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Comparative Performance Analysis of R134a and R290/R600a Refrigerants in a Vapor Compression Refrigeration

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ABSTRACT

Vapor compression technology is used in the majority of space cooling and food refrigeration applications. Refrigerated ships and marine branches, such as merchant, naval, fishing or cruise-shipping are used to transport perishables. This system is running in several situations on R134a, a HFC refrigerant having excellent thermodynamic and thermo-physical properties, but an adverse environmental impact, considering its global warming potential. This paper deals with a theoretical performance study of a vapor compression refrigeration system working with the pure refrigerant R134a and a mixture, R290/R600a (50% / 50%), considering the effect of the main factors that affect the coefficient of performance: interior tube diameters, working pressures and inlet water temperatures. Are highlighted cases in which the performance when using the mixture is higher than the one when using R134a.

1. Introduction

Standards of our present life depend on refrigeration equipment for food preservation or transport and human comfort. Different types of refrigerating systems are met in marine shipboard refrigeration and air conditioning. Vapor compression refrigeration systems with reciprocating compressors are the mainstay of marine refrigeration and air conditioning sector. Clausius statement indicates that energy (heat) will not flow from a cold region to a hot one, without external assistance. The technology used to achieve this result is named “refrigeration unit”. Refrigeration is used to reduce and maintain the temperature of a space or material under the temperature of surroundings. In this respect, the heat is removed from the body needed to be cooled and transferred to other one, whose temperature is under that of the refrigerated body.

Figure 1 shows the main component parts of a typical vapor compression refrigeration plant: compressor, condenser, expansion valve and evaporator.

The refrigerant vapors enter in the compressor with low temperature and pressure where suffer an isentropic compression, resulting high temperature and pressure overheated vapors. In the condenser, they are cooled and condensed resulting high pressure liquid which is then throttled to the evaporator pressure and after that led to absorb heat from the refrigerated space.

The theoretical analysis is developed on the following assumptions:

- steady state operation;
- refrigerant is under saturated vapor state when enters in the compressor;
- no pressure loss occurs in the pipes and valves, pressure changes being met only at the compressor and expansion valve;
- gains and losses of heat are neglected;
- compressor presents ideal volumetric efficiency and ideal isentropic efficiency of 75% (Almeida et al., 2010).

For the cycle analyses are introduces following formula, aiming the evaluation of the performance of refrigeration equipment. (Thangavel et al., 2013) Commonly it is expresses by the Coefficient of Performance (COP).

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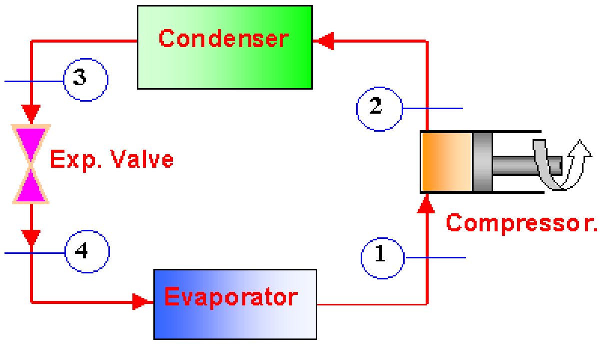
Figure 1: Vapor compression refrigeration system



Source: Author

It will be considered a control volume enclosing the refrigerant side of the evaporator in order to apply conservation of mass and energy for the assessment of the rate of heat transfer per unit mass of refrigerant flow in the evaporator:

$$q_c = \frac{Q_e}{m} = h_1 - h_4 \quad (1)$$

where h is the enthalpy and m is the mass flow rate of the refrigerant and Q_e is amount of heat absorbed in the evaporator.

Applying the conservation of mass and energy rate to a control volume enclosing the compressor, one can get:

$$l_c = \frac{P_c}{m} = h_2 - h_1 \quad (2)$$

where P_c is the power given to the compressor.

For a control volume enclosing the refrigerant side of the condenser, the rate of heat transfer from the refrigerant per unit mass of refrigerant is:

$$q_c = \frac{Q_c}{m} = h_2 - h_3 \quad (3)$$

where Q_c is the amount of heat rejected in the condenser.

During the throttling process, the enthalpy remains constant, so:

$$h_4 = h_3 \quad (4)$$

The Coefficient of Performance is the measure of performance of the refrigeration cycle, on the first law of thermodynamics basis; it is the refrigerating effect produced per unit of work required (Bolaji et al., 2011).

$$COP = \frac{Q_e}{P_c} = \frac{h_1 - h_4}{h_2 - h_1} \quad (5)$$

The refrigerant must carry away from the evaporator the heat it has absorbed. The refrigerant R134a presents a quite high global warming potential, in the near future its production and use being under the sign of restriction.

This paper deals with a comparative analysis of the performance of a vapor compression refrigeration cycle working with R134a and an ecologic mixture of R290 and R600a (50% / 50%) , on theoretical basis. It will be assessed the influence of working parameters on the COP values. The performance of the system considered depends on capillary tube diameters, working pressures and inlet water temperatures (Agrawal et al., 2013).

Table 1: Estimates for consumption of R134a, in k tones

Year	Consumption
1997	69
1998	79
2000	99
2005	128
2010	154
2015	174

Source: Author

2. The Need of Change

Refrigerants are used to transport heat between the interior and exterior of a refrigeration system.

In the past, HCFC refrigerants were wide spread, but in the 1980's, specialists indicated them as ozone depleting substances; as a result, under the Montreal Protocol, developed countries agreed to fully phase-out their production by 2020. Thus, efforts were directed towards developing refrigerants having null ozone depletion potential. In this framework, refrigeration industry is phasing-out conventional HCFC refrigerants and switching to HFC.

HFC refrigerants contain Hydrogen, Fluorine and Carbon and they do not contain ozone depleting Chlorine. Even if HFCs do not deplete the ozone layer, they are extremely potent greenhouse gases, some of them even more powerful than CFCs. There is currently no international agreement to phase them out. They are included in the United Nations Framework Convention on Climate Change (UNFCC) basket of controlled gases.

According to the Kyoto Protocol, worldwide governments are voluntarily committed to reduce the greenhouse gas emission to the atmosphere, fact that led investigations to identify long-term energy-efficient and environment-friendly alternative to HFC 134a (R134a) (Mohanraj et al., 2008), since this refrigerant is one of the most strong representative of HFCs if we rely on data indicating its consumption (Boumaza, 2007), as seen in Table 1.

In E.U., Hydrocarbons (HCs) are considered to be the suitable substitutes for HFCFs (Matsunaga, 2002). These refrigerants are environmentally friendly and show features which make them attractive for the refrigeration sector.

Moreover, HCs have good physical and thermodynamic properties, present material capability, are not expensive and are safe in operation. Some useful properties of the refrigerants involved in the study are given in Table 2.

Table 2: Thermo-physical properties of R134a, R290 and R600a

Refrigerant	R134a	R290	R600a
Class	HFC	HC	HC
Molecular Mass (g/mol)	102,03	44,10	58,12
Critical Temperature (^oC)	101,1	96,7	134,7
Critical Pressure (MPa)	4,06	4,25	3,67
ODP	0	0	0
GWP (years)	16	< 1	< 1

Source: Author

3. COP Assessment According to the Influence of Working Parameters

The performance expressed by COP is analyzed when factors affecting this value are varying.

Thus, are considered three levels for the refrigerant pressure ($4,82 \cdot 10^5$ Pa; $5,17 \cdot 10^5$ Pa; $5,51 \cdot 10^5$ Pa), inlet water temperatures ($20^oC, 28^oC, 38^oC$) and interior diameters (0,09 cm, 0,11 cm, 0,13 cm).

For the lowest pressure value considered ($p = 4,82 \cdot 10^5$ Pa) (see table 3), when using the mixture as a refrigerant in the system COP value is close or even higher to the one of R134a for the bigger interior diameter considered ($d = 0,13$ cm) and for the highest level of inlet water temperature (38^oC).

When increasing the refrigerant pressure till ($p = 5,17 \cdot 10^5$ Pa) (see table 4), when using the mixture COP value is same to the one of R134a for the bigger interior diameter ($d = 0,13$ cm) and the lower temperature considered (20^oC).

For the higher pressure value considered ($p = 5,51 \cdot 10^5$ Pa) (see table 5), COP value resulted for the mixture is higher than the one for R134a when inlet water temperature is 20^oC and for all three diameters, while if increasing this temperature, COPR290/R600a is higher only for the bigger interior diameter ($d = 0,13$ cm).

4. Conclusions

The performance of a vapor compression refrigeration system was analyzed in this paper because this is the most common Was discussed the effect of refrigerant type and values of working parameters such as refrigerant pressure, inlet water temperature and interior diameter, on COP.

Because of the high GWP of R134a, a refrigerant mixture of R290/R600a (50/50%) is seen as an alternative. From environmental data point of view, the substitution is justified because this mixture has a zero ODP and a negligible GWP.

Most of the results showed that COP has better values when R134a is the working fluid.

Still, in some situations, the mixture leads to an improved COP, such is the case of $p = 5,51 \cdot 10^5$ Pa, when it is found also the best COP value of the analysis: $COP_{R290/R600a} = 1,55$ when $t = 20^oC$ and $d = 0,11$ cm.

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Table 3: Inlet water temperature and pressure influence on COP for $p = 4,82 \cdot 10^5$ Pa

$p = 4{,}82 \cdot 10^5$ Pa									
	t = 20ºC			t = 28ºC			t = 38ºC		
d [cm]	0,09	0,11	0,13	0,09	0,11	0,13	0,09	0,11	0,13
COP_{R134a}	1,38	1,38	1,38	1,48	1,49	1,39	1,29	1,30	1,44
$COP_{R290/R600a}$	1,02	1,02	1,21	1,10	1,00	1,38	1,19	1,11	1,52

Source: Author

Table 4: Inlet water temperature and pressure influence on COP for $p = 5,17 \cdot 10^5$ Pa

$p = 5{,}17 \cdot 10^5$ Pa									
	t = 20ºC			t = 28ºC			t = 38ºC		
d [cm]	0,09	0,11	0,13	0,09	0,11	0,13	0,09	0,11	0,13
COP_{R134a}	1,37	1,71	1,36	1,28	1,15	1,38	1,37	1,04	1,37
$COP_{R290/R600a}$	1,09	1,00	1,36	1,11	1,04	1,27	1,13	1,00	1,30

Source: Author

Table 5:Inlet water temperature and pressure influence on COP for $p = 5,51 \cdot 10^5$ Pa

$p = 5{,}51 \cdot 10^5$ Pa									
	t = 20ºC			t = 28ºC			t = 38ºC		
d [cm]	0,09	0,11	0,13	0,09	0,11	0,13	0,09	0,11	0,13
COP_{R134a}	1,53	1,21	1,12	1,38	1,28	1,13	1,44	1,29	1,23
$COP_{R290/R600a}$	1,53	1,55	1,37	1,13	1,07	1,27	1,18	1,16	1,38

Source: Author