Journal of Marine Technology and Environment
DOI: 10.53464/JMTE.01.2023.10
ISSN (Print): 1844-6116
ISSN (Online): 2501-8795
https://www. jmte.eu

AN ATTEMPT TO IMPROVE ENERGY EFFICIENCY OF VAPOUR COMPRESSION REFRIGERATION ON SYSTEMS WORKING WITH R134a

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Abstract: Refrigeration is an industry of high importance in our modern times. It plays also a key role in maritime transport of perishables, where vapour compression refrigeration systems are dominant. These energy systems are indispensable, but they should be wise exploited because their high energy necessity. One of the frequent refrigerant chemical adopted in this system is the hydrofluorocarbon R134a. This refrigerant came to substitute traditional refrigerants, such as chlorofluorocarbons or hydro chlorofluorocarbons – substances being under environmental regulations. In this study, it is approached a single stage vapour compression refrigeration system working with R134a. The aim is to find the conditions in which this system is more energy efficient. In this respect, based on the laws of thermodynamics, are obtained information on Coefficient of Performance and energy destruction trends – when the evaporator temperature increases. Our results indicate that, although the analysis based on the first law of thermodynamics reveals that the performance of the system is higher for high evaporator temperatures, the energy destructions in this system increase together with the evaporator temperature increase.
Key words: vapour compression refrigeration, performance, exergy, evaporator temperature.

1. INTRODUCTION

Vapour compression refrigeration systems (VCRSs) are energy systems playing a key role in cooling and preservation, while consuming high amounts on energy; in this respect, energy efficiency when using these systems in of high importance [1].

On board the ships, VCRSs are able to keep a constant temperature while transporting chilled or frozen goods [2].

Energy efficiency aspect is not the only research direction; the environmental aspect of the use of these systems is also a topic to be considered. Despite the advantages shown by the refrigerants belonging to chlorofluorocarbons (CFCs), such as good thermo physical behaviour and chemical stability, these working fluids were banned because of the chlorine release; after signing the Montreal Protocol (1987), ozone depleting substances are under regulations and Hydrofluorocarbons (HFCs) are now in use [3].

Marine refrigeration, as any other refrigeration sector, deals with ozone layer protection and global warming; this means that refrigerants on board the ships have not to be harmful for the ozone layer (ODP=0) and to have a low contribution to the global warming (low value of its GWP) [4].

Since the role of VCRSs is to remove heat from a zone with a lower temperature to another one, with a higher temperature, these systems needs four main elements: compressor, condenser, expansion valve and evaporator, the closed cycle being shown in Figure 1. Here can be observed the following processes: isentropic compression of vapours, cooling and condensation of saturated vapours – with heat rejection, isenthalpic expansion of saturated liquid, evaporation of vapour-liquid mixture – with heat absorption [5], [6].

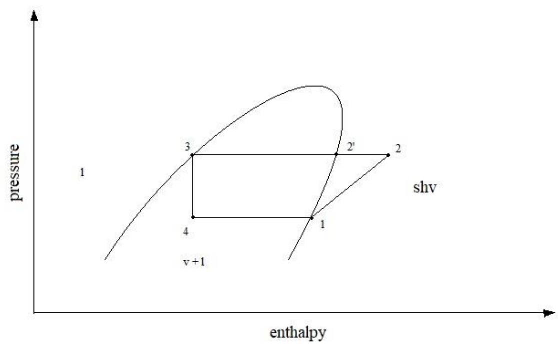

Figure 1 VCRS cycle without super heating and sub cooling [5]

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The processes taking place in each main part of the plant are given below:

1-2 – in the hermetic compressor – reciprocating type,
2-2'-3 – in the condenser,
3-4 – in the expansion valve,
4-1 – in the evaporator.

The evaporator and the condenser are two heat exchangers, in which the refrigerant changes its phase with heat absorption (evaporator) and heat remove (condenser).

The compressor is able to increase both pressure and temperature – with work consumption.

The expansion valve is able to decrease pressure, being also seen as a control valve of the refrigerant flow.

The refrigerant selected for this study is R134a, a HFC often used in VCRSs met on board the ships. R134a is in A1 safety group and it is also known as 1,1,1,2 – tetrafluoroethane.

Some of its properties are provided below [7]:
ODP=0
GWP_{100}=1430
molecular mass = 102 g/mol
critical temperature = 374, 2 K
critical pressure = 4, 06 MPa.

R134a is not toxic or flammable and also it is not corrosive.

It has a high heat of vaporization and a medium density value in liquid form.

This paper deals with a theoretical analysis of a VCRS with no superheating and no sub cooling.

The thermodynamic analysis is based on both first and second laws of thermodynamics, in order to get a realistic image when energy efficiency is aimed.

2. METHODS AND MATERIALS

Any theoretical assessment of VCRSs is based upon the following assumptions: [8]

- the operation is according to steady state regime;
- R134a in saturated vapour state enters in the compressor;
- pressure losses are neglected in pipes and valves;
- heat gains and heat losses are also neglected;
- theoretical isentropic efficiency of the compressor is 75%.

The classical thermodynamic analysis was initially developed only on the first law of thermodynamics. According to this law, which is the law of energy conservation, it is not possible to be aware about the energy degradation in a refrigeration system.

In order to have information on energy losses, it is compulsory to apply exergy analysis [9].

When applying the first law of thermodynamics, it is possible to find only one indicator of performance: the Coefficient of Performance (COP). By applying the exergy analysis, one can find the energy losses in the components of the system and the total energy loss. Exergy is a concept introduced by the second law of thermodynamics; it gives the measure of the useful energy.

The necessity of this approach derives from the fact that all the real processes are irreversible. The irreversibilities encountered in refrigeration cycles have the following causes [10]:

- friction;
- heat transfer through finite temperature difference;
- super heating and sub cooling;
- pressure drops;
- heat gains.

The aimed results will be obtained by applying the following mathematical modelling [11]:

Heat absorbed in the evaporator:

$$Q_e = m_r(h_1 - h_4) \quad , \tag{1}$$

where:
m_r – mass of refrigerant, kg.;
h - enthalpy, kJ/kg;

Heat evacuated at the condenser:

$$Q_c = m_r(h_2 - h_3) \quad . \tag{2}$$

Work consumption at the compressor:

$$W_{cp} = m_r(h_2 - h_1) \quad . \tag{3}$$

Exergy loss in the evaporator:

$$I_{lv} = m_r[(h_4 - h_1) - T_0(s_4 - s_1)] + Q_e\left(1 - \frac{T_0}{T_e}\right) , \tag{4}$$

where:

s – entropy, ky/(kgK);
T_0 – ambient temperature, K;
T_e – evaporator temperature, K;

Exergy loss in the condenser:

$$I_{lc} = m_r[(h_2 - h_3) - T_0(s_2 - s_3)] - Q_c\left(1 - \frac{T_0}{T_c}\right), \tag{5}$$

where:

T_c – condenser temperature;

Exergy loss in the compressor:

$$I_{lcp} = m_r[(h_1 - h_2) - T_0(s_1 - s_2)] + W_{el} \tag{6}$$

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where:

W_{el} – electrical work done, kJ/kg.

Exergy loss in the expansion valve:

$$I_{\overline{lexv}} = m_r(s_4 - s_3) \quad . \quad \textbf{(7)}$$

Coefficient of Performance:

$$COP = \frac{Q_e}{W_{el}} \quad . \quad (8)$$

Total exergy loss:

$$I_{lT} = I_{le} + I_{lc} + I_{lcp} + I_{lexv} \quad . \quad (9)$$

3. RESULTS AND DISCUSSIONS

The following results are obtained based on the below provided input data:

- condenser temperature: 15^0C;
- electrical efficiency: 75%;
- ambient temperature: 27^0C;
- R134a mass flow rate: 1 kg/s.

The evaporator temperature will vary in the range $(-10 \div -2)\ ^0$C.

In Figures 2 and 3 are depicted the influences of evaporator temperature increment on the Coefficient of Performance and on the total exergy loss.

From these representations it is obvious that evaporator temperature influences the indicators of performance of the analysed cycle.

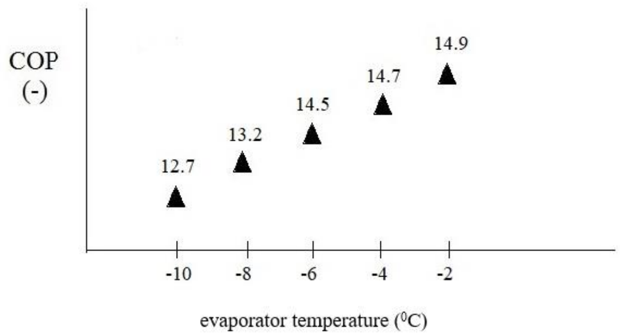

Figure 2. COP versus evaporator temperature

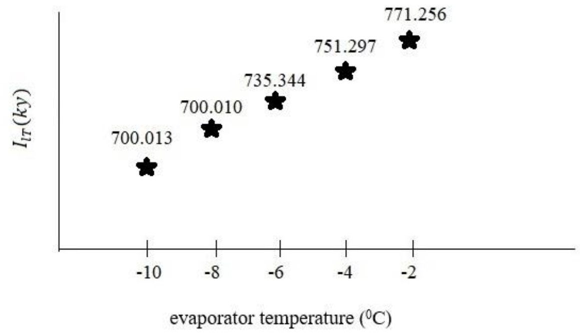

Figure 3 Total exergy loss versus evaporator temperature

The increase in the evaporator temperature leads to a better first law of thermodynamics efficiency (COP), but also to more important energy degradation.

When evaporating R134a at the highest considered temperature (-2^0C), the Coefficient of Performance increases around 17%, but the energy degradation will also increase, with about 10%.

4. CONCLUSIONS

Marine refrigeration should be subject of energy efficiency improvement, especially in the present context.

First and second laws of thermodynamics are the main tools used in this thermodynamically approach.

Our theoretical thermodynamic study focused on a VCRS with no super heating and no sub cooling.

From this research results that evaporator temperature influences the values of the Coefficient of Performance and of the total exergy loss in the system. The increase of the evaporator temperature is found in the increase of the above-mentioned performance indicators. The analysis based exclusively on the first law of thermodynamics is not a realistic one, being needed also the application of the second law of thermodynamics.

The obtained results have shown that exergy analysis is an important tool when it is aimed the energy efficiency increase by diminishing the inefficiency in the refrigeration system.

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