Comparison of Performance Parameters of Four Types of Refrigerants

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Abstract. The use of refrigerants requires to meet ecology and legislation requirements. The aim of the legislation is also to reduce the global warming potential (GWP). Natural refrigerants such as carbon dioxide, ammonia, and hydrocarbons such as propane, isobutene, and propylene are used mainly because of their environmental benefits compared to synthetic refrigerants. This work compares two natural refrigerants: R-744 and R-290 and two synthetic refrigerants: R-134a and R-32. All these refrigerants are used mainly in heat pumps. In this work were calculated and compared the following performance parameters: heat rejected in the condenser, cooling power, compressor power, and the coefficient of performance (COP). The most important parameter is the coefficient of performance because when it decreases, electric energy consumption increases. It requires reaching a high value of COP. Further, this work deals with the economic analyses of selected refrigerants. The last aim of this article is their ecologic analysis based on the GWP factor.

Keywords: *refrigerants, heat pumps, global warming potential coefficient of performance*

1 Introduction

Nowadays, the use of refrigerants requires to meet ecology and legislation requirements. Legislative regulations set the use of refrigerants in electrical equipment, heating, and cooling. The use of refrigerants was governed by technical standards, although hazardous refrigerants such as sulphur dioxide, ammonia, and methyl chloride were used. There are already regulations describing the detailed use of individual types of refrigerants. The aim of the legislation is also to reduce the global warming potential (GWP) for all refrigerants. While the GWP in Europe averaged 2000 in 2015, it is currently 900 and is expected to fall to 400 by 2030 [1, 2].

GWP represents the ability to capture heat in the atmosphere or to bounce it back to the earth's surface. Its value determines how many times a given gas contributes more to the greenhouse effect than carbon dioxide. The equation (1) is used to calculate its quantity [3].

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$$GWP_x = \frac{\int_0^{TH} ax.[x(t)]}{\int_0^{TH} ar.[r(t)]} \quad (1)$$

TH is the time horizon over; *ax* is the radiative efficiency, *ar* is the radiative efficiency of the reference sample; *x(t)* is the time-dependent decay in abundance of the substance following an instantaneous release of it at time t=0 and *r(t)* is the time-dependent decay of the reference sample [2, 3].

Refrigerants based mainly on fully halogenated hydrocarbons (CFCs), later partially halogenated hydrocarbons (HCFCs) have been used in the past. Both groups of refrigerants are already banned for environmental protection by reducing emissions. Fluorocarbons and their mixtures are currently used (HFCs). These HFCs have been developed as a replacement for ozone-depleting refrigerants [4]. However, the Europe regulation EU 517/2014 calls for a massive reduction in the consumption of HFCs in Europe. This reduction scheme is known as HFC phase-down [5].

Natural refrigerants such as carbon dioxide, ammonia, and hydrocarbons (propane, isobutene, and propylene) are used mainly because of their environmental benefits. With zero ozone depletion potential (ODP) and very low to zero GWP factor, they are considered a great alternative to synthetic refrigerants because they pollute the atmosphere less [6,7].

In this work were calculated and compared the following parameters of refrigerants used in heat pumps: heat rejected in condenser, cooling power, compressor power and the coefficient of performance. Heat pumps are alternative devices for the production of thermal energy compared to conventional production by the combustion of fossil fuels. The principle of their function is based on the thermodynamic circulation of mechanical cooling equipment [7].

Further, this work deals with the economic analyses of selected refrigerants. The last aim of this article is their ecologic analysis based on the GWP factor.

2 Material and method

As refrigerants were chosen two natural refrigerants (R-744, R-290) and two synthetic refrigerants (R-134a, R-32) described in Table 1. Nowadays, all these refrigerants are used mainly in heat pumps.

Table 1. Refrigerants.

Code	Chemical	Name
R-744	CO_2	Carbon dioxide
R-290	C_3H_8	Propane
R-134a	CH_2FCF_3	1,1,1,2-Tetrafluoroethane
R-32	CH_2F_2	Difluoromethane

Heat rejected in condenser (*Qk*) was calculated according to equation (2), where *Qo* is cooling power and *P* is compressor power [8].

$$Qk = Qo + P \quad (2)$$

Cooling power (*Qo*) was calculated according to equation (3), where *m* is mass flow rate and *qo* is refrigeration duty. Mass flow rate (*m*) is further calculated according to equation (4), where *h1* and *h5* is enthalpy [8].

$$Qo = m.qo \tag{3}$$

$$m = \frac{Qo}{qo} = \frac{Qo}{h1 - h5} \tag{4}$$

Compressor power (*P*) was calculated according to equation (5), where *a* means a difference between enthalpy *h2* and *h1* [8].

$$P = m.a \tag{5}$$

$$a = h2 - h1 \tag{6}$$

The coefficient of performance (*COP*) was calculated according to equation (7) and it is the ratio of cooling power and compressor power [8].

$$COP = \frac{Qo}{P} \tag{7}$$

It is contemplated that all of the selected refrigerants can be used in a single-stage steam circuit shown in Figure 1.

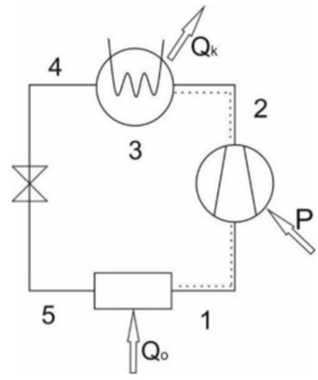

Fig. 1. Single-stage steam circuit [8].

As input parameters were the same temperatures for all calculated refrigerants: evaporation temperature of -6 °C and condensation temperature of 40 °C.

3 Results

Results from the calculation of individual performance parameters of chosen refrigerants are stated in Table 2. The most important calculated parameter is the coefficient of performance with its high value. When COP decreases, electric energy consumption increases. Of the selected refrigerants, R-744 has the lowest value of COP, and R-32 has the highest value of COP.

Table 2. Performance parameters of individual refrigerants**.**

Code of refrigerants	Qk [kW]	P[kW]	COP[-]
R-744	14 169	4 169	2.40
R-290	12 523	2 523	3.96
R-134a	12 474	2 474	4.04

R-32	11 299	1 299	7.70

The comparison of prices for selected refrigerants is shown in Table 3. This comparison was realized for 1 kilogram of refrigerants commonly available in Slovakia. The most economical of the selected refrigerants is the R-744 because the price is around 5 € per 1 kg of refrigerant. R-290 has the second-best price with the price of 10 € per 1 kg of refrigerant. R-134a and R-32 were half as expensive as the previous two refrigerants.

Table 3. The comparison of prices for individual refrigerants**.**

Code of refrigerants	The amount [kg]	Price [€]
R-744	1	5
R-290	1	10
R-134a	1	20
R-32	1	20

Based on the work of Krainer and Duda, the GWP for selected refrigerants is stated in Table 4. According to an ecological point of view, the most environmentally friendly refrigerant is R-744, because its GWP factor has a value of 1. The second most environmentally friendly refrigerant is R-290, where its GWP reaches 3. R-32 has a significantly higher GWP value of 675. R-134a has the highest GWP value of 1430 from all selected refrigerants.

Table 4. The comparison of GWP for individual refrigerants [4].

Code of refrigerants	GWP [-]
R-744	1
R-290	3
R-134a	1430
R-32	675

4 Conclusion

The world's effort is to find a refrigerant with a low value of GWP factor and also ODP factor. Natural refrigerants could be a suitable solution. However, they have a lower cooling factor and thus consume more electricity in the cooling circuits. The calculation compared two natural refrigerants and two synthetic refrigerants. The most ideal refrigerant in terms of price and ecology would be carbon dioxide R-744. However, it has the lowest refrigeration factor of the selected refrigerants. Which means it has the highest energy consumption. Of the selected refrigerants, the suitable refrigerant is propane R-290. Propane is a natural refrigerant with better properties than R-32 and R-134a, and also R-290 has a low GWP factor.

This publication has been produced with the support of the project KEGA No. 021ŽU-4/2021: Primary energy conversion into heat/cold using thermodynamic cycles and compressor cycle with working substance (refrigerant) CO2 and co-financed within the work on the task solved by the UNIVNET association no. 0201/0004/20 supported from the funds of the Ministry of Education, Youth and Sports of the Slovak Republic.

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