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# Sürdürülebilir Çevre için Buhar Sıkıştırmalı Soğutma Sisteminde R450A Soğutucu Akışkanın Performans Analizi

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## ÖZET

Soğutma sektöründe kullanılan ve atmosfere salınan soğutucu akışkanlar çevre sorunlarına neden olur. Soğutma ve iklimlendirme alanında, kloroflorokarbonların ve hidrokloroflorokarbonların kullanımı ozon tabakasının incelmesi ve küresel ısınmanın ana nedenidir. Soğutucu akışkan olarak kullanılan hidroflorokarbonların ve düşük küresel ısınma potansiyeline (GWP) sahip soğutucu akışkanların değiştirilmesi, çevresel sorunların önlenmesinde öncelikli konular arasındadır. Bu çalışmada, R134a'ya alternatif olarak kullanılabilecek düşük GWP oranına sahip R134a/R1234ze (E) karışımından oluşan R450A ve R134a soğutucuların enerji parametreleri teorik ve çevresel olarak analiz edilmiştir. Parametre analizinde iki farklı evaporatör sıcaklığı (-15$^0$ ve 15$^0$C) ve kondenser sıcaklıkları (35$^0$C) dikkate alınmıştır.

***Anahtar Kelimeler:*** *Yeni nesil soğutucu akışkanlar, R450A, küresel ısınma, çevre ve ekonomik analiz, CO2 emisyonu*

# Performance Analysis of R450A Refrigerant in Vapor Compression Cooling System for Sustainable Environment


## ABSTRACT

The refrigerants used in the cooling industry and released to the atmosphere cause environmental problems. In the field of refrigeration and air conditioning, the use of chlorofluorocarbons and hydrochlorofluorocarbons is the main cause of ozone depletion and global warming. Replacing hydrofluorocarbons used as refrigerants and refrigerants with low global warming potential (GWP) is among the priority issues in preventing environmental problems. In this study, energy parameters of R450A and R134a refrigerants composed of R134a / R1234ze (E) mixture with low GWP ratio which can be used as an alternative to R134a were analyzed theoretically and environmentally. Two different evaporator temperatures ($-15^0$ and $15^0$C) and condenser temperatures ($35^0$C) were taken into account in the parameter analysis.



***Keywords:*** *New generation refrigerants, R450A, global warming, enviromental and enviroeconomic analysis, CO2 emission*



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## 1. INTRODUCTION

With the industrial revolution, greenhouse gases in the atmosphere increased. Industrial activities led to the destruction of the ozone layer and the rise of global temperatures under the influence of greenhouse gases. Previous generation refrigerants and carbon dioxide emissions are the main causes of global warming. The increase of greenhouse gases in the atmosphere is the main reason for climate change. Due to these effects, targets have been determined to reduce the accumulation of greenhouse gases in the atmosphere and to prevent the impact of climate change on people, and the Kyoto Protocol was created in 2005 in line with this target (Kumaş vd.,2019). Within the scope of the protocol, various targets and mechanisms have been established to reduce greenhouse gas emissions. The protocol has raised awareness among countries, institutions and organizations, investors, and producers to reduce carbon emissions (Kumaş vd., 2019).

Hydrofluorocarbons (HFCs) are alternative refrigerants preferred by many European countries due to concern about the relatively high GWP of HFC refrigerants. There are many attempts to replace HFCs and hydrochlorofluorocarbons (HCFCs) that adversely affect the ozone layer and can cause global warming, such as the Montreal Protocol and the Kyoto Protocols (Bolaji vd.,2019; Farooq vd., 2020).

Finding suitable alternative refrigerants is one of the most important issues for the cooling industry(Sun vd.,2020). Some criteria such as refrigerant selection, thermo-physical and economic properties, environmental factors should be taken into account for applications.

Ozone Depletion Potential (ODP) and high GWP are important parameters for the choice of refrigerants(Yatağanbaba vd., 2015). HFCs proportionally have the largest slice in the current refrigerant market, without ODP but with an extremely high GWP. Hydrofluoroolefins (HFOs) are fourth generation refrigerants and have been produced with low GWP values for environmental purposes(Zhang vd., 2017). As an alternative to HFOs, HFCs and HFOs were mixed in various proportions and refrigerants such as R513A-R450A were obtained. One of the refrigerants created from the HFC / HFO mixtures is R450A refrigerant. R450A is a non-flammable mixture obtained by mixing R134a and R1234ze (E) at a ratio of 42/58 percent by mass(Llopisvd.,2017; Yıldız and Yıldırım, 2020). R450A refrigerant is classified as non-toxic and non-flammable fluid (A1) by ASHRA. The main features of R134a and R450A are shown in Table 1(Mota-Babiloni vd., 2015; Makhnatch vd., 2017). Thermophysical properties of the fluids are given in Fig. 1, pressure-enthalpy diagram and pressure temperature graph in Fig. 2.

Table 1. General properties of R513A and R134a (Makhnatch vd., 2017).

| ***Refrigerant*** | ***R134a*** | ***R450A*** |
|---|---|---|
| *Pure* | Compound | R134a/R1234ze (E) 42/58 |
| *ODP* | 0 | 0 |
| *GWP* | 1300 | 547 |
| *Critical temperature [$^oC$]* | 101.10 | 104.47 |
| *Critical pressure [kPa]* | 4059.3 | 3814 |
| *Boiling point [$^oC$]* | -24.60 | -23.36 |
| *Liquid density *[kg/m$^3$]* | 1295.3 | 1253.28 |
| *Vapor density *[kg/m$^3$]* | 14.35 | 13.93 |
| *Liquid $C_p$* [kJ/kg $^oC$]* | 1.34 | 1.32 |

Table 1 (continued)

| ***Refrigerant*** | ***R134a*** | ***R450A*** |
|---|---|---|
| *Vapor $C_p$* [kJ/kg °C]* | 0.89 | 0.90 |
| *Liquid heat conduction coefficient *[W/m °C]* | 92.01 | 86.23 |
| *Liquid heat conduction coefficient *[W/m °C]* | 11.50 | 11.70 |
| *Liquid viscosity *[Pa s]* | 266.53 | 264.23 |
| *Vapor viscosity *[Pa s]* | 10.72 | 11.15 |

**at 0 °C*

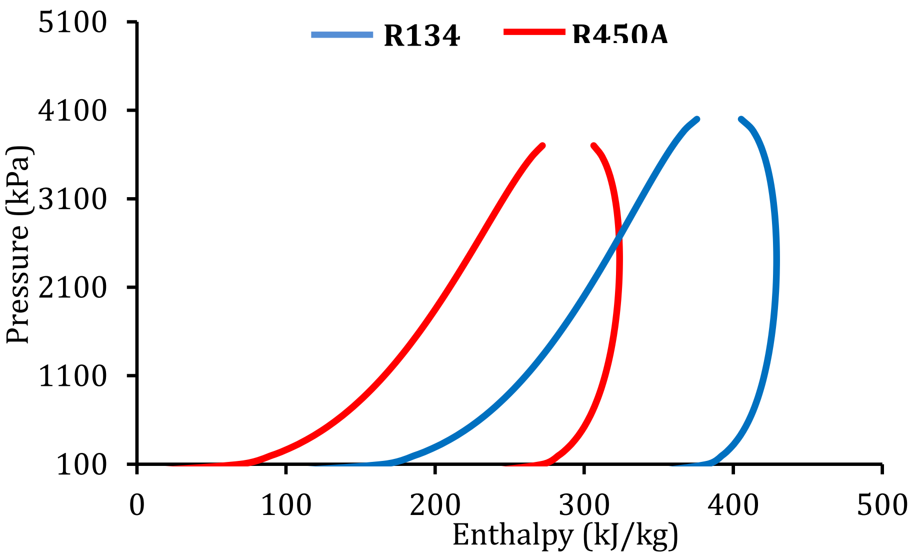


Figure 1. Pressure - enthalpy diagram of R134a and R450A refrigerants

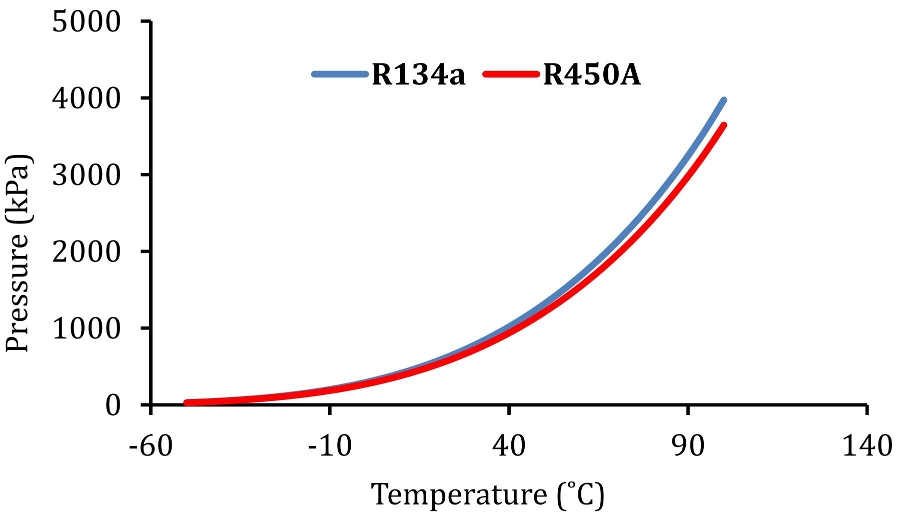


Figure 2. Pressure - temperature graph of R134a and R450A refrigerants

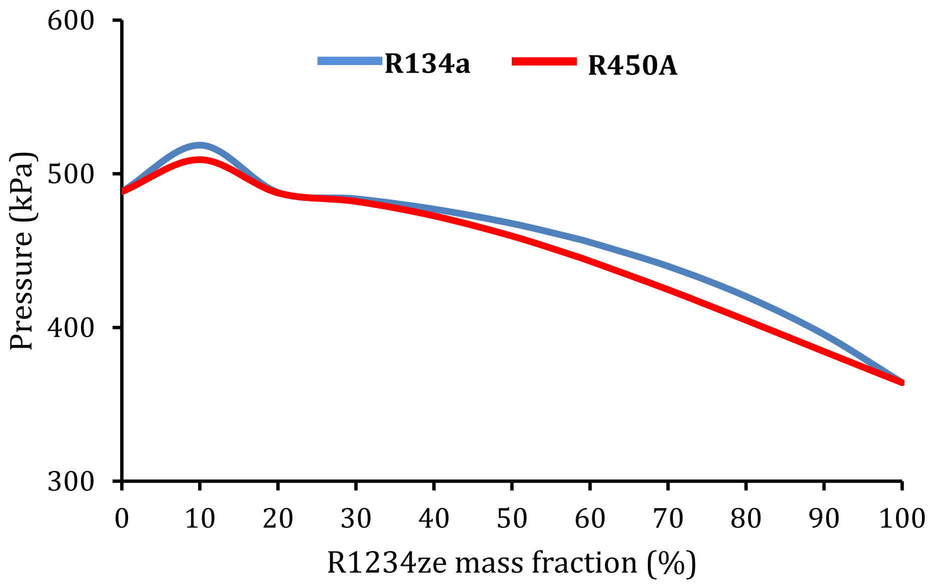


Figure 3. Pressure-mass graph of R134a and R450A refrigerants

Many studies have been carried out by examining different evaluation criteria such as maximum thermal efficiency and minimum cost in different temperatures, different system components and working fluids related to cooling systems. Yataganbaba et al. (2015) examined the exergy analysis of two refrigeration systems using R1234yf, R1234ze (E) and R134a refrigerants. As a result, they stated that R1234yf and R1234ze (E) are better alternative fluids with their environmentally friendly properties than R134a (Yatağanbaba vd., 2015)

Meng et al. (2016) theoretically analyzed the use of mixtures with different mass ratios from R1234ze (E), R152a and R152a and R1234ze (E) instead of R134a in the vapor compression system(Meng vd., 2016).Mendoza-Miranda et al. (2016) studied the performance of R450A with a shell - microfin tube evaporator model using R450A, R448A, R134a and R404A. They stated that the evaporator performance of R450A was similar to R134a (Mendoza-Miranda vd., 2016). Belman-Flores et al. (2017) used R1234yf as an alternative to R134a for home-type refrigerators, and it was observed that the system had a minimum energy consumption (Belman-Flores vd., 2017).

Llopis et al. (2017) studied R513A and R450A according to the energy consumption of the compressor for 24 hours. While R513A and R450A can be preferred in terms of greenhouse gas emissions, their energy consumption is higher than R134a (Llopis vd., 2017). Makhnatch et al. (2017) experimentally examined the new generation refrigerant R450A, which is a mixture of R1234ze (E) and R134a, an alternative to R134a. In the study, it was stated that R450A provides more energy saving than R134a (Makhnatch vd., 2017).

Devecioğlu and Oruç (2018) theoretically analyzed R1234yf, R1234ze (E), R513A, R445A and R450A refrigerants with low GWP values used instead of R134a at different evaporator and condenser temperatures. As a result, it has been determined that the COP values of R450A and R134a are close to each other and there is a difference in the GWP value (Devecioğlu vd., 2018). Meng et al. (2018) investigated the performance of a mixture of R1234yf/R134a (89/11 wt.%) as an alternative to R134a for automotive air conditioning systems.

As a result, they stated that the capacity of R1234yf / R134a is similar to R134a and the COP value of R1234yf/R134a was 4-16% lower than that of R134a (Meng vd., 2018). Maiorino et al. (2018) compared R134a and R152a used in home refrigerators theoretically and experimentally. It has been stated that if R152a is used instead of R134a, there will be a decrease in the total refrigerant charge and energy consumption (Maiorino vd., 2018). Makhnatch et al. (2019) analyzed R134a, R513A and R450A at 40 °C, 50 °C and 60 °C condensation temperatures. They stated that the energy performance of R513A was similar to R134a with its total equivalent warming effect, and that the energy performance (COP) and cooling capacity of R450A were lower than that of R513A and R134a (Makhnatch vd., 2019). Bolaji et al. (2019) conducted a theoretical analysis of the energy potential of environmentally friendly refrigerant mixtures R430A, R440A and R450A for a household refrigerator. They found that the COP value of R450A was 3.36% lower than R134a, and the cooling capacity was 4.62% higher (Bolaji vd., 2019). Yıldız and Yıldırım (2020) have investigated R134a, R1234yf and R513A characteristics in a heat pump. Also, they have made life cycle climate performance analyses of the refrigerants. They stated that R513A and R1234yf refrigerants have 14.45% and 17.16% less emissions than R134a, respectively (Yıldız and Yıldırım, 2020).

New generation refrigerants generally have lower GWP ratio, so more research should be done on the behavior of the fluid before its application due to its use in vapor compression systems. It is very important to know the compatibility of these refrigerants with systems operating with R134a with minor modifications. It is thought that R450A refrigerant can replace R134a in cooling and air conditioning systems.

In this study, the energy performance analysis of R134a and R450A refrigerants was examined theoretically. In addition, environmental and economic analysis of R134a and R450A refrigerants was performed. It is very important to study on new generation refrigerants with low GWP ratio to reduce climate change. When the literature is examined, there are few studies on this subject. For this reason, it is thought that the study will contribute to researchers working in this field and to the literature.

## 2. MATERIALS AND METHOD

In this study, the energy performance of the R134a / R1234ze (E) mixture R450A refrigerant was investigated in a single stage theoretical vapor compression mechanical refrigeration cycle. Schematic representation of the vapor compression refrigeration cycle and the cycle points of the system are given in Fig. 4. The T-s diagram of the single stage vapor compression refrigeration cycle is given in Fig. 5. Thermodynamic and environmental analysis were performed for R134a and R450A . The basic elements of the system are compressor, condenser, expansion valve and evaporator. The assumptions in the analysis of the system are given in Table 2. In addition, it has been considered that the system operates under continuous regime conditions, heat and pressure losses in the cooling system elements and pipes are neglected, and the loop elements are constantly open flow.

Table 2. The assumptions in the analysis of the system

| | |
|---|---|
| *Refrigeration load* ( $\dot{Q}_e$) | 1 kW |
| *Condenser temperature*($T_k$) | 35 $^oC$ |
| *Evaporator temperature (Te)* | -15 $^oC$ ile 15 $^oC$ |
| *Compressor isentropic efficiency* | 0.70 |
| *Overheating* | 5 $^oC$ |
| *Overcooling* | 5 $^oC$ |

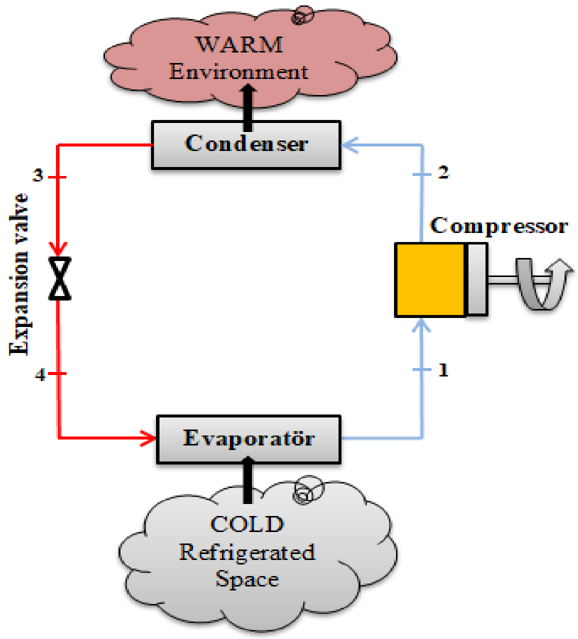


Figure 4. Schematic view of a single stage vapor compression refrigeration cycle.

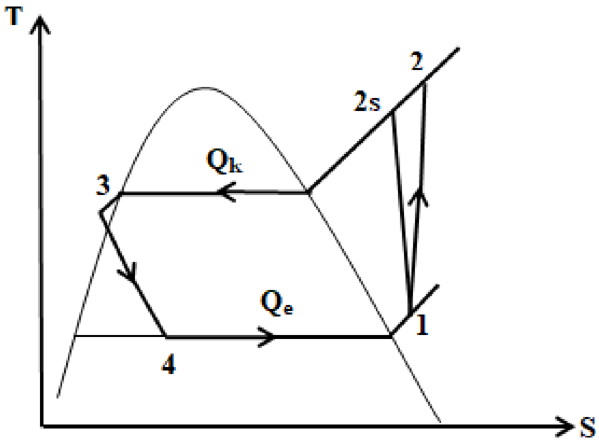


Figure 5. T-s diagram for a single stage vapor compression refrigeration cycle.

## 2.1. Energy Analysis

Energy analysis of the single stage vapor compression refrigeration cycle has been made according to the first law of thermodynamics. The energy equations of the system are given below. The energy consumed by the compressor can be calculated with Equation 1.

$$\dot{W}_k = \dot{m}_{sa}(h_2 - h_1) \tag{1}$$

The heat released from the condenser can be found in Equation 2.

$$\dot{Q}_k = \dot{m}_{sa}(h_2 - h_3) \tag{2}$$

The cooling capacity of the evaporator can be calculated with Equation 3.

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

The performance coefficient (COP) of the cooling system is given in Equation 4.

$$COP = \frac{\dot{Q}_e}{\dot{W}_k} \tag{4}$$

Volumetric cooling capacity (VCC) can be calculated from Equation 5 (Zhang vd., 2019).[20].

$$VCC = \rho_1(h_1 - h_4) \tag{5}$$

In the equations given above (Equations 1-5), h indicates the enthalpy value (kJ / kg) by the relevant index. $\dot{m}_{sa}$ indicates the refrigerant flow (kg/s) and $\rho_1$ indicates the suction line density (kg / m$^3$).

## 2.2. Environmental Analysis

The environmental analysis can be calculated by Equation 6(Caliskan ,2017).

$$x_{CO_2} = y_{CO_2}\dot{E}_{in}\, t_{working} \tag{6}$$

$x_{CO_2}$ is the greenhouse releasing ($CO_2$) in a period of time (kg$CO_2$ / time), $y_{CO_2}$ is the emission value for the energy option (kg$CO_2$ / kWh), $\dot{E}_{in}$ is the energy rate of the energy option (kW) and $t_{working}$ is working time of the system (h / time).

Emission values for some energy sources are given in Table 3 (Caliskan,2017). As seen in Table 3, the emission values of renewable energy sources are less than traditional energy sources.

Table 3. CO2 emission value of the energy sources used for electricity generations (Caliskan,2017)

| ***Electricity generation source*** | ***CO2 Emission value (kgCO2 / kWh)*** |
|---|---|
| *Hydro* | 0.0037 – 0.237 |
| *Wind* | 0.0097- 0.1237 |
| *Solar thermal* | 0.0136 – 0.202 |
| *Nuclear* | 0.0242 |
| *Biomass* | 0.035 – 0.178 |
| *Solar PV* | 0.0534 – 0.250 |
| *Coal* | 0.9753 |
| *Oil* | 0.7421 |

## 2.3. Enviroeconomic Analysis

The enviroeconomic analysis can be calculated by Equation 7(Caliskan,2017).

$$C_{CO_2} = c_{CO_2}x_{CO_2} \tag{7}$$

$x_{CO_2}$ is the result of environmental analysis (kg$CO_2$ / time), $c_{CO_2}$ is the $CO_2$ emission price (\$/kg$CO_2$) and $C_{CO_2}$ is enviroeconomic analysis (\$/time). Assumptions for environmental analysis and enviroeconomic analysis are given in Table 4.

Table 4. Assumptions for Environmental and Enviroeconomic Analysis

| $t_{working}$ | *12 h / day* |
|---|---|
| $c_{CO_2}$ | 0.0145 \$ / kg$CO_2$ (Caliskan,2017) |
| *Energy source preference for electricity generation* | Hydro, Wind, Solar PV, Coal, Oil, Nuclear |
| $c_{CO_2}$ | 0.0145 \$ / kg$CO_2$ (Caliskan,2017) |

## 3. RESULTS AND DISCUSSION

In the study, the energy performance of R450A fluid in cooling systems has been analyzed according to the first law of thermodynamics. The refrigerant flow rate, compressor energy consumption, COP and volumetric cooling capacity obtained as a result of the analysis are presented in Fig. 6-9.

The refrigerant flow rate depends on the density of the refrigerant, the geometric structure of the compressor and the isentropic efficiency of the compressor. Condensation temperature was kept constant (35°C) in the analysis. Fig. 6 shows that R450A refrigerant has a higher refrigerant flow rate than R134a. At 35°C condensation temperature, the refrigerant flow rate of R450A varies between 6.29 and 7.16 g / s, while the refrigerant flow rate of R134a varies between 5.87 and 6.57 g/ s.

When the refrigerant flow rate is evaluated, it is seen that R450A has 7 % to 9 % more refrigerant than R134a. The cooling effect of R450A (evaporator enthalpy difference) is lower than R134a. The cooling effect of R450A for the evaporator temperatures -15, 0 and 15 °C are 139.55, 149.39 and 158.88 kJ / kg, respectively. The cooling effect of R134a for the same evaporator temperatures are 152.08, 161.35 and 170.18 kJ/kg, respectively.

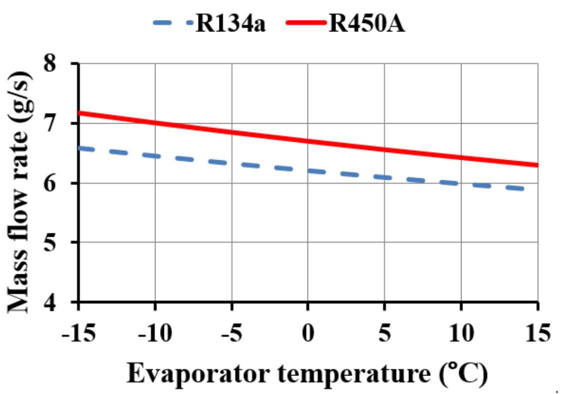


Figure 6. Mass flow rate of refrigerants

The volumetric cooling capacity (VCC) of the refrigerants has been examined to make comparisons between refrigerants (Fig. 7). The volumetric cooling capacity of R450A at 35 °C condensation and -15,-10, -5, 0, 5, 10 and 15 °C evaporator temperatures is 1111, 1376, 1691, 2062, 2497, 3004 and 3594 kJ/ m3, respectively. Under the same conditions, the volumetric cooling capacity of R134a are 1230, 1521, 1865, 2270, 2743, 3294 and 3933 kJ/m$^3$, respectively. When the refrigerants are evaluated in general, it is seen that R134a has approximately 9 % to 10 % higher volumetric cooling capacity than R450A

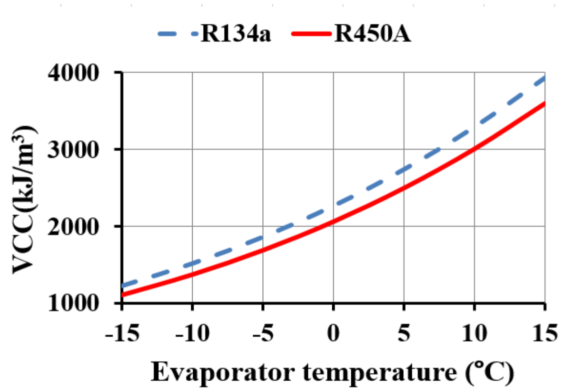


Fig. 7. Volumetric cooling capacity

The evolution of the COP value obtained by the ratio of cooling capacity to compressor energy consumption according to temperature is shown in Fig. 8. While the compressor energy consumption of R450A and R134a refrigerants is the same at some evaporator temperatures (5, 10, and 15°C), it is higher than R134a at temperatures between -15-0 °C.

At 35 °C condenser temperature, the compressor energy consumption of R450A are 107 to 342 W, for R134a it is between 107 and 338 W.

When refrigerants are compared, R450A has 1% more compressor energy consumption in the evaporator temperature range of -15°C-0°C compared to R134a.

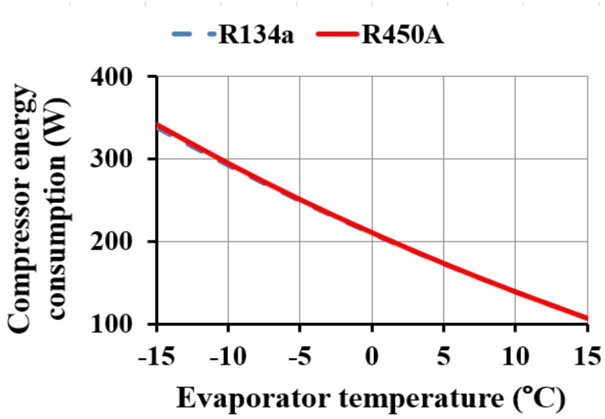


Figure 8. Compressor power consumption of refrigerants

When the COP values of the refrigerants are examined (Fig. 9), it is seen that the values are close to each other. The COP value of R450A is 2.92, 3.39, 3.98, 4.74, 5.76, 7.20 and 9.36 at evaporator temperatures of -15, -10, -5, 0, 5, 10 and 15 °C where the condensing temperature is kept constant. Under the same conditions, the COP value of R134a is 2.95, 3.42, 4.01, 4.77, 5.79, 7.21 and 9.37, respectively.

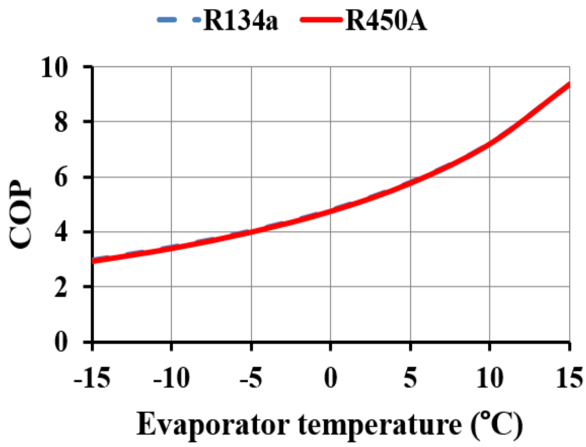


Figure 9. COP of refrigerants

The environmental and enviroeconomic analyzes of the R134a and R450A for the different energy sources are given in Table 5 and Table 6. Environmental analysis of R134a for hydro, wind, solar PV, coal, oil and nuclear energy sources at -15 °C evaporator temperature was determined as 0.489, 0.271, 1.233, 3.963, 3.016 and 0.438 kg$CO_2$/month, respectively(Fig.10). Under the same conditions, environmental analyzes of R450A are 0.494, 0.274, 1.246, 4.005, 3.048 and 0.443 kg$CO_2$ / month for the given sources, respectively. The results obtained for R450A are slightly higher than for R134a. Even small differences are important in environmental assessment. It is seen that wind energy has the lowest environmental effective value.

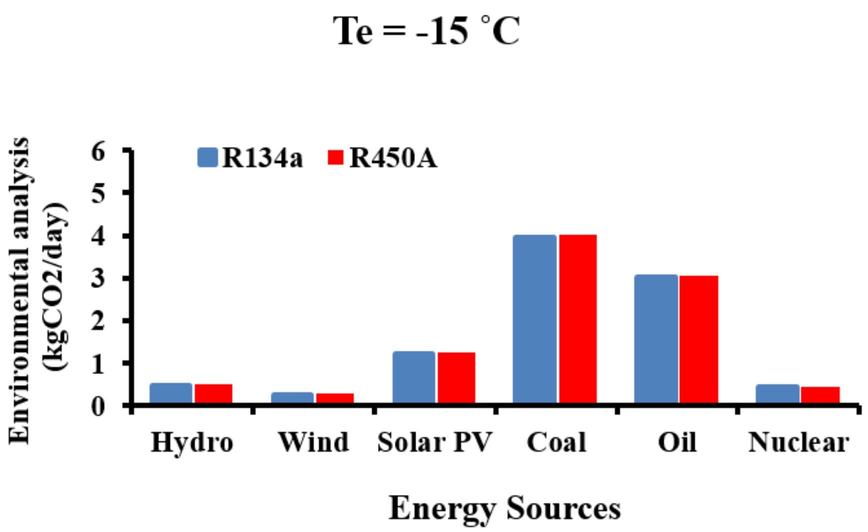


Figure 10. Environmental analysis for different energy sources at -15°C evaporator temperature

Table 5. Environmental results of R134a R450A / for various energy sources at different evaporator temperatures

***Environmental analysis ($kgCO_2$/day)***

| ***Refrigerant*** | **Te, °C** | **Hydro** | **Wind** | **Solar PV** | **Coal** | **Oil** | **Nuclear** |
|---|---|---|---|---|---|---|---|
| ***R134a*** | -15 | 0.489 | 0.271 | 1.233 | 3.963 | 3.016 | 0.438 |
| | -10 | 0.422 | 0.234 | 1.063 | 3.418 | 2.601 | 0.378 |
| | -5 | 0.360 | 0.199 | 0.907 | 2.914 | 2.217 | 0.322 |
| | 0 | 0.303 | 0.168 | 0.762 | 2.451 | 1.865 | 0.271 |
| | 5 | 0.249 | 0.138 | 0.629 | 2.020 | 1.537 | 0.223 |
| | 10 | 0.200 | 0.111 | 0.505 | 1.622 | 1.234 | 0.179 |
| | 15 | 0.154 | 0.085 | 0.388 | 1.249 | 0.950 | 0.138 |
| ***R450A*** | -15 | 0.494 | 0.274 | 1.246 | 4.005 | 3.048 | 0.443 |
| | -10 | 0.426 | 0.236 | 1.074 | 3.451 | 2.626 | 0.381 |
| | -5 | 0.363 | 0.201 | 0.914 | 2.937 | 2.234 | 0.325 |
| | 0 | 0.305 | 0.169 | 0.767 | 2.467 | 1.877 | 0.273 |
| | 5 | 0.250 | 0.139 | 0.631 | 2.029 | 1.544 | 0.224 |
| | 10 | 0.201 | 0.111 | 0.506 | 1.625 | 1.236 | 0.180 |
| | 15 | 0.154 | 0.085 | 0.389 | 1.249 | 0.950 | 0.138 |

Enviroeconomic analysis for hydro, wind, solar PV, coal, oil, and nuclear energy sources at -15 °C evaporator temperature for R134a yielded the results of 0.007, 0.004, 0.018, 0.057, 0.044, and 0.006 $ / month, respectively (Fig.11).

Under same conditions the enviroeconomic analysis of R450A are 0.007, 0.004, 0.018, 0.058, 0.044, and 0.006 $/month. The environmental economic consequences for both refrigerants are very small due to their use in a small scale refrigeration system. Wind power has the lowest environmental economic values for both refrigerants.

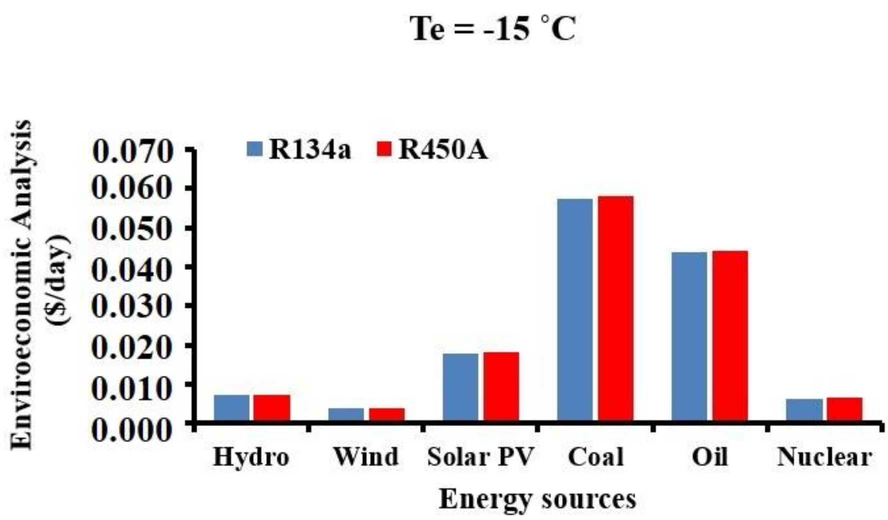


Figure 11. Enviroeconomic analysis for different energy sources at -15°C evaporator temperature

Table 6. Enviroeconomic results of refrigerants for various energy sources at different evaporator temperatures

***Enviroeconomic Analysis ($/day)***

| ***Refrigerant*** | **Te. °C** | **Hydro** | **Wind** | **Solar PV** | **Coal** | **Oil** | **Nuclear** |
|---|---|---|---|---|---|---|---|
| ***R134a*** | -15 | 0.007 | 0.004 | 0.018 | 0.057 | 0.044 | 0.006 |
| | -10 | 0.006 | 0.003 | 0.015 | 0.050 | 0.038 | 0.005 |
| | -5 | 0.005 | 0.003 | 0.013 | 0.042 | 0.032 | 0.005 |
| | 0 | 0.004 | 0.002 | 0.011 | 0.036 | 0.027 | 0.004 |
| | 5 | 0.004 | 0.002 | 0.009 | 0.029 | 0.022 | 0.003 |
| | 10 | 0.003 | 0.002 | 0.007 | 0.024 | 0.018 | 0.003 |
| | 15 | 0.002 | 0.001 | 0.006 | 0.018 | 0.014 | 0.002 |
| ***R450A*** | -15 | 0.007 | 0.004 | 0.018 | 0.058 | 0.044 | 0.006 |
| | -10 | 0.006 | 0.003 | 0.016 | 0.050 | 0.038 | 0.006 |
| | -5 | 0.005 | 0.003 | 0.013 | 0.043 | 0.032 | 0.005 |
| | 0 | 0.004 | 0.002 | 0.011 | 0.036 | 0.027 | 0.004 |
| | 5 | 0.004 | 0.002 | 0.009 | 0.029 | 0.022 | 0.003 |
| | 10 | 0.003 | 0.002 | 0.007 | 0.024 | 0.018 | 0.003 |
| | 15 | 0.002 | 0.001 | 0.006 | 0.018 | 0.014 | 0.002 |

## 4. CONCLUSION

The environmental and enviro-economic analysis of R450A replacing R134a in a vapor compression refrigeration system was studied. The following results can be obtained from this study:

- R450A has a higher mass flow rate than R134a as it has lower cooling effect than R134a.
- R450A has slightly higher compressor energy consumption than R134a.
- R134a has higher COP than R450A.
- Coal and oil are bad options according to environmental and environmental analysis. However, if there was an obligation to choose between oil and coal, oil would be the better choice. In general, renewable energy sources and nuclear energy are better options than traditional energy sources. Wind energy is the best choice among all energy sources.
- Environmental and enviroeconomic analyzes provide useful information on $CO_2$ emissions and prices over a period of time. Thanks to these analyzes, success can also be achieved for the reduction of greenhouse gases and economic management.

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