Study the Effect of Ambient Temperature on the Refrigeration Cycles Using Energy and Exergy Analyses

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***Abstract*– In this study, a refrigeration cycle with one and two intercoolers is thermodynamically examined. This work attempts to substitute the effect of environmentally harmful agents in nature such as R134a with environment-friendly fluids in nature: R152a, R404a and R744 examine the effect of this substitution on the performance of the cycle and compare it to the previous working fluids and finally, the best refrigerant considering properties and performance is selected. The consequence shows the highest irreversibility is related to the throttle valve and then the compressors.**

***Keywords*– Refrigeration System, Modeling, Simulation, Performance and Comparison**

I. 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. 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. 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 [1] did energy and exergy analyses on the simple absorption refrigeration cycle and showed the results in graphs. He 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. He 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 [2] 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 [3] 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.

Cladeve [4] 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 [5]-[10].

This study examines the thermodynamics analyses of two refrigeration cycles shown in Fig. 1 and Fig. 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.

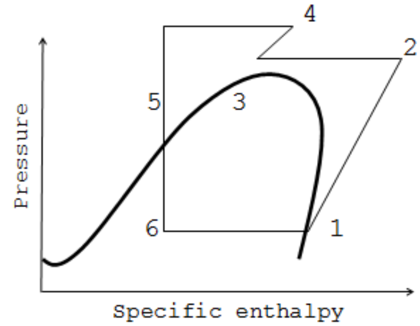

Fig. 1: A schematic view of the cycle with one intercooler for the refrigerant (R-744) CO2

II. 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%.

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

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

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

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

$$w_c = \frac{[(h_2-h_1)+(h_4-h_3)+(h_6-h_6)]}{\eta_{mech}} \tag{4}$$

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

$$q_{ic,1} = h_2 - h_3 \tag{5}$$

$$q_{ic,2} = h_4 - h_5 \tag{6}$$

$$q_{gc} = h_6 - h_7 \tag{7}$$

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

$$q_{ev} = h_1 - h_8 \tag{8}$$

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

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

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

$$COP = \frac{q_{ev}}{w_c} \tag{10}$$

The efficiency of the second law of thermodynamics of the system is calculated using Formula (11).

$$\eta_{II} = \frac{w_c-(i_c+i_{gc}+i_{ic}+i_{tv}+i_{ev})}{w_c} \tag{11}$$

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.

III. RESULTS AND DISCUSSION

In Fig. 2, 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.

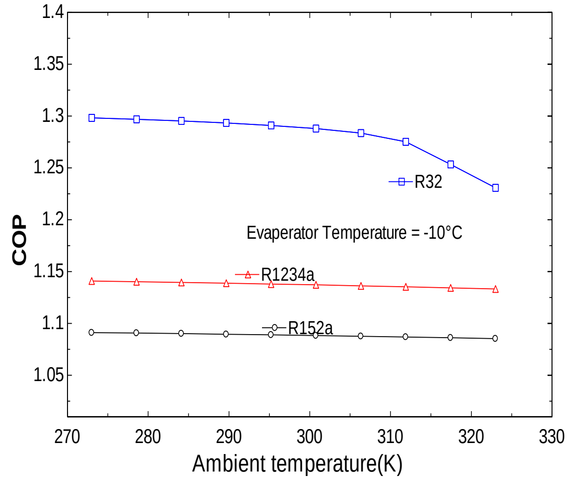

Fig. 2: The coefficient of performance of the cycle in terms of the ambient temperature in evaporator temperature of -10℃

In Table 1, the irreversibility of various components of the cycle with one intercooler is calculated. As can be seen in the table, the highest irreversibility is related to the throttle valve and then the compressors. It is true that a great deal of the energy in the condenser is lost, but this energy has low temperature and pressure and its working ability, called exergy, is also low. Therefore, the irreversibility due to the waste of heat in the condenser is in the third rank.

Table 1: The irreversibility of various components of the cycle with one intercooler for refrigerant R744

Components	Irreversibility (kJ/kg)	Component irreversibility/Total Irreversibility (%)
Compressors	22.67	27.53
Inter cooler	7.65	9.3
condenser	18.41	20.6
evaporator	3.32	4.3
Throttle valve	30.28	36.77
COP	-	1.2
IIη	-	30.89
total	82.33	100

In Table 2, the level of irreversibility of various components of the cycle with two intercoolers for refrigerant R744 is calculated. As can be seen in Table 5, the highest percentage of irreversibility is related to the throttle valve with 39.7% and after that the compressors with 29.23%. Comparing tables 4 and 5 shows that the cycle with two intercoolers has a lower irreversibility and better coefficient of performance since the cycle is closer to its state of ideal Carnot cycle thermodynamically and this is compatible with thermodynamic concepts.

Table 2: The irreversibility of various components of the cycle with two intercoolers for refrigerant R744

Components	Irreversibility(k J/kg)	Component irreversibility / Total irreversibility (%)
Compressors	22.3	29.23
Inter cooler1	7.65	10.0
Inter cooler2	9.9	12.98
condenser	2.8	3.67
evaporator	3.32	4.23
Throttle valve	30.28	39.7
COP	-	1.27
IIη	-	32.1
total	76.26	100

As can be seen in Table 3, different components of the refrigeration cycle are compared to each other considering the type of refrigerants in terms of the level of irreversibility and efficiency. In terms of efficiency, the refrigerant material R32 is in a better condition compared to the other two refrigerants and it is promising that by using this refrigerant instead of R134a not only will the efficiency not decrease, but also it will increase. As shown in Table 3 the highest irreversibility is related to the high-pressure parts of the system, i.e., the compressor and the intercooler which shows that their design demands more attention.

IV. CONCLUSIONS

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.

Table 3: Comparison of the level of irrevers]
ibility and efficiency of different refrigerants in evaporator temperature of -10°C and environment conditions (C°P_{atm}=1 bar, T_{atm}=25)

Refrigerant	Compressor (Kw)	Evaporator (Kw)	Condenser (Kw)	Inter cooler(Kw)	Throttle valve (Kw)	Total irreversibility(Kw)	Second law efficiency (%)	Cop
R134a	22.16	2.911	4.061	43.77	17.02	89.93	24.84	1.137
R152a	36.34	4.857	8.088	85.81	22.6	157.7	24.2	1.088
R32	33.19	5.207	33.19	67.39	20.81	138	26.79	1.286

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