# A Comparison Between Refrigerants Used In Air Conditioning

Derya Özkan, Özden Agra and Özlem Çetin

University of Yildiz Technical University, Turkey

*Corresponding email: tumer@yildiz.edu.tr*

## SUMMARY

It's clearly known that growing dimensions of the hole on ozone layer has very important damages and effects on living creatures today. Investigations show that refrigerants that commonly used in air conditioning have great impacts on damage of ozone layer. For this reason, researches on alternative refrigerants to be used for air conditioning are still continuing. In this study, performance of different refrigerants like R600a, R134a, R290, R1270, R32, R22, and R152a, in vapor compression refrigeration cycles and heat pumps was investigated. Analyses was made on the ideal vapor compression refrigeration cycle and a second cycle which was created by adding subcool and superheat regions on the first one. While evaporation temperature is changing between -40 °C and – 10 °C, condensation temperature Tcond = 40 °C is constant for 2,2kW of cooling load. Also a comparison between refrigeration performance and variation on compressor power was carried out at different evaporation temperatures of different refrigerants.

## INTRODUCTION

Natural elements such as carbon dioxide, air, water and ammonia have been used as refrigerants in cooling systems which started being developed at the second half of 19th century. During the following century, chlorofluorocarbons and hydro chlorofluorocarbons have replaced some of these elements and have seen heavy use. [1] However, as a result of the dispersal of these elements into the atmosphere, several environmental problems such as damages on the atmosphere and the greenhouse effect have occurred. Especially the ozone layer which protects living beings from the harmful rays of the sun, is being damaged as the chlorine atoms are released from the structure of cooling elements and start damaging the weak ozone molecules.[4] The problem that is the destruction of the ozone layer has gained worldwide significance and countries have united to find a way to prevent it. With the Montreal Protocol that has been signed by 43 countries in the year 1987, the production and usage of CFC class refrigerants which also include R12 have been gradually constrained. Aside from the countries that have signed the protocol, other countries have set up new law regulations regarding the import, export and production of these refrigerants. It was expressed by medical authorities that there was an increase in the number of several clinical diseases with the growing of the holes in the ozone layer. As a result of the studies that were carried out about this issue which is highly important for environment and human life, it was found out that the CFC group refrigerants have got a great potential of damaging the ozone layer. Many alterative refrigerants were invented to be used instead of these harmful refrigerants and the researches for developing new are still taking place. The refrigerants that are used as replacement for the HFC's are R134a, R404A, R407A, R410A, R22, and hydrocarbons (propane and butane) and ammonia. Propane could also be used, with an acceptable degree of risk, for car air conditioning, again provided that appropriate precautions were taken. Some tens of thousands of car air conditioning systems have been ‘‘unofficially’’ converted to operate on propane by private individuals in USA and Australia. [5]

In this study, the thermodynamic analysis of the R22 refrigerant, the pure refrigerants R134a, R32 and R152a as well as the easy-to-obtain, cost efficient, environment-friendly natural refrigerants R290, R1270 and R600a have been carried out in a single phase steam compression cooling cycle. The mass flow rate, compressor power and COP changes of the aforementioned refrigerants have been shown as graphs. While evaporation temperature is changing between -40 °C and – 10 °C, condensation temperature Tcond = 40 °C is constant for 2,2kW of cooling load. Analyses was made on the ideal vapor compression refrigeration cycle and a second cycle which was created by adding subcool and superheat regions

## THE COMPARISON OF THE THERMODYNAMIC STATISTICS OF COOLING LIQUIDS

While designing air conditioning and cooling systems, refrigerants that do not damage the ozone layer or cause global warming should be preferred instead of those that have the same physical features but have harmful effects.

Table 1. Refrigerants of thermodynamics property

| REFRIGERANTS | MOLAR MASS (KG/KMOL) | SATURATED TEMPERATURE($^0$C) | $T_C$ ($^0$C) | $P_C$ (BAR) | TLV (PPM) | LFL (%) | DELTA $h_{comb}$ (MJ/Kg) | ODP | GWP (100 YEARS) | ATMOSPHERIC LIFETIMES (YEARS) |
|---|---|---|---|---|---|---|---|---|---|---|
| **R600a** | 58,112 | -11,670 | 134,67 | 36,4 | 800 | 1,8 | 49,4 | 0 | ~20 | - |
| **R134a** | 102,03 | -26,074 | 101,06 | 40,593 | 1000 | 0 | 4,2 | 0 | 1300 | 14,6 |
| **R290** | 44,096 | -42,090 | 96,675 | 42,471 | 2500 | 2,3 | 50,3 | 0 | ~20 | - |
| **R1270** | 42,080 | -47,690 | 92,420 | 46,646 | 375 | 2 | - | 0 | 2 | - |
| **R32** | 52,024 | -51,651 | 78,105 | 57,820 | 1000 | 13,3 | 9,4 | 0 | 650 | 5,6 |
| **R22** | 86,468 | -40,810 | 96,145 | 49,900 | 1000 | 0 | 2,2 | 0,04 | 1500 | 12,1 |
| **R152a** | 66,051 | -24,023 | 113,26 | 45,168 | 1000 | 3,1 | 17,4 | 0 | 140 | 1,5 |

The R22 refrigerant which is used as an alternative to CFC-included refrigerants, has got a low ODP value and thus, its use is permitted until the year 2030. As a result, a refrigerant that has similar thermodynamic properties could be an alternative to R22. As Table 1 shows, taking into account the Global Warming Effect (GWE), the Ozone Depletion Coefficient and the other statistics, the R134a could be an alternative to R22. However, the fact that R134a has a relatively high global warming effect requires an alternative to be found for this refrigerant too. The hydrocarbons like R600a, R290 and R1270 are good alternatives to R12, R22 and R502 since they do not damage the ozone layer much and they have a very low greenhouse effect. Even though their high rate of flammability prevents them from being used commonly, the propane-butane and propane-isobutene mixtures are good alternatives to R12 in house-type coolers. Most of the refrigerants that are to be compared against one another in a simple coolant cycle are chosen from hydrocarbons in this study too.

## THEORETICAL ANALYSIS

This study has been carried out on a compressed vapor cooling cycle which runs on -30 °C evaporation temperature and 40 °C condensation temperature and which has been designed for a no-frost refrigerator. The saturated and boiling steam properties of refrigerants R22, R134a, R32, R152a, R290, R1270 and R600a to be analyzed have been taken from the Refprop 7.0 software.

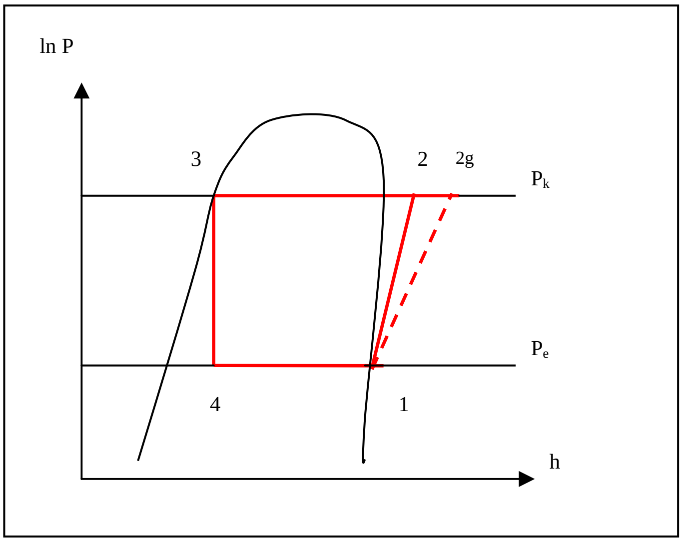


Figure 1. lnP-h diagram of ideal vapor compression cycle

Table 2 Refrigerants enthalpy value

| Refrigerants / Enthalpy | R600a | R134a | R290 | R1270 | R32 | R22 | R152a |
|---|---|---|---|---|---|---|---|
| $h_1$ (kj/kg) | 515,21 | 380,32 | 540,22 | 548,17 | 506,27 | 392,69 | 485,55 |
| $h_2$ (kj/kg) | 605,19 | 432,33 | 639,23 | 650,83 | 603,17 | 450,38 | 569,1 |
| $h_{2g}$ (kj/kg) | 627,68 | 445,332 | 663,982 | 676,495 | 627,395 | 464,802 | 589,98 |
| $h_3$ (kj/kg) | 297,03 | 256,41 | 307,82 | 305,01 | 275,61 | 249,65 | 271,35 |
| $h_4$ (kj/kg) | 297,03 | 256,41 | 307,82 | 305,01 | 275,61 | 249,65 | 271,35 |

Taking the cooling capacity of the evaporator as 2.2 kW's, the various mass flow rates, compressor works and condenser capacities have been calculated for different refrigerants and the COP values have been acquired. Thus,

$Q_l$= 2,2 (kW)

the mass flow rate of the liquid to travel through the cooling cycle is calculated as:

$$m = Q_l \,/\, (h_1 - h_4) \; (kg/s), \qquad (1)$$

The work done by the compressor has been calculated at Equation 3, by taking the isentropic efficiency as (0,80).

$$0{,}8 = (h_1 - h_2) \,/\, (h_1 - h_{2g}), \qquad (2)$$

$$W_{comp} = m \, (h_{2g} - h_1) \;\; (kj/s), \qquad (3)$$

The condenser capacity has been calculated according to Equation 4.

$$Q_k = m (h_{2g} - h_3), \qquad (4)$$

Cooling performance COP;

$$COP = Q_l \,/\, W_{comp}, \qquad (5)$$

has been calculated at Equation 5.

The change in the compressor power has been compared in Figure 2 by changing the evaporation temperature of the refrigerants in use between -10 °C and – 40 °C. The increasing compressor power is a parameter that decreases the COP. It is understood from the figure that for all the cooling liquids, the compressor power decreases linearly with an increase in the evaporation temperature. It is shown that R290 requires more compressor power than the other refrigerants at evaporation temperatures lower than -20 °C, while R152a requires less. It is also shown that R 32 requires more compressor power than the other refrigerants at evaporation temperatures higher than -20 °C, while R 22 requires less.

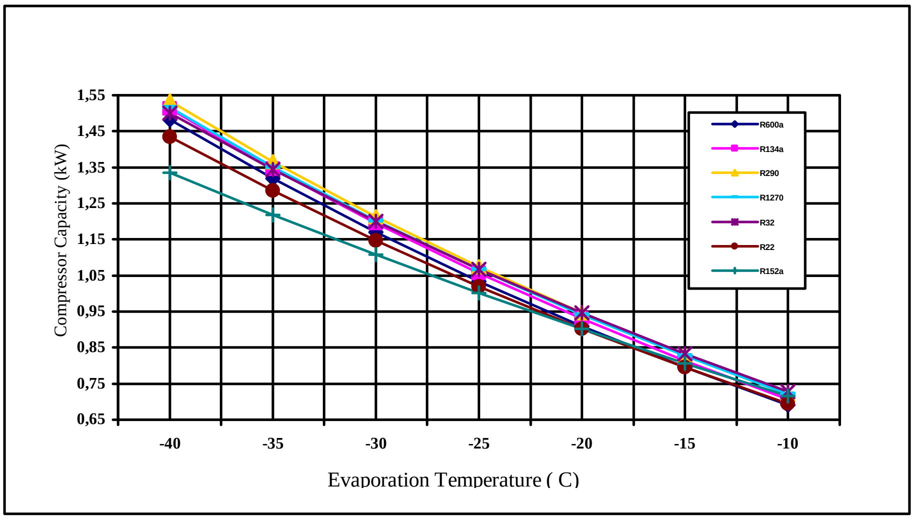


Figure 2. Effect of evaporation temperature changes of refrigerants on compressor capacity

Figure 3 shows the change of the mass flow rate of refrigerants along with the changing evaporation temperatures, for 2.2 kW's of cooling capacity. And for all the refrigerants, mass flow rate decreases linearly with increasing evaporation temperature. The highest mass flow rate between the temperature range of -40 °C and -10 °C is R134a liquid's, while the lowest is the R1270's. Having a low mass flow rate with in the system is a parameter that reduces the cost of operating.

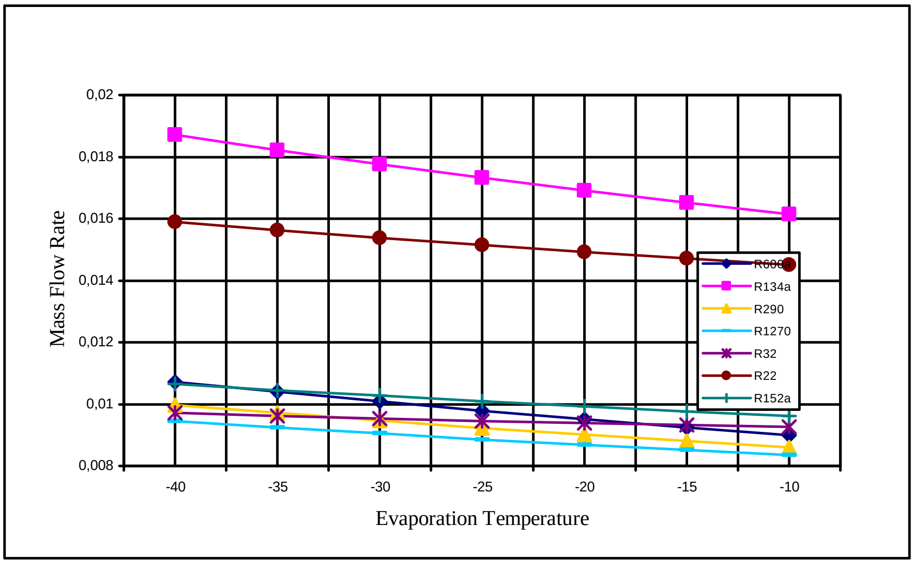


Figure 3. The mass flow rate changes of refrigerants with the changing evaporation temperatures, for 2.2 kW's of cooling capacity

Figure 4 shows the change of the cooling performance (COP) of refrigerants for a cooling cycle with a cooling load of 2,2 kW and with a -30 °C evaporation temperature and 40 °C condensation temperature. According to the figure, it is seen that the COP of R 152 a is the highest while the COP of R 290 is the lowest.

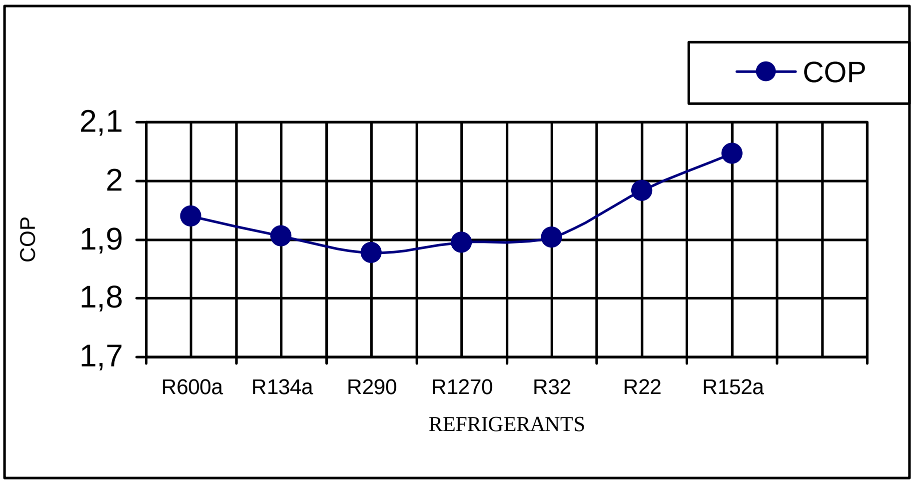


Figure 4. The change of the COP of refrigerants for a cooling cycle

The COP of R 22 has been considered to be 100% in Figure 5 and the comparison for the COP's of the rest of the alternative refrigerants has been made. It was seen that the performance of R 152 a is better than R 22, while the others are worse.

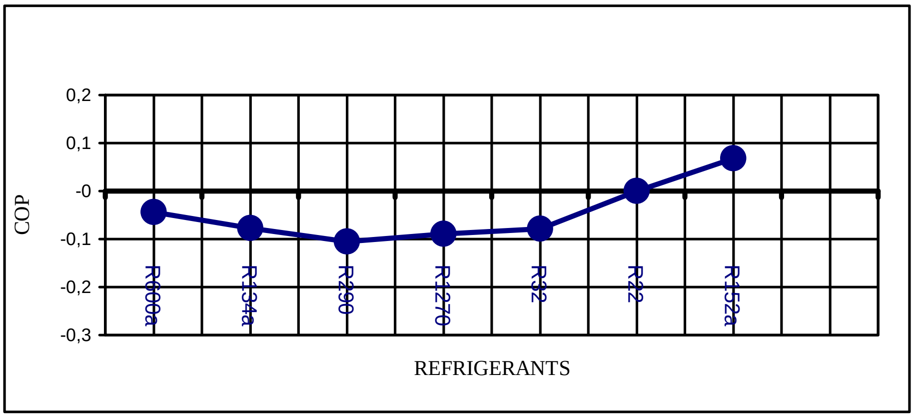


Figure 5. The comparison between R 22 COP and alternative refrigerant's COP's

Figure 6 shows the COP changes of the refrigerants chosen for this work between 40 °C condensation temperature and -40 °C to -10 °C evaporation temperature. In the refrigerants R600a, R134a, R290, R1270, R32, R22 and R152a, the COP increases with increasing evaporation temperature. But this increase is varying upon the refrigerant used.

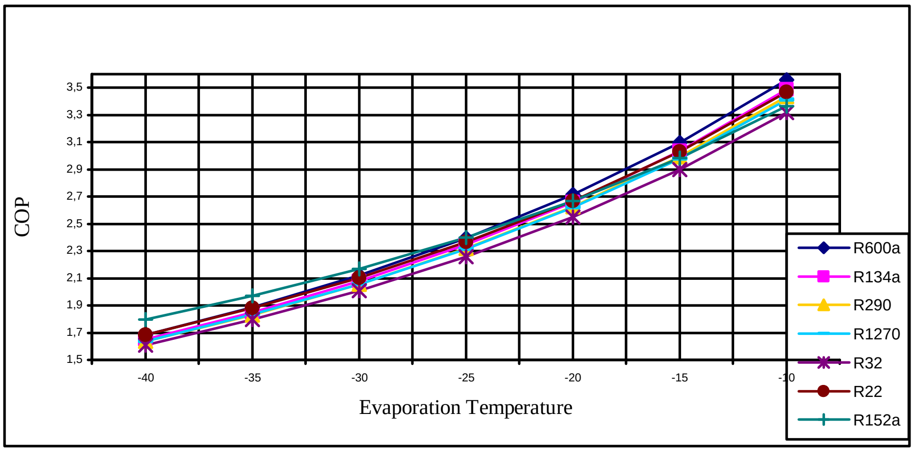


Figure 6. The change of the COP of refrigerants with the changing evaporation temperatures

From this graph it is possible to conclude that the COP value of R 152a is high for evaporation temperatures below -25 °C and the COP value of R 600a is higher than the rest of the refrigerants between -25 °C to -10 °C evaporation temperatures and that it can be preferred to the other refrigerants within this temperature range.

The cooling performances of refrigerants have been tested by making 7 °C of subcooling is made within the condenser and 7 °C of superheating in the evaporator.

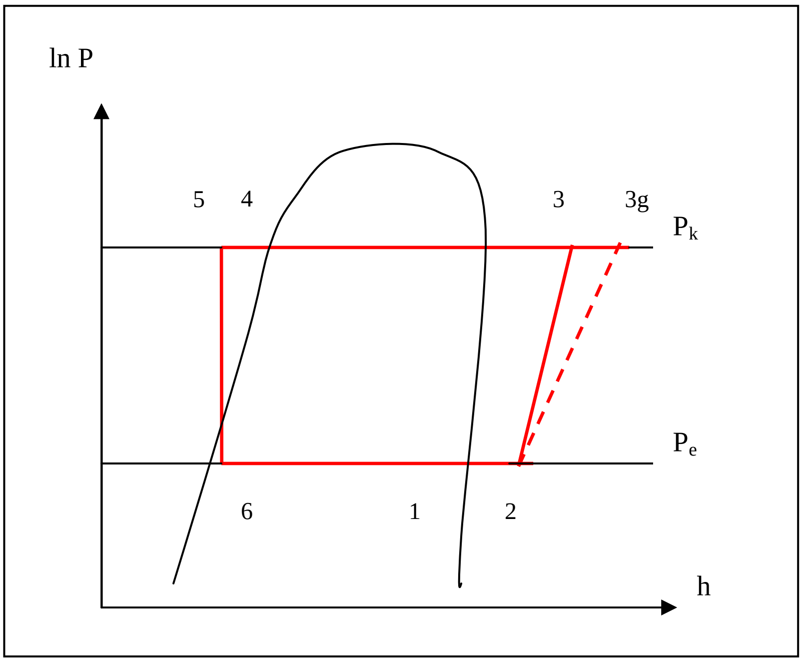


Figure 7. lnP-h diagram of ideal vapor compression cycle by making subcooling and superheating

Table 3: Refrigerant's enthalpy value

| Refrigerants / Enthalpy | R600a | R134a | R290 | R1270 | R32 | R22 | R152a |
|---|---|---|---|---|---|---|---|
| $h_1$ (kj/kg) | 515,21 | 380,32 | 540,22 | 548,17 | 506,27 | 392,69 | 485,55 |
| $h_2$ (kj/kg) | 525,45 | 385,79 | 551,03 | 558,17 | 513,1 | 397,78 | 492,24 |
| $h_3$ (kj/kg) | 618,27 | 439,61 | 653,57 | 664,49 | 613,78 | 457,7 | 578,49 |
| $h_{3g}$ (kj/kg) | 641,475 | 453,065 | 679,205 | 691,07 | 638,95 | 472,68 | 600,0525 |
| $h_4$ (kj/kg) | 297,03 | 256,41 | 307,82 | 305,01 | 275,61 | 249,65 | 271,35 |
| $h_5$ (kj/kg) | 279,34 | 246,07 | 287,71 | 285,3 | 261,01 | 240,45 | 258,32 |
| $h_6$ (kj/kg) | 279,34 | 246,07 | 287,71 | 285,3 | 261,01 | 240,45 | 258,32 |

For the situations that 7 °C of subcooling and 7 °C of superheating has been made, the amount of heat that the evaporator is going to absorb is found out by equation 6.

$$Q_{l2} = m\,(h_2 - h_6), \qquad (6)$$

Taking into account the isentropic efficiency of the compressor, the work expanded by the compressor has been calculated for various refrigerants for the 2nd cooling cycle that has sub cooling and superheating.

$$0{,}8 = (h_2 - h_3) / (h_2 - h_{3g}), \qquad (7)$$

$$W_{comp} = m\,(h_{3g}-h_2)\ \ (kj/s), \qquad (8)$$

Condenser capacity has been calculated at equation 9

$$Q_k = m\,(h_{3g}-h_5), \qquad (9)$$

COP has been calculated at equation 10

$$COP = Q_{l2} / W_{comp}, \qquad (10)$$

Figure 8 shows the COP values for the refrigerants that work within the ideal vapor compression cooling cycle and the comparison of these COP's for the 7 °C subcooling and 7 °C superheating cooling cycle situations.

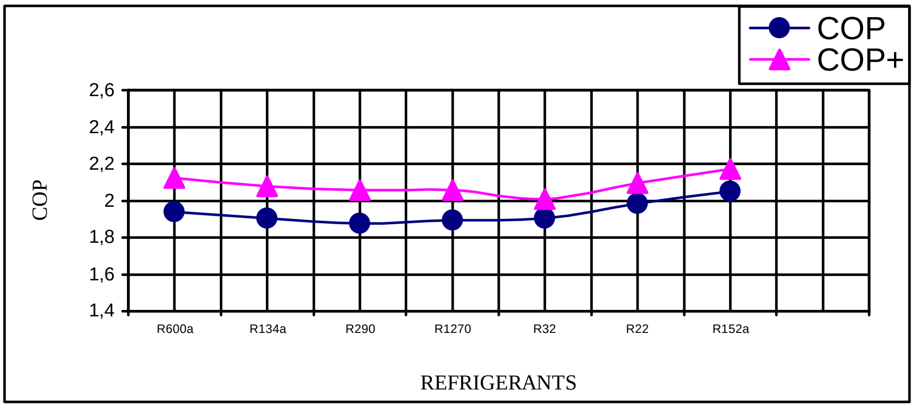


Figure 8 Comparison between COP and COP+.

The increase in the COP has been calculated by applying subcooling and superheating to the vapor compression cooling cycle. The increase rate of the COP's of the refrigerants have been shown to be different. Figure 9 shows the COP increase rates for different refrigerants. According to this, R600 has the greatest increase and R152a has the least.

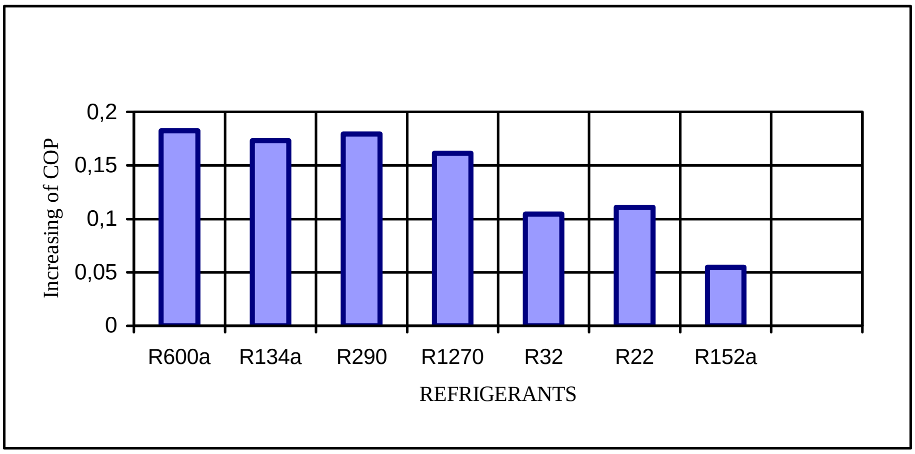


Figure 9. Comparison of COP increase rates of refrigerants by applying subcooling and superheating

## RESULTS

Within this study, the different thermodynamic properties of refrigerants R600a, R134a, R290, R1270, R32, R22 and R152a have been analyzed. And in the modern day world which ozone destruction is very important, it is very interesting to find out that the R152a that belongs to the hydro fluorocarbon (HCF) group has an ozone damage rate of zero-to-none. In addition to this very important feature of it, its effect on the global warming is only 2% of the effect of R12. R152a is an alternative at heating pumps for R12 and R500. It also works well with mineral oils. R152a is not flammable and it is odorless. It shows no poisonous properties. Thus, there is no need for the modification of the compressor in the cycle of the cooling system that this refrigerant is used in. The hydrocarbon based refrigerants used in the study have high flammability and this prevents their fields of use to be limited. Although they can be used on their own, they can also be used as mixtures of each other. Propane-isobutene and propane-butane mixtures can be used as alternatives to R12 in house type cooling systems. They can be used together with oils that could be used together with R12. In addition to the fact that among the hydrocarbons, Propane is cheap and easy-to-obtain, its cooling capacity per volume is around 35-50& higher than R12's, and these facts make this coolant a possible alternative for R12.

Further in this study, the condensation temperature ($T_c$ = 40 °C) has been taken as a constant for 2.2 kW of cooling load and the evaporation temperature ($T_e$) has been changed between -40 °C and -10 °C. It was seen that for all the refrigerants, the mass flow rate and the compressor power increase while the COP values decrease, with increasing evaporation temperatures. It can be concluded that the COP value of R 152a is high for evaporation temperatures below -25 °C and it is advisable to use this refrigerant rather than the others at these temperatures while the COP value of R 600a is high for evaporation temperatures between -25 °C and -10 °C and it is advisable to use this cooling liquid rather than the others at these temperatures.

As a conclusion of the study, the comparison of COP's for the vapor compression cooling cycle situations and the situations that superheating and subcooling have been carried out. It was found out that superheating and subcooling are elements that increase the COP but this increase rate varies depending on the type of refrigerant used. The COP increase for the R600a, R290 and R1270 type refrigerants which belong to the hydrocarbon family is higher. The increase of COP means energy savings. This shows that the hydrocarbons might be the choice for alternative refrigerants in the future.

## REFERENCES

1. ANZECC 1994. Revised strategy for ozone protection on Australia. Australian and New Zelland Environment and Conservation Council Report No: 30, Commonwealth of Australia April p72
2. ASHRAE. 1993. 1993 ASHRAE Handbook Fundamentals, American Society of Heating, Refrigerating, and Airconditioning Engineers, Inc. Atlanta
3. ASHRAE (2001). Designation and Safety Classification of Refrigerants, ANSI /ASHRAE Standard 34-2001"/*ASHRAE*. Atlanta, GA, USA.
4. Pearson S.F. 2003. New, Naturel and Alternative Refrigerants, Policy/Website/Edinburgh 2003/ webpapers/6cpearson.doc
5. Onat A., İmal P., İnan T. 2004. Investigation of effects refrigerants on ozon layer and alternative refrigerants, KSU Journal of Science and Engineering 7(1) pp 32 – 38