_3)$ (6)

(c) Gas cooler irreversibility:

$i_{gc}=(h_2-h_3)-T_o (s_2-s_3)$ (7)

(d) Evaporator irreversibility:

$i_{ev}=T_o (s_1-s_4)-q (T_o/T_{ev})$ (8)

Second law (exergy) efficiency for the system can be expressed as the ratio of net exergy output to the exergy input to the compressor, i.e.:

$\eta_{ii}=(W_c-(i_c+i_{tv}+i_{ev}+i_{gc}))/W_c$ (9)

For the R170 and R1150 transcritical cycle with an internal heat exchanger, the specific work input to the compressor is expressed by:

$W_c=(h_2-h_1)$ (10)

The specific refrigerating effect obtained from the evaporator is expressed as:

$q=(h_6-h_5)$ (11)

The cooling cop:

$COP= (q/W_c)$ (12)

(a)Throttling device irreversibility:

$i_{tv}=T_o (s_4-s_5)$ (13)

(b) Evaporator irreversibility:

$i_{ev}=T_o (s_6-s_4)-q(T_o/T_{ev})$ (14)

(c) Heat exchanger irreversibility can be given as:

$i_{he}=T_o ((s_1-s_6)-(s_3-s_5))$ (15)

For the internal heat exchanger, the effectiveness and energy balance can be given by equation (16) & (17) respectively

$\varepsilon_{he}=((T_1-T_6)/(T_3-T_6))$ (16)

$(h_1-h_6)=(h_3-h_5)$ (17)

The second law efficiency after employing internal heat exchanger s given as:

$\eta_{ii}=(W_c-(i_{tv}+i_c+i_{gc}+i_{he}+i_{ev}))/W_c$ (18)

IV RESULTS AND DISCUSSION

The compressor efficiency has been taken as 75% in the present work. The ambient temperature is assumed to be 25˚C and the temperature of the secondary fluid in the evaporator is taken as 5˚Cabove the evaporator temperature.

COMPARISON OF COP, OPTIMUM DISCHARGE PRESSURE AND SECOND LAW EFFICIENCY USING ETHANE AND ETHYLENE INDIVIDUALLY IN THE BASIC TRANSCRITICAL VAPOR COMPRESSION REFRIGERATION SYSTEM

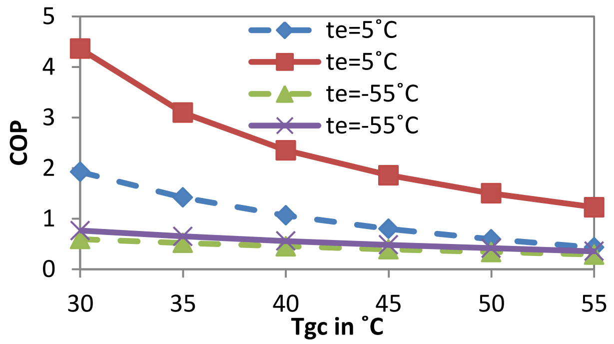

Fig.5: Distinction of COP with Gas cooler exit temperature

----------------- dotted line shows basic cycle for Ethylene

~~Solid line shows~~ basic cycle for Ethane

In Fig.5. Distinction of COP with Gas cooler exit temperature (Tgc) has been shown .The Gas cooler exit temperature ranges from 30˚C to 55˚C .The result shows that the cop obtained when using ethane is greater than the cop obtained from ethylene in the basic cycle at every evaporator temperature (te).For both the refrigerants when the evaporator temperature increases and the gas cooler exit temperature decreases ,the COP increases.

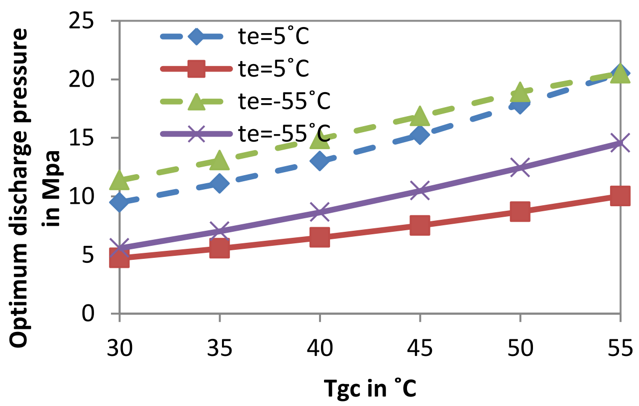

Fig. 6: Distinction of Optimum discharge pressure with gas cooler exit temperature

----------------- dotted line shows basic cycle for Ethylene

Solid line shows basic cycle for Ethane

In Fig.6. Distinction of Optimum discharge pressure with gas cooler exit temperature (Tgc) has been shown . The Gas cooler exit temperature ranges from 30˚C to 55 ˚C. The result shows that optimum discharge pressure obtained from the ethylene in basic cycle is greater than optimum pressure obtained from ethane in basic cycle .On decreasing the gas cooler exit temperature and increasing the evaporator temperature the Optimum Pressure reduces for both the refrigerants which is desirable.

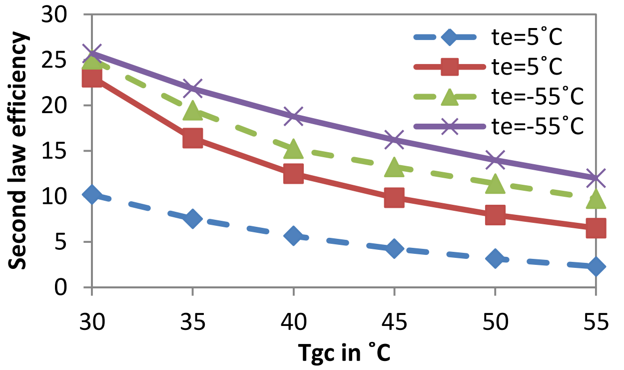

Fig. 7: Distinction of second law efficiency with gas cooler exit temperature

----------------- dotted line shows basic cycle for Ethylene

Solid line shows basic cycle for Ethane

In Fig. 7 Distinction of second law efficiency with the gas cooler exit temperature has been shown. The Gas cooler exit temperature ranges from 30˚C to 55˚C .The result shows that When using ethane in the basic cycle the second law efficiency obtained is greater than the second law efficiency obtained using ethylene in the basic cycle .For both the refrigerants when the evaporator temperature and gas cooler exit temperature decreases ,the second law efficiency increases.

COMPARISON OF COP, OPTIMUM DISCHARGE PRESSURE AND SECOND LAW EFFICIENCY USING ETHANE AND ETHYLENE INDIVIDUALLY IN THE BASIC TRANSCRITICAL VAPOR COMPRESSION REFRIGERATION SYSTEM WITH INTERNAL HEAT EXCHANGER

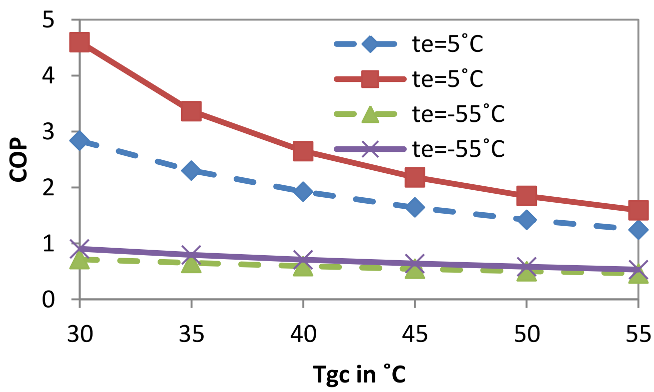

Fig.8: Distinction of COP with Gas cooler exit temperature

----------------- dotted line shows basic cycle for Ethylene

Solid line shows basic cycle for Ethane

In fig.8. Distinction of COP with gas cooler exit temperature for basic cycle with internal heat exchanger has been shown. The Gas cooler exit temperature ranges from 30˚C to 55 ˚C. The results shows that COP obtained from ethane is greater than ethylene for the basic cycle with internal heat exchanger. Also on employing internal heat exchanger in the basic cycle the cop increases by 5.43% for ethane at te=5˚C and by 18.01% at te=-55˚C at Tgc =30˚C,for ethylene at te=5˚C by 47.34% and by 20.43% at te=-55˚C at Tgc =30˚C .

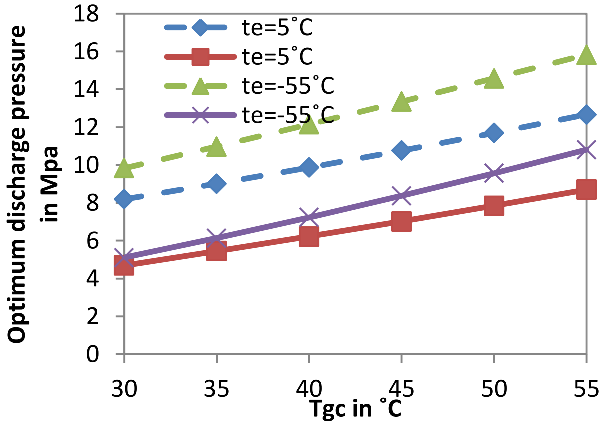

Fig. 9: Distinction of Optimum discharge pressure with gas cooler exit temperature

----------------- dotted line shows basic cycle for Ethane

Solid line shows basic cycle for Ethylene

In Fig.9. Distinction of optimum discharge pressure with gas cooler exit temperature for basic cycle with internal heat exchanger has been shown. The Gas cooler exit temperature ranges from 30˚C to 55 ˚C. The result shows that optimum discharge pressure obtained from ethylene is greater than the ethane for basic cycle with internal heat exchanger. On employing the internal heat exchanger in the basic cycle the pressure reduces by 0.72 % at te=5˚C and te=-55˚C by 8.42% for Ethane at Tgc=30˚C and for ethylene the pressure reduces by 13.55% at te=5˚C ,at te=-55˚C by 13.60% at Tgc=30˚C.

In Fig.10. Distinction of second law efficiency with gas cooler exit temperature for basic cycle with internal heat exchanger has been shown. The Gas cooler exit temperature ranges from 30˚C to 55 ˚C. The result shows that after employing the internal heat exchanger the secondary law efficiency increases. Second law efficiency for ethane is greater than ethylene. The second law efficiency increases by 5.45% at te=5˚C any by 18.04% at te=-55˚C for ethane at Tgc=30˚C .For ethylene at te=5˚C it increases by 47.39% at te=5˚C and by 4.39% at te=-55˚C at Tgc=30˚C.

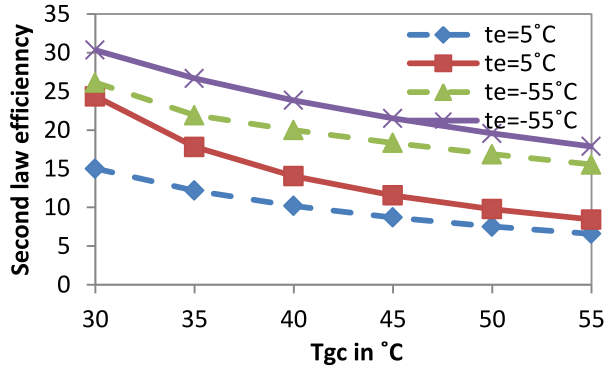

Fig. 10: Distinction of second law efficiency with gas cooler exit temperature

----------------- dotted line shows basic cycle for Ethane

Solid line shows basic cycle for Ethylene

Table -1

S.no	Energetic and exergetic comparison between ethane and ethylene for basic cycle at t_e=5˚C and T_{gc}=30˚C		
	Parameters	Ethane	Ethylene
1.	Optimum discharge pressure (MPa)	4.727	9.478
2.	Volumetric cooling capacity (kJ/m³)	8932	9523
3.	Compressor discharge temperature (°C)	44.94	52.47
4.	Cooling COP	4.361	1.924
5.	Compressor irreversibility (%)	23.52	22.97
6.	Expansion device irreversibility %	30.98	48.3
7.	Gas cooler irreversibility (%)	14.14	14.9
8.	Evaporator irreversibility (%)	8.251	3.64
9.	Second law efficiency (%)	23.1	10.19

Table -2

S.no	Energetic and exergetic comparison between ethane and ethylene for basic cycle with internal heat exchanger at te=5˚C and Tgc=30˚C		
	Parameters	Ethane	Ethylene
1.	Optimum discharge pressure (MPa)	4.693	8.193
2.	Volumetric cooling capacity (kJ/m³)	9354	10650
3.	Compressor discharge	59.7	66.06

S.no	Energetic and exergetic comparison between ethane and ethylene for basic cycle with internal heat exchanger at te=5˚C and Tgc=30˚C		
	Parameters	Ethane	Ethylene
	temperature (°C)		
4.	Cooling COP	4.598	2.835
5.	Compressor irreversibility (%)	22.52	22.09
6.	Expansion device irreversibility %	18.87	25.93
7.	Gas cooler irreversibility (%)	20.43	24.06
8.	Evaporator irreversibility (%)	8.7	5.362
9.	Second law efficiency (%)	24.36	15.02

5 CONCLUSIONS

Based on the result got above for both ethane and ethylene basic transcritical and basic transcritical cycle with internal heat exchanger, the following conclusion drawn are listed below:

1. Both ethane and ethylene are natural refrigerants but ethane give better results than ethylene.

2. The COP, optimum discharge pressure and second law efficiency obtained from basic cycle as well as for basic cycle with internal heat exchanger is greater than ethylene.

3. On decreasing the evaporator temperature and gas cooler exit temperature ,the second law efficiency increases for both refrigerants and for both cycle that is basic as well basic with internal heat exchanger.

4. To obtain the maximum cooling COP, the evaporator temperature should increases and gas cooler exit temperature should decreases.

5. To obtain the reduced optimum pressure, the evaporator temperature should increases and gas cooler exit temperature should decreases.

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