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Energy and exergy analyses of *intercoolers Refrigeration cycles with* R134a, R12, R152a *with R744*

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ABSTRACT

This study examines the thermodynamics analyses of two refrigeration cycles with a single intercooler and two intercoolers. The working fluid is one of the three common refrigerants: R134a, R32 and R152a. The performance of these refrigerants is compared to the environment-friendly fluid in natureR744 (CO_2) refrigerant and the best refrigerant fluid is selected considering properties and performance. Also, the best pressures of cycles in relation to each other was obtained using optimization algorithms. The analysis shows that three stages cycle has higher performance than two stage cycle. The R744 cycle performance is higher than the other working fluids that used in this paper. The most exergy losses occur in throttle valve following by compressors. Increases in evaporator temperature and decreases in gas cooling exit temperature causes the performance enhancement of the cycles for different working fluids.

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INTRODUCTION

The average world temperature will be increasing from 1.5K to 4.5K in the next 100 years. The key factor in global warming is greenhouse gas emissions. A part of produced greenhouse gases is due to the use of HFC refrigerants in cooling systems(Nicholidas, 1998). These refrigerants strongly affect global warming. Using environment-friendly refrigerants has always been the concern of environmentalists and the world community (R744)CO_2,R152a and R32 are among refrigerants that can solve the issues of greenhouse gas emissions and further depletion of the ozone layer at the present time and in future(Nicholidas,1998). Yet another concern is regarding the performance of these refrigerants.Therefore, this study compared the performance of these refrigerants with that of CFC ones, e.g. R134a.Appernatenta (1995) did energy and exergy analyses on the simple absorption refrigeration cycle and showed the results in graphs. Appernatenta calculated the lost exergy in different parts of the cycle and showed that irreversibility due to the transmission of heat in the evaporator has a profound effect on the performance of the cycle. The results indicated that the highest level of internal irreversibility occurs in the absorbent and the generator. Appernatenta (1995) showed that this irreversibility is reducible by increasing the heat transmission coefficient of transformers. By considering the condenser temperature to vary from 298K to 308K and the evaporator temperatures to vary from 238K to 228K and analyzing the effects of temperature variations on the irreversibilities of the cycle, Nicholidas (1998) conducted an exergy analysis on the two-phased R22 refrigeration cycle. He indicated that changes in the weather have considerable effects on the performance of the cycle and concluded that the environment weather is an important factor in the optimal design of the refrigeration cycle.Considering the increasing size of the hole in the ozone layer, global warming and the pressures by the legal community, McMullen (2002) stated that the types and manner of using refrigerants and the related industries should be reconsidered. He discussed imminent problems and the way industries can go along with these issues. In this study, he also discussed alternative refrigerants, the complexity of using combinations of refrigerants and the complexity dangers in design and manufacturing for the use of combinations of refrigerants against common refrigerants.

(Yari2009) studied an exergy analysis of a two-phased refrigeration cycle with a CO2 refrigerator in 2009. He used a new injection expender in his cycle and concluded that in his cycle, the efficiency of the second law and the coefficient of the performance of the cycle are as much as 16.5 and 18.4 more than those of the usual cycles. Finally, he did a regression analysis on the evaporator temperature and gas cooler in order to optimize

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COP, compressor pressure and output pressures of the gas cooler. (Sarkar2009a) conducted energy and exergy analyses on the Brayton cycle with a CO2 refrigerant. He obtained the effect of different parameters on the efficiency of energy, exergy, proportion of pressure, and the irreversibility of cycle components. He concluded that the influence of low temperature on the efficiency of the cycle and the proportion of pressure is considerably higher than that of high working temperature of the cycle. (Sarkar 2010 b) stated that considering the existent dangers of industrial refrigerants for the ozone layer and global warming, we should think of substituting them by alternative natural refrigerants. He believed that CO_2 refrigerant is proper thanks to having acceptable coefficient of heat transmission, negligible GWP, and zero ODP. In this article, he introduced various cycles with the ability to work with the CO_2 refrigerant and studied their strengths and weaknesses. (Davalloo 2010) studied the refrigeration cycle of a two-parted cooler. He used an evaporation condenser to increase the cycle efficiency in hot and dry weather. The results indicated that in this kind of weather using an evaporation condenser works in a way that using this method improves the performance of the cycle by 50% and influences the decrease of energy consumption by 20%.

(Giovanni *et al*. 2011) studied the performance of a cascade cycle, the low temperature working fluid of which contained CO_2 and R1270, R1150, R290, and RE170 hydrocarbons and the high temperature working fluid of which contained ammonia (R717). The purpose of their study was to find out how carbon dioxide composite can be used in temperatures below the critical point. But the appeal of using R744 is its low ODP, GWP.Cladeve(2011) examined the environment-friendly refrigerant R1234yf instead of the common refrigerant R134a and concluded that the performance of this refrigerant is lower compared to common refrigerants. They also utilized numerical analysis in order to optimize condenser and evaporator. More research is conducted regarding refrigeration cycles that can be examined in articles [(Tozer*et al* 1998), (Kilicarslan 2012), (Yari 2008), (Menlik*et al* 2013), (Kabul 2011)].

This study examines the thermodynamics analyses of two refrigeration cycles shown in figure 1 and 2 with a single intercooler and two intercoolers. The working fluid is one of the three common refrigerants: R134a, R32 and R152a. The performance of these refrigerants is compared to the environment-friendly fluid in natureR744 (CO_2) refrigerant and the best refrigerant fluid is selected considering properties and performance. Also, the best pressures of cycles in relation to each other was obtained using optimization algorithms.

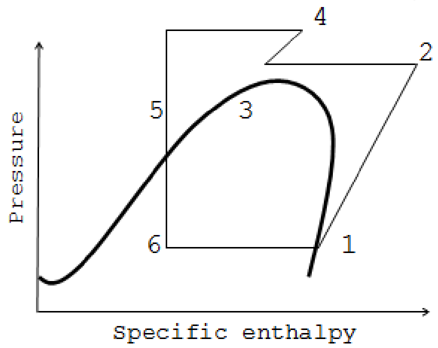

Fig. 1: A schematic view of the cycle with one intercooler for the refrigerant (R-744) CO2

The following assumptions are made in the calculations:

1. The compression process is an adiabatic and uncompressible process.
2. The process of evaporation of the intercooler and the gas cooler is considered to be an isobar process.
3. The output vapor from the evaporator is in the state of dry saturation.
4. The output vapor of the intercooler is in the form of superheat.
5. The process of expansion is considered to be an isentropic process.
6. The dead state (T_0, P_0) is in the pressure of 1 atm and temperature of 25 ℃.

In transcritical cycles, gas coolers are used in high pressure instead of regular condensers. In this process, the temperature of the refrigerant gas CO2 decreases considerably because pressure and temperature are not interdependent.

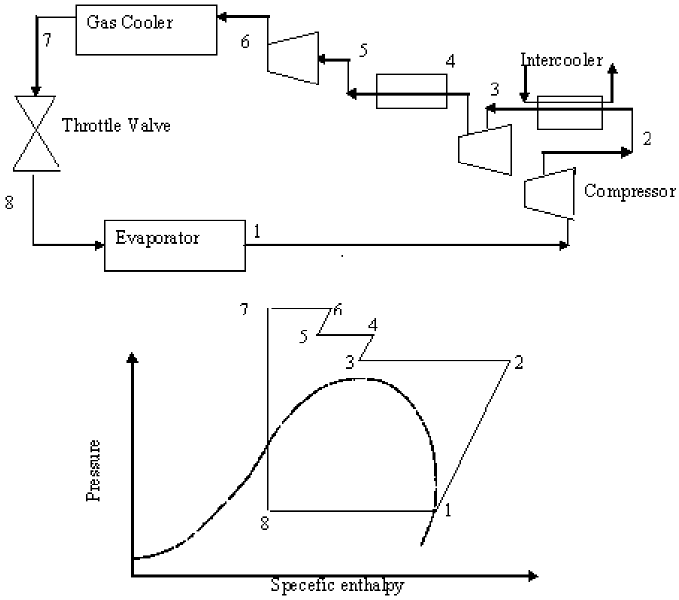

Fig. 2: A schematic view of the cycle with two stages of intercooler for the refrigerant (R-744) CO2

In this cycle, the saturated vapor is condensed from state 1 to state 2 in the low pressure compressor and reaches state 3 in the intercooler considering the heating of the external fluid. The supercritical vapor in state 3 is compressed to the pressure of intermediate compressor to reach stage 4 and after passing the high pressure compressor, the working fluid is cooled by the gas cooler and reaches state 7 and then expanded in the expansion valve to reach stage 8.

Methodology:

The isentropic yield of the low, intermediate and high pressure compressor is calculated using the formulae (1-3), which will be considered to be 70, 75, and 80%.

$$\eta_{is,c,Lp} = \frac{h_{2s}-h_1}{h_2-h_1} \quad (1)$$

$$\eta_{is,c,Ip} = \frac{h_{4s}-h_3}{h_4-h_3} \quad (2)$$

$$\eta_{is,c,Hp} = \frac{h_{6s}-h_5}{h_6-h_5} \quad (3)$$

The special work of the compressor is calculated using Formula (4).

$$w_c = \frac{[(h_2-h_1)+(h_4-h_3)+(h_6-h_6)]}{\eta_{mec\,h}} \quad (4)$$

The output heat from the intercooler and the gas cooler are calculated using formulae (5-7).

$$q_{ic,1} = h_2 - h_3 \quad (5)$$

$$q_{ic,2} = h_4 - h_5 \quad (6)$$

$$q_{gc=}h_6 - h_7 \quad (7)$$

The heat transmitted from the evaporator is calculated using Formula (8).

$$q_{ev} = h_1 - h_8 \quad (8)$$

The energy balance of the cycle is calculated using Formula (9).

$$w_c = \left(q_{gc} + q_{ic,1} + q_{ic,2}\right) - q_{ev} \quad (9)$$

Finally, the performance of the cooling system is as Equation (10).

$$COP = \frac{q_{ev}}{w_c} \quad (10)$$

The exergy analysis is carried out by applying the second law of thermodynamics, such that by this analysis, the input exergy of each point in the cycle, wasted exergy and the efficiency of the second law of thermodynamics is calculated and determined by the potential exergy analysis for optimization.

The wasted exergy in the compressor is calculated by Formula (11).

$$i_{ic} = T_0(s_2 - s_1) + T_0(s_4 - s_3) + T_0(s_6 - s_5) \quad (11)$$

The wasted exergy in intercoolers is calculated using formulae (12 and 13).

$$ex_{des,ic1} = ex_2 - ex_3 \quad (12)$$

$$ex_{des,ic2} = ex_4 - ex_5 \quad (13)$$

Formulae (14 and 15) are equivalent to formulae (12 and 13).

$$i_{ic,1} = (h_2 - h_3) - T_0(s_2 - s_3) \quad (14)$$

$$i_{ic,2} = (h_4 - h_5) - T_0(s_4 - s_5) \quad (15)$$

The wasted exergy in the gas cooler is calculated using Formula (16).

$$ex_{des,gs} = ex_6 - ex_7 \quad (16)$$

Formula (17) is equivalent to Formula (16).

$$i_{gs} = (h_6 - h_7) - T_0(s_6 - s_7) \quad (17)$$

The wasted exergy in the throttle valve is calculated using Formula (18).

$$i_{tv} = T_0(s_7 - s_8) \quad (18)$$

The irreversibility in the evaporator is calculated using Formula (19).

$$i_{ev} = T_0(s_1 - s_8) - q_{ev}\frac{T_0}{T_{ev}} \quad (19)$$

The efficiency of the second law of thermodynamics of the system is calculated using Formula (20).

$$\eta_{II} = \frac{w_c - (i_c + i_{gc} + i_{ic} + i_{tv} + i_{ev})}{w_c} \quad (20)$$

In order to perform thermodynamic calculations, a code is written in EES software and exergy and energy analyses are done on the cycles so that the strengths and weaknesses of the cycles are determined for optimization and the comparison of refrigerants.

RESULTS AND DISCUSSION

In Figure 3, the coefficient of performance of the system in terms of evaporator temperature and type of refrigerant is examined. As shown in the figure 3, the efficiency of the cycle is increases with the increase of the evaporator temperature.

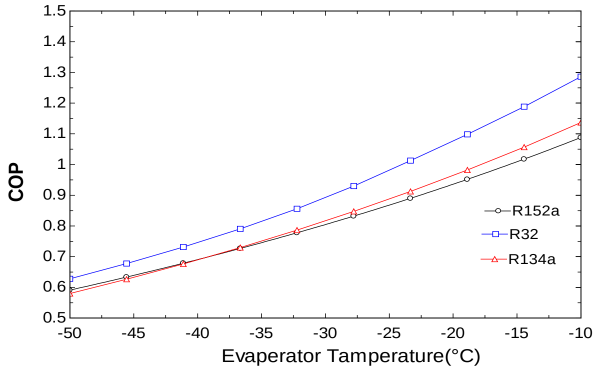

Fig. 3: The coefficient of performance in terms of the evaporator temperature

In Figure 4, the coefficient of performance is illustrated in terms of three types of refrigerants in evaporator temperatures of 0, -20℃, -30℃, and -50℃. As shown, the total efficiency of the cycle decreases with the increase of the condenser temperature since the compressor requires more power and this issue applies to all evaporator temperatures.

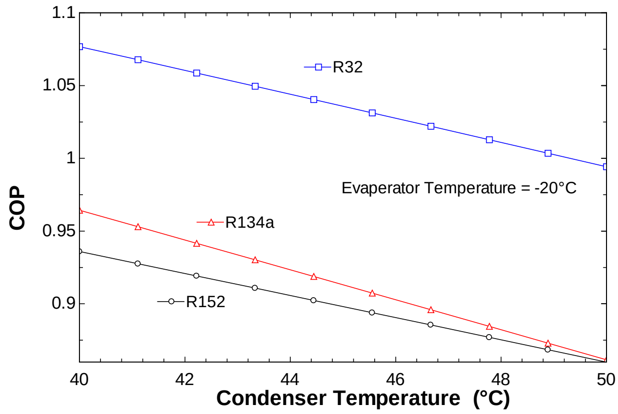

Fig. 4: The coefficient of performance of the cycle in terms of the condenser temperature in evaporator temperature of -20℃

In Figure 5, the coefficient of performance of the cycle is calculated for three types of refrigerants in terms of the ambient temperature in evaporator temperature of -20℃. As shown in this figure, the efficiency of the cycle decreases with the increase of the ambient temperature.

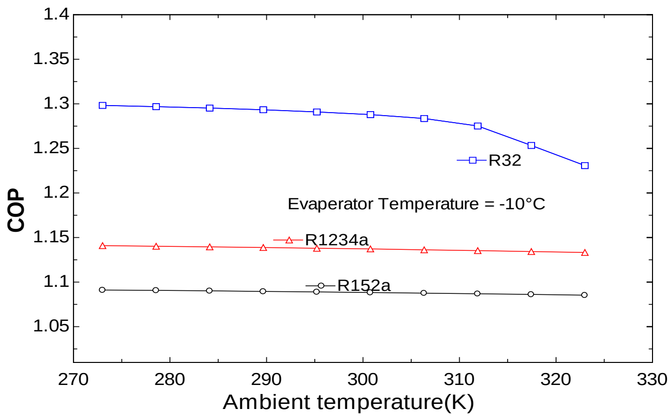

Fig. 5: The coefficient of performance of the cycle in terms of the ambient temperature in evaporator temperature of -10℃

In Figure 6, the effect of the gas cooling temperature on the coefficient of performance of the cycle for fluid R744 in different evaporator temperatures is shown. As you can see in this figure, both the increase in evaporator temperature and the increase in gas cooling temperature have an unfavorable effect on the performance of the cycle. The performance of the cycle decreases with the increase of these factors. Closer study of the figure shows that the effect of evaporator temperature on the performance of the cycle is considerably more than that of the gas cooling temperature and more activities could be focused on this part for the optimization of energy consumption.

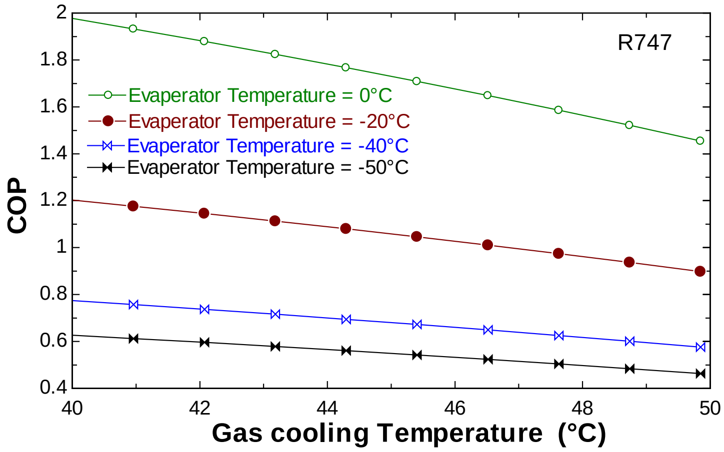

Fig. 6: The effect of Gas cooling temperature on the coefficient of performance of the cycle in different evaporator temperatures

In Figure 7, the effect of gas cooling temperature on the second law efficiency of the cycle in different evaporator temperatures for refrigerant R747 is shown. Studying this figure indicates that the increase in condenser and evaporator temperature does not have a favorable effect on the cycle efficiency and leads to its reduction.

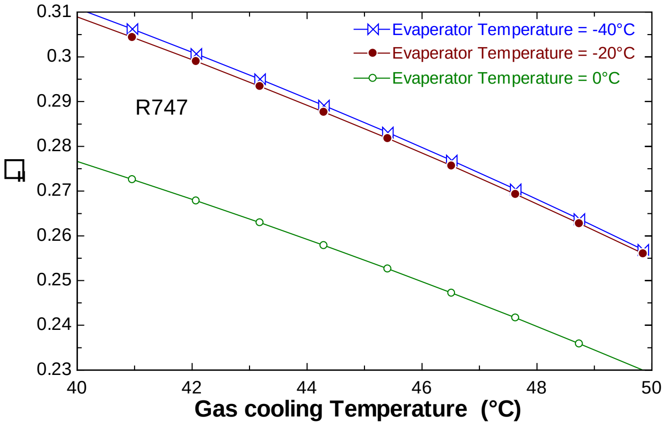

Fig. 7: The effect of gas cooling temperature on the second law efficiency of the cycle in different evaporator temperatures

Figure 8 is another way of stating the concepts shown in Figure 7 and indicates the effect of gas cooling temperature on the level of irreversibility of different components of the cycle on various evaporator temperatures. With the study of Figure 7, this trend was expectable in Figure 8, because irreversibility usually increases with the decrease of the second law efficiency.

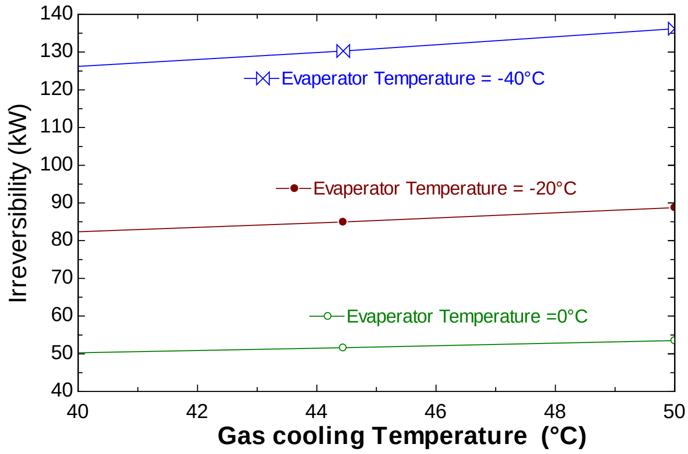

Fig. 8: The effect of the gas cooling temperature on the level of irreversibility of the cycle in different evaporator temperatures

Another important parameter in analyzing refrigeration cycles, the examination of which seems necessary, is to study the effect of ambient temperature on the coefficient of the performance of the cycle in different evaporator temperatures which is done in Figure 9 for refrigerant R744. Close attention to this figure indicates that the performance of the cycle decreases with the increase of ambient temperature and this is normal. A solution should be sought for this decrease during hot times of the year. With more studies on the cycle, it is found that the decrease in evaporator temperature has a more unfavorable effect on the performance of the cycle compared to the ambient temperature.

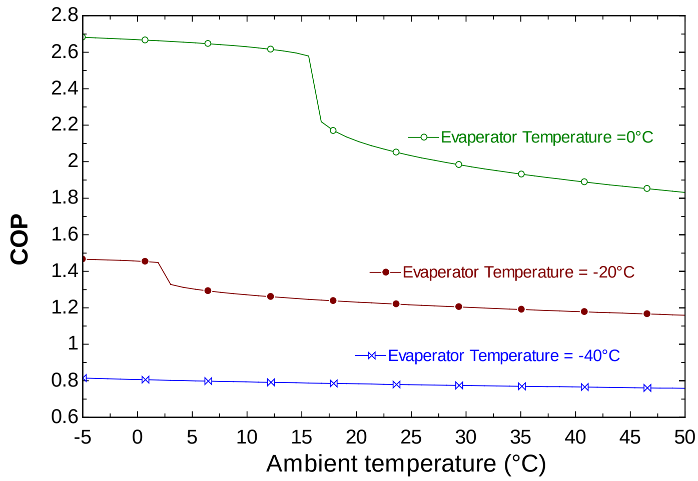

Fig. 9: The effect of ambient temperature on the coefficient of performance of the cycle in various evaporator temperatures

The studies conducted on figures and results indicate that the evaporator temperature is an important factor in the decrease and increase of the coefficient of performance of the cycle. Hence, the degree of effect of this parameter on the performance of the cycle with refrigerant R744 was separately examined. Figure 10 illustrates the effect of evaporator temperature on the performance of the cycle in various gas cooling temperatures. By paying close attention to this figure, the degree of effect of this important parameter could be measured and evaluated.

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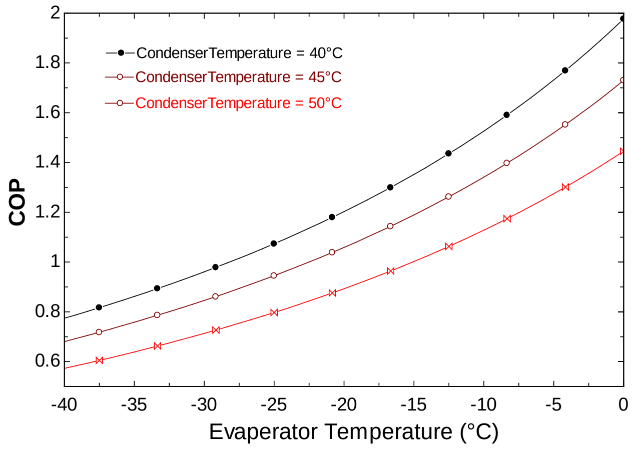

Fig. 10: The effect of evaporator temperature on the coefficient of performance of the cycle in various gas cooling temperatures

In Figure 11, the coefficient of performance of the environment-friendly refrigerant R744 is compared to other common refrigerants. This comparison indicates that the coefficient of performance of refrigerant R744 is more than other refrigerants. Closer study of the figure shows that the incremental trend of the coefficient of performance of refrigerant R744 compared to other common refrigerants increases with the increase of evaporator temperature which in itself is another proof of this refrigerant's power as a relatively suitable substitute compared to environmentally harmful refrigerants. However, allocating environment-friendly refrigerants to refrigeration systems requires time, and manufacturing and production issues can also defer the use of some of these refrigerants. Inevitably, we must think of a way to use these refrigerants for saving and protecting the world we live in.

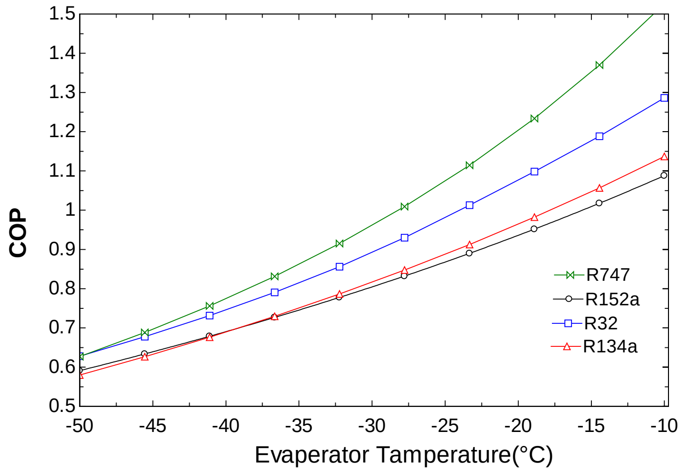

Fig. 11: Comparison of the coefficient of performance of the cycle in various evaporator temperatures for different temperatures

Conculations:

Both energy and exergy analyses comprising optimization studies of two and three stages transcritical R744 cycles are implemented. COP and η_{II} optimized based on Inter-stages and gas cooler pressure simultaneously. Additionally performance compressions between the working fluids R32, R152a, R134a and R744 are also presented. The analysis shows that three stages cycle has higher performance than two stage cycle. The R744 cycle performance is higher than the other working fluids that used in this paper. The most exergy losses occur in throttle valve following by compressors. Increases in evaporator temperature and decreases in gas cooling exit temperature causes the performance enhancement of the cycles for different working fluids. It was also found that when ambient temperature increases, the performance of cycles decreases. As can be seen, with little changes due to optimizing pressures, all parameters such as the coefficient of performance of cycles and the efficiency of the second law of the cycles is increased.

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