JOURNAL OF MARITIME RESEARCH

Vol XI. No. III (2014) pp 83–87

ISSN: 1697-4040, www.jmr.unican.es

A Performance Analysis on a Vapor Compression Refrigeration System Generated by the Replacement of R134a

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ARTICLE INFO

Article history:
Received 26 November 2014;
in revised form 28 November 2014;
accepted 17 December 2014.

Keywords:
Global Warming Potential,
Performance, Evaporation Temperature

ABSTRACT

Vapor compression refrigeration is commonly used on board the ships, R134a being one of the most spread refrigerant in this type of systems. In this work, a performance analysis of a vapor compression refrigeration cycle working with R134a and RE170 was carried out. The motivation of this comparison is based on the efforts done to solve the problem of high GWP of R134a, since RE170 shows a significantly lower one.

The study is developed on the analysis of the effect of evaporation pressure on some of important factors which should be considered in the selection of a new refrigerant: evaporation pressure, pressure ratio, Coefficient of Performance, power per ton of refrigeration, volumetric cooling capacity. The evaporation temperature will vary in the range $(-20, +10)^{o}C$ and the condensation temperature is kept constant, at $45^{o}C$. Since cycle performance can be improved by superheating and sub cooling inclusion, these two processes were considered in the cycle.

Comparative results show that RE170 could replace R134a, due to its low evaporation pressure and pressure ratio and also to its better COP and similar volumetric cooling capacity.

1. Introduction

Refrigeration is a technology used to cool goods, which is based on continuous cyclic extraction of heat from a low temperature reservoir and the release of heat to a high temperature reservoir, at the expense of work input. It is used for long term storage or transport of perishables, in ice making and many different other industrial processes.

Chemicals as CFCs and HCFCs have been main refrigerants used in refrigeration and air conditioning on board the ships, but now are banned – as a result of international concern and regulations, because of their negative impact on the environment. Thus, the ozone depleting potential (ODP) and global warming (GWP), which are the indicators of the action of refrigerants on the environment, became lately important requirements in assessing and choosing a refrigerant.

HFCs have been seen as the main potential substitutes of CFCs and HCFCs, since they have no chlorine content.

In this respect, they show a null ODP, but a quite high GWP because of the presence of fluorine atoms in the chemical formula. Their GWP is lower than CFCs, but higher than HCs – the refrigerants which might replace HFCs in the future.

For the moment, HFCs are among the six target greenhouse gases under Kyoto Protocol of United Nations framework convention on climate change, held in 1997 (Baskaran and Mathews, 2010).

The vapor compression refrigeration cycle is the most spread cycle for refrigerators, air conditioning or heat pumps, most of refrigeration systems on board the ship using reciprocating compressors (Harbach, 2005). R134a is a refrigerant belonging to HFC family and it is one of the most commonly used refrigerants in marine vapor compression refrigeration. Because of the international concern resulted from its quite high GWP, some of the European countries decided to eliminate it already, in the future its production and use being canceled (Bolaji et al, 2011).

In this respect, efforts are oriented toward investigations having as goal the identification of low GWP refrigerants for

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Table 1. Comparing properties of the studied refrigerants

Refrigerant	R134a	RE170
Chemical composition	CH_2FCF_3	CH_3OCH_3
Molecular weight (g/mol)	102.03	46.07
Critical temperature (°C)	101.06	127.23
Critical pressure (MPa)	4059	5.34
Normal boiling point (°C)	–26.07	–24.78
Safety class	A1	A3
Lower flammability limit	none	3.3
ODP	0	0
GWP	1300	3

Source: Author

future vapor compression refrigeration systems.

This study is a theoretical comparative investigation of a vapor compression refrigeration cycle working with R134a and an eco-friendly HC, namely RE170, which will supply some information on the performance of such a system. The evaporation temperature (t_o) will vary and the condensation temperature (t_c) will be kept constant. The cooling capacity (Q_o) will be given and the ideal cycle will be considered in the case in which superheating and sub cooling take place.

Table 1 shows some features of these two refrigerants, being obvious the environmentally behavior of RE170 (Bolaji and Huan, 2012).

2. Methods and Materials

Since the effect of superheating and sub cooling taking place in vapor compression refrigeration systems is found in the improvement of performance coefficient values, the refrigeration cycle analyzed is the one shown in Figure 1 (Paharia and Gupta, 2013).

The studied cycle is composed by an adiabatic, isentropic compression, followed by an isobaric superheating, after which occurs the condensation at constant pressure and temperature; the sub cooled liquid refrigerant is expanded at constant enthalpy in order to reach the lower pressure from the evaporator; it will take place, after that, the evaporation – also at constant pressure and temperature.

For the development of the theoretical study, the following assumptions have been done:

- in all components steady state operations are considered
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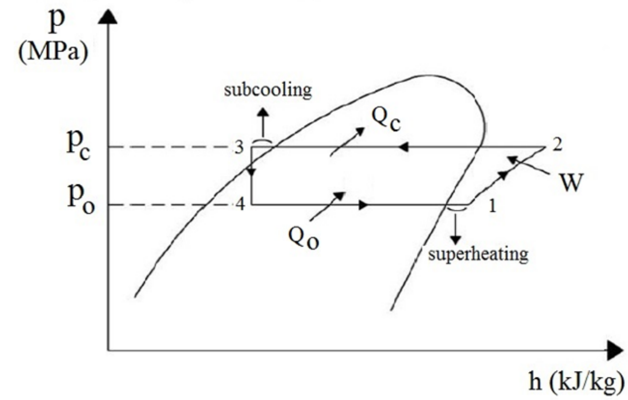
figure 1. Conventional vapor compression refrigeration cycle, with superheating and sub cooling



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- there are no pressure losses in pipes
- gains or losses of heat are neglected
- compressor has ideal isentropic efficiency
- cooling capacity: $1000W$
- evaporation temperature: $(-20, +10)^oC$
- condensation temperature: 45^oC
- superheating and sub cooling: 5^oC / 5^oC.

The equations related with the study of this cycle are revealed based on mass and energy conservation (Almeida et al, 2010, Ramu et al, 2014).

The volumetric cooling capacity (VCC) is a factor which influences the size of the compressor for specific working conditions; it is a significant factor when selecting a substitute for an old refrigerant:

$$VCC = \frac{Q_0}{m_r \cdot v_1}\mu_v \quad (1)$$

where

Q_0 cooling effect,

m_r refrigerant mass flow,

v_1 specific volume at compressor inlet,

μ_v volumetric efficiency.

The pressure ratio (δ) is a significant factor considered for choosing a new refrigerant; it is given by the rate between the condensation pressure (p_c) and the evaporation pressure (p_o). Thus:

$$\beta = \frac{p_c}{p_o} \quad (2)$$

The Coefficient of Performance is the measure of the performance of the vapor compression system, based on the energy analysis, and it is defined as the ratio between the cooling effect and the work done by the compressor:

$$COP = \frac{Q_o}{P_c} \quad (3)$$

The cooling effect, or the heat transfer rate of the evaporator is expressed by:

$$Q_o = m_r\,(h_1 - h_4) \quad (4)$$

In the above equation, h is the specific enthalpy of the refrigerant. The compressor power consumption is found with:

$$W = m_r\,(h_2 - h_1) \quad (5)$$

The refrigerant mass flow rate is assessed with:

$$m_r = \frac{Q_o}{q_o} \quad (6)$$

in which qo is the specific cooling capacity.

The volumetric efficiency is calculated with:

$$\mu_v = 1 + C - C\left(\frac{v_1}{v_2}\right) \quad (7)$$

where

v_2 specific volume at compressor exit,

C clearance ratio,

$C = V_c/V_{st}$,

V_c clearance volume,

V_{st} stork volume.

The cooling effect produced is assessed by the help of tons of refrigeration (TR).

The power per ton of refrigeration (PTR) is other indicator of the efficiency of a refrigeration system

$$PTR = 3.5W/Q_o \quad (8)$$

3. Results and Discussion

Figure 2 indicates how affects the variation of the evaporation temperature the evaporation pressure.

The evaporation pressure should be positive and close to the atmospheric one, in order to avoid entry of air and moisture into the system. Also, this pressure should not be too low, because if it is, it would result a large volume of suction vapor. The evaporation pressure should not be too high, because if it is, will be required a heavier construction, with higher prices of the system.

The analyze of the above mentioned dependency show that evaporation pressure of RE170 is comparable with the one of R134a, slightly lower.

Figure 3 shows the effect of evaporation temperature on the pressure ratio; the power consumption is proportional with the

Figure 2. Relationship between evaporating temperature and evaporating pressure

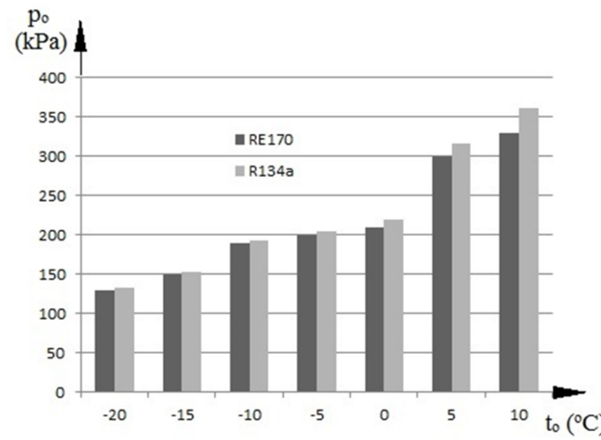

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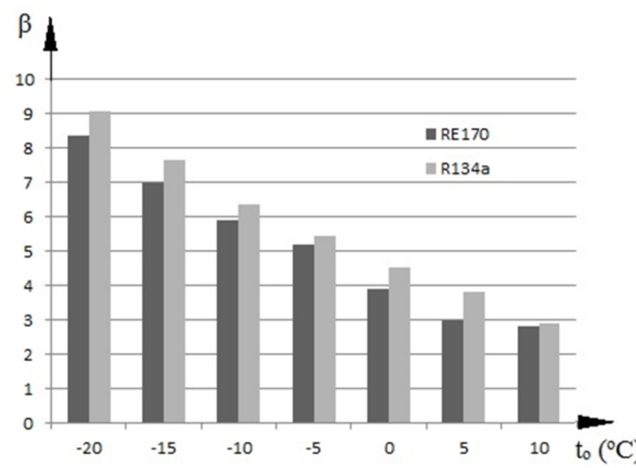
Figure 3. Effect of evaporating temperature on pressure ratio



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pressure ratio. Thus, low pressure ratio leads to efficiency improvement by diminishing the power consumption to the compressor. Low values of pressure ratio are benefic for compressor life.

The analyze of this relationship shows that pressure ratio decreases with the increase of the evaporation temperature.

Refrigerant RE170 offers lower values for the pressure ratio than R134a.

In Figures 4 and 5 are illustrated the variations of Coefficient of Performance and power per ton of refrigeration with evaporating temperature.

While the Coefficient of Performance is increasing together with the increase of the evaporating temperature, power per ton of refrigeration is decreasing.

A performance improvement is seen in the case of using RE170 as the working refrigerant.

The influence of the evaporating temperature on the volumetric cooling capacity is shown in Figure 6.

The analyze of this influence reveals that volumetric cool-

Figure 4. Effect of evaporating temperature on Coefficient of Performance

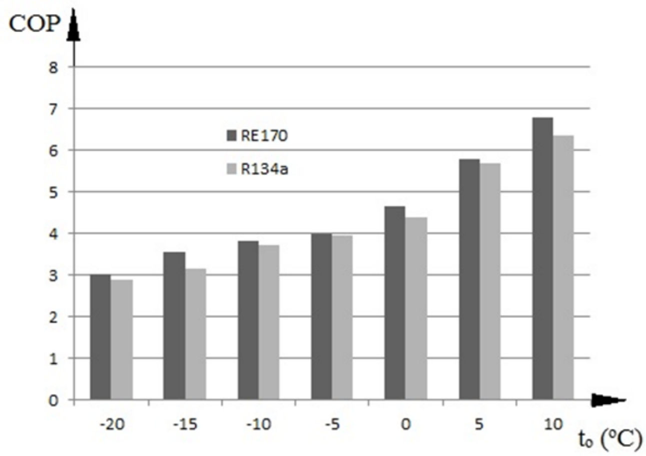

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Figure 5. Effect of evaporating temperature on power per ton of refrigeration

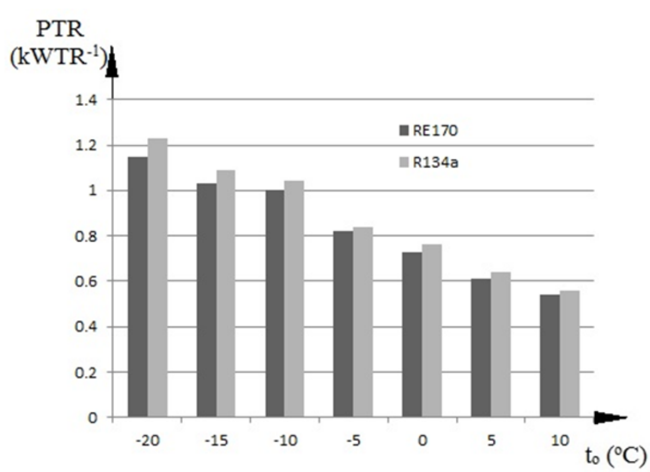

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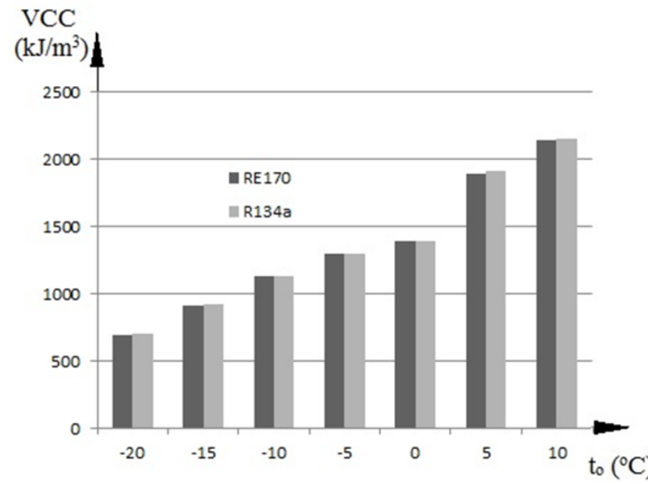
Figure 6. Effect of evaporating temperature on volumetric cooling capacity



Source: Author

ing capacity values increase with the increase of evaporation temperature. As the volumetric cooling capacity increases, the requirement is for small size compressor.

Refrigerant RE170 shows slightly lower volumetric cooling capacity values, but still comparable with the ones of R134a.

4. Conclusions

The major problem associated with R134a is its GWP, which will lead to its phase–out in refrigeration.

The theoretical study developed for a vapor compression system working with R134a and RE170 revealed the following results:

- RE170 offers better environmental properties than R134a,
- the evaporation pressures for RE170 are comparable, slightly lower to the ones for R134a,
- the pressure ratio is decreasing with increase of the evaporation temperature; RE170 offers lower values for the pressure ratio than R134a,
- the Coefficient of Performance is increasing together with the increase of the evaporating temperature; better COP values are found for RE170,
- volumetric cooling capacity is increasing with the increase of the evaporating temperature; RE170 shows similar values as R134a, slightly lower,
- RE170 might be accepted as a substitute of R134a, since it shows comparable values for volumetric cooling capacity and better COP values.

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