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COMPARATIVE ENERGETIC ANALYSIS OF A REFRIGERATION SYSTEM BY USING R123 AND ITS ALTERNATIVE R514A REFRIGERANTS

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ABSTRACT

In this study, the energy analysis of a single-stage vapor compression refrigeration system operating with R514A refrigerant, which is used as an alternative to R123 refrigerant, has been made and compared. Within the scope of energy analysis, the mass flow rates of refrigerants, compressor energy consumption, cooling capacities, cooling effects (evaporator enthalpy difference), COPs, and discharge temperatures have been examined. It has been observed that R123 refrigerant has a higher mass flow rate and compressor energy consumption than R514A. In addition, although R123 has a low cooling effect, it has a higher cooling capacity than R514A, and this is because R123 has a high mass flow rate. R514A is superior to R123 in terms of discharge temperature. Finally, it has been seen that the COPSM of R514A is almost the same (slightly lower) as R123. As a result, the use of R514A in the cooling system will reduce direct emissions. However, the operating life of the system should be considered. In other words, indirect emissions (especially due to energy consumption) should not be neglected in the selection of refrigerants.

1. INTRODUCTION

Today, systems such as heat pumps, cooling machines, etc. operating according to the vapor compression refrigeration cycle have been widely used. The energy expended during the use of these systems is substantial. The energy consumption of these systems worldwide corresponds to approximately 16% - 50% of the energy consumed in buildings. In other words, this means 33% of the total greenhouse gas emissions [1]. Combustion of fossil fuels, industrial and commercial processes, etc. cause significant greenhouse gas emissions. Heating or cooling systems operating on a vapor compression cycle greatly contribute to these greenhouse gas emissions [2,3]. The direct emission of vapor compression systems (emissions from refrigerant leaks) accounts for approximately 20% of the total CO2 emissions of these systems. About 80% of the total CO2 emissions of vapor compression systems are caused by indirect emissions (electricity consumption, production of system equipment, refrigerant production, material recycling, etc.) [4–6].

In order to reduce greenhouse gas emissions from systems operating according to the vapor compression refrigeration cycle, it is necessary to increase energy efficiency by reducing the energy consumption of the systems. In addition, it is necessary to use environmentally friendly refrigerants in these systems. In this study, the first law of thermodynamics analysis of the use of R514A refrigerant, which is an alternative to R123 refrigerant, in a vapor-compressed single-stage refrigeration system was performed. R514A has a GWP of 2, has no ODP and is non-flammable, and is safety class B1. R123 has a GWP value of 79, an ODP value of 0.02, and a non-flammable and safety class B1 [7–9].

When the general features of R514A are considered, it is seen that it has better environmental properties than R123. However, this situation alone is not a sufficient criterion for refrigerant selection. Therefore, a comprehensive energy analysis is required. because, as explained above, a significant portion of the total greenhouse gas emissions of vapor compression systems is due to their energy consumption.

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2. MATERIALS AND METHODS

While heat transfer takes place from a high-temperature environment to a low-temperature environment following the laws of thermodynamics, the reverse can't occur spontaneously. For this, a heat pump or a cooling machine is required. The heat pump and refrigeration machine operate on a vapor compression refrigeration cycle. However, their intended use is different. In the vapor compression refrigeration cycle, the refrigerant enters the compressor as saturated or superheated vapor. The refrigerant pressure and temperature are increased in the compressor and pass into the condenser in the form of superheated steam. The refrigerant that loses its heat in the condenser condenses and becomes a saturated liquid. The pressure and temperature of the refrigerant, which turns into a saturated liquid, is lowered by the expansion valve and passes to the evaporator in the form of wet steam. It turns into steam by absorbing heat from the environment in the evaporator and is sent back to the compressor. This cycle repeats constantly [10,11]. A schematic view of the vapor compression system is shown in Fig 1.

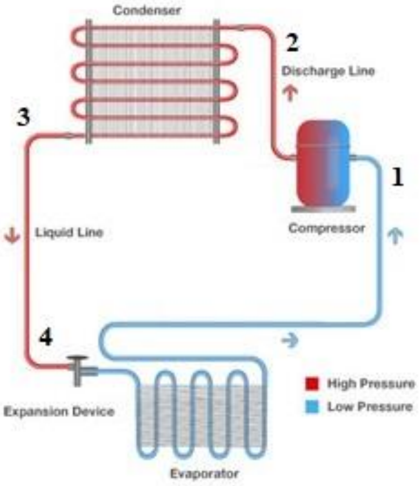

Fig 1. Schematic representation of a single-stage vapor compression refrigeration cycle [12]

In this paper, the single-stage refrigeration cycle given in Figure 1 was used to evaluate the performance of the refrigerants (R123 and R514A). Some assumptions made for the cooling system as follows:

- Evaporator temperature: Between -20 °C and +5 °C
- Compressor efficiency: 0.70
- Condenser temperature: 35 °C
- Superheating and subcooling temperature: 5 °C
- Compressor swept volume: 26.11 cm3/rev
- Revolution of the compressor: 50 rev/s
- There are no pressure losses in the pipes.
- All elements of the system are studied as a continuous open flow.

Considering the 1st law of thermodynamics, the energy analysis of the single-stage vapor compression refrigeration cycle has been performed. Since all the elements in the vapor compression refrigeration cycle are in a continuous flow, the cycle consisting of these elements can also be considered as a continuous flow. The kinetic and potential energy of the refrigerant can be neglected as it is very small relative to the work and heat. Thus, the continuous flow energy equation for unit mass can be written as in Equation 1 [10,11].

$$q\text{-}w = \Delta h \qquad (1)$$

Compressor adiabatically (q=0) receives work from outside. The energy consumed by the compressor can be given by Equation 2. [10,11].

$$\dot{W}_c = \dot{m}_r \, (h_2 - h_1) \qquad (2)$$

Here, $\dot{m}_r$ the refrigerant flow rate, h_1, and h_2 are the compressor inlet and outlet enthalpy values of the refrigerant, respectively. There is no work interaction (w=0) in the evaporator and condenser. Thus, the energy absorbed in the evaporator ($\dot{Q}_e$) and the energy released in the condenser ($\dot{Q}_c$) are calculated by Equation 3 and equation 4, respectively [10,11].

$$\dot{Q}_e = \dot{m}_r (h_1 - h_4) \tag{3}$$

$$\dot{Q}_c = \dot{m}_r (h_2 - h_3) \tag{4}$$

Here, h_4 shows the evaporator inlet enthalpy and h_3 shows the condenser outlet enthalpy value. The efficiency coefficient of the refrigeration machine (COP_{SM}) operating according to the vapor compression refrigeration cycle is given in Equation 5 [10,11].

$$COP_{SM} = \frac{\dot{Q}_e}{\dot{W}_c} \tag{5}$$

3. RESULTS AND DISCUSSION

In this study, the energy analysis of a single-stage vapor compression refrigeration system operating with R514A refrigerant, which is used as an alternative to R123 refrigerant, has been made and compared. The variation of the refrigerant mass flow rates depending on the evaporator temperature of the refrigerants is shown in Fig 2. The mass flow rate of R123 varies between 1.13 g/s and 3.54 g/s, while the flow rate of R514A is between 0.96 g/s and 3.06 g/s. It has been observed that the mass flow rate of R123 is higher than R514A. The reason for this is that the density of R123 refrigerant in the cooling system suction line is higher than that of R514A. Suction line densities of refrigerants are shown in Fig 3 for different evaporator temperatures.

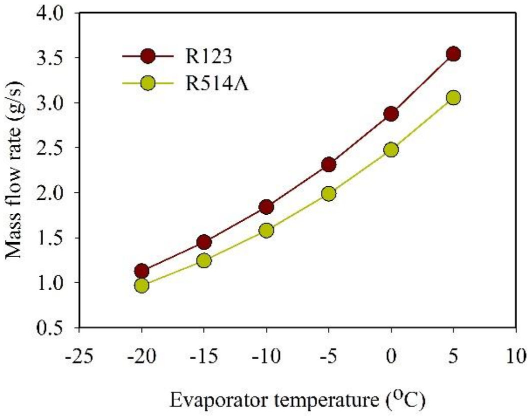

Fig 2. The mass flow rate of refrigerants

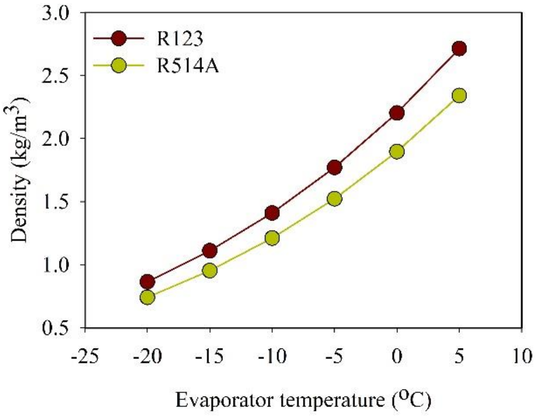

Fig 3. Suction line density of refrigerants

Compressor energy consumption is dependent on the refrigerant-specific compression work and the refrigerant flow rate. Compressor energy consumption of refrigerants depending on the evaporator temperature is shown in Fig 4. The compressor energy consumption of R123 ranges from 58.83 W to 92.49 W, and the compressor energy consumption of R514A ranges from 54.41 W to 87.33 W. The cooling system using R514A refrigerant has lower power consumption than that of R123.

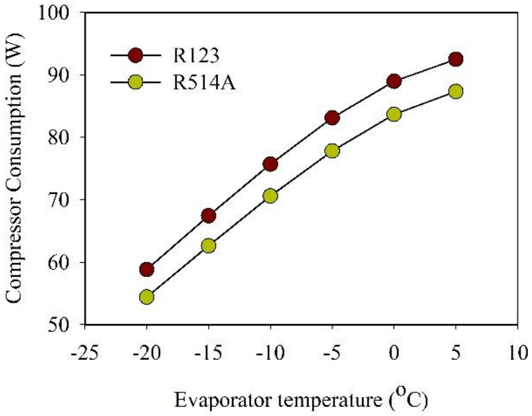

Fig 4. Compressor power consumption

The cooling capacity relies on the cooling effect (evaporator enthalpy difference) and the refrigerant mass flow rate. The cooling capacities and cooling effects of R123 and R514A are presented in Fig 5 and Fig 6, respectively. The cooling capacity of R123 ranges from 160.60 W to 558.60 W, while the cooling capacity of R514A ranges from 145.20 W to 522.70 W. Although the cooling effect of R514A is higher than R123 (Figure 6), its cooling capacity is slightly lower than R123 (Figure 5). Because it has been explained above that the refrigerant mass flow rate of R514A is lower than R123.

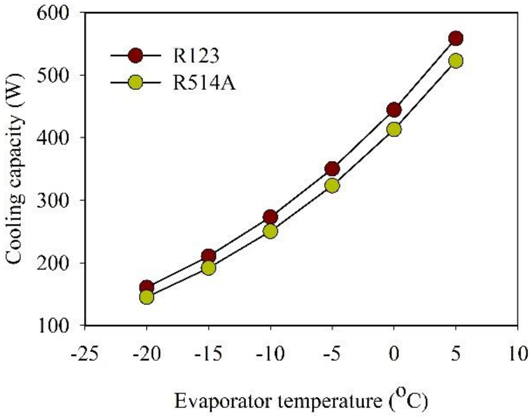

Fig 5. Cooling capacity

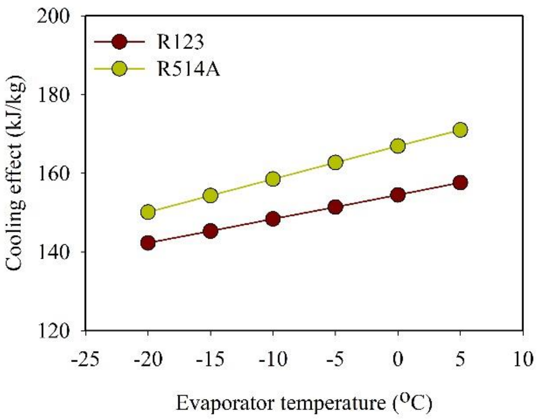

Fig 6. Cooling effect

The COPSM of the cooling system is the ratio of the cooling capacity to the compressor energy consumption. The comparison of COPSM values of refrigerants is given in Fig 7. The COPSM of R123 ranges from 2.73 to 6.04, while the COPSM of R514A ranges from 2.67 to 5.99. The COPSM of R514A is almost the same (slightly lower) as R123.

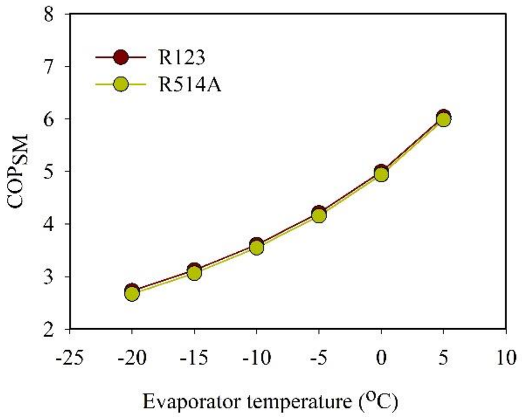

Fig 7. COP

The discharge temperature of the refrigerant is one of the important criteria in the selection of refrigerant. Because high discharge temperature leads to shortened compressor life. In the case of using R123 and R514A refrigerants in the cooling system, discharge temperatures for different evaporator temperatures are shown in Fig 8. As seen in Figure 8, R514A is superior to R123 in terms of discharge temperature.

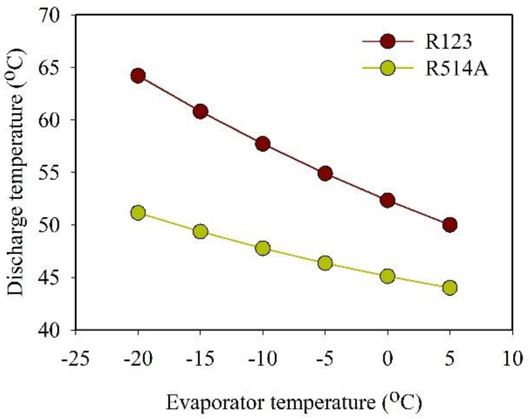

Fig 8. Discharge temperature

4. CONCLUSIONS

In this study, the energy performance of R514A, which is an alternative refrigerant with a lower GWP ratio that can be used instead of R123, was investigated and compared for a single-stage cooling system. In general, it has been seen that the COPSM of R514A is almost the same (slightly lower) as R123. In terms of the GWP ratio, the GWP value of R123 is 79 and the GWP value of R514A is 2. Therefore, the use of R514A in cooling systems is very effective in reducing direct emissions from cooling systems. However, considering that these systems will be used for many years, even a small difference between the COP values will change the greenhouse gas emission resulting from energy consumption, which is in the indirect emission category. This situation should not be ignored in the selection of refrigerant.

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