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ASSESSMENT OF THE PERFORMANCE A VAPOUR COMPORESSION. REFRIGERATION CYCLE WORKING WITH AMMONIA

Ionela Ticu [1], Elena Gogu [2]

[1]Constanta Maritime University, Faculty of Naval Electro-Mechanics, 104 Mircea cel Batran Street, 900663, Constanta, Romania, e-mail address: ionela.ticu@yahoo.com
[2] Gheorghe Duca" Technological High School, Vifor Haiducul Street, No 34, Constanta, Romania, e-mail address: goguelena@yahoo.com

Abstract: This paper is a part of the efforts done in order to analyse the performance of vapour compression refrigeration cycles. These technologies are used with a high rate in marine refrigeration and are responsible for important amounts of energy consumptions. The obtained results are indicating the fact that the performance of the cycle is decreased when increasing the condensation temperature and keeping constant the evaporation temperature. Gains in the performance are obtained when degrees of superheating and sub cooling are increased, resulting that the cycle with superheating and sub cooling is superior to the one without these two processes. Ammonia or (R717) is a refrigerant often used on board the ships due to its very good thermodynamic properties. Moreover, the concern regarding the environment and the fact that ammonia is a natural refrigerant, offers to this refrigerant the chance to be adopted in the future plants, on board of new ships. The performance of an ammonia based cycle is discussed in terms of coefficient of performance (COP) and exergy efficiency, the theory of the first and second laws of thermodynamics being fundamental.
Key words: ammonia, cycle, performance, superheating, sub cooling, consumption.

1. INTRODUCTION

Present time refrigeration is, as all other sectors, under the sign of global warming concern and environment protection actions. Expected solutions aim the exploitation of refrigeration systems with no impact on the ozone layer, low contribution to global warming and low energy consumption.

Single or two stage vapour compression refrigeration systems are usually met on board of ships, in order to transport perishables goods overseas or to ensure thermal comfort for crew and passengers [13].

Environmental impacts of refrigerants are given by ODP – measuring the depletion of the ozone layer by some chemical constituents of the refrigerants and by GWP – measuring the global warming effect of the gases [2].

The Montreal Protocol and the amendments that have followed and the Kyoto Protocol as well, forced the replacement of CFCs (chlorofluorocarbons) and of HCFCs (hydrofluorocarbons), with refrigerant presenting null ODP and, even more, with natural refrigerants (such as ammonia) [3].

Natural refrigerants, with a long history in mechanical refrigeration, which were ignored lately because of their toxicity and flammability, are reconsidered, now, on environmental and energetic considerations [4].

Ammonia, or R717, is an attractive solution for vapour compression systems on board, due to its null ODP and GWP, but also to its very good thermodynamic properties [5].

The performance of a single stage vapour compression refrigeration cycle working with ammonia was analysed in terms of COP (Coefficient of Performance) and exergy efficiency.

The theoretical analysis is carried out by considering and by not considering superheating and sub cooling, for a better understanding of the energy efficiency concept.

2. THE CONSIDERED SYSTEM

The main processes encountered in vapour compression refrigeration cycles are: compression, condensation (followed or not by sub cooling), expansion and evaporation (followed or not by superheating), so that the cycle without sub cooling and superheating is as seen in Figure 1.

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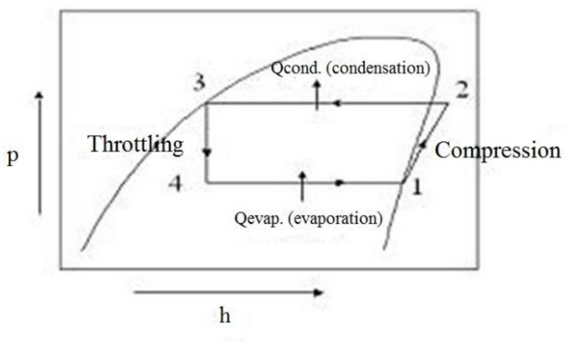

Figure 1 Vapour compression refrigeration cycle without sub cooling and superheating in (p-h) diagram.

The refrigerant, ammonia in our case, changes its phase in the evaporator (where removes heat from the chilled medium) and in the condenser (where releases heat to the environment); vapour refrigerants are compressed in the compressor (with energy consumption) and the refrigerant in liquid state is expanded in the throttling valve [6].
The evaporation and condensation processes occur at constant pressures and temperatures, the lowest pressure and temperature being met during evaporation. Vapours leaving the evaporator can be superheated and liquid produced in the condenser can be subcooled.

The compression process is adiabatic. Before being condensed, superheated vapours are cooled isobaric. Also, sub cooling of the liquid refrigerant is an isobaric process. Expansion occurs isenthalpic and is used to reduce the pressure of the refrigerant.

3. THERMODYNAMIC ANALYS

The performance of the refrigeration cycle is expressed through out COP (Coefficient of Performance) and exergy efficiency, by applying the first and second laws of thermodynamics; COP assessment is based on conservation of energy principle, while exergy efficiency is based on energy degradation law and it considers the irreversibilities of processes [7].

Performance found in COP term is a traditional analysis, COP being the rate between heat absorbed by the refrigerant in the evaporator and the work consumed by the compressor.

Due to the fact that all processes are irreversible and the quality of the energy is degraded, the performance assessment should be oriented towards the irreversibility estimation by applying exergy analysis.

Exergy is the part of energy that can be transformed in any other type of energy.

Such an approach focuses on exergy destruction diminishment, these destructions being caused by irreversibilities.

The equations used in such a type of performance analysis are provided bellow [8], [9], [10].

Specific work consumed in the compressor (w_c), specific thermal load of the condenser (q_{cond}), specific refrigeration load (q_{evap}) are given by specific enthalpies variations:

$$w_c = \Delta h_e \quad (1)$$

$$q_{cond} = \Delta h_{cond} \quad (2)$$

$$q_{evap} = \Delta h_{evap} \quad (3)$$

where:
h – enthalpy
The performance indicators are found as:

$$cop = \frac{q_{evap}}{w_c} \quad (4)$$

$$\eta_{ex} = \frac{Ex_{des.evap}}{W_c} \quad (5)$$

where:
η_{ex} – exergy efficiency
$Ex_{des.evap}$ – exergy destruction in the evaporator.
Generally, exergy destruction is calculated with:

$$Ex_{des} = W_{c\,rev.out} - W_{c\,out} \quad (6)$$

where:
W_{rev} – the reversible work.

4. RESULTS AND DISCUSSION

The analysis is developed by considering two situations: cycle without sub cooling of condensate ammonia and superheated of ammonia vapours and cycle with sub cooling and superheating.

In the first situation, the condensation temperature varies between $(30 \div 60)^{\circ}C$, while the evaporation temperature is kept constant (at $-40^{\circ}C$).

In the second situation, the condensation temperature is constant $(55^{\circ}C)$.

In Figures 2 and 3 are given COP and exergy efficiency values obtained when the condensation temperature varies.

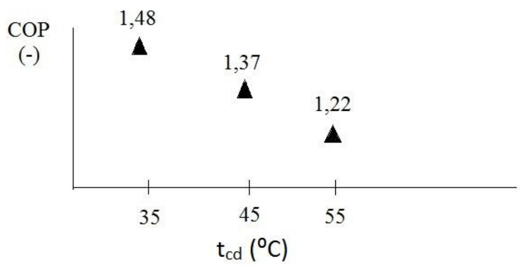

Figure 2 COP versus condensation temperature (evaporation temperature is kept constant)

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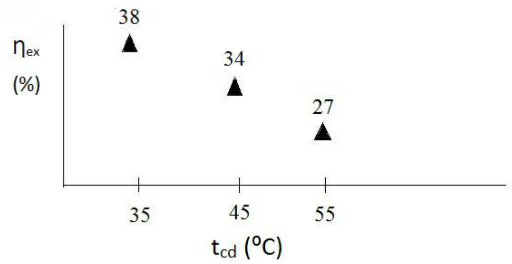

Figure 3 Exergy efficiency versus condensation temperature (evaporation temperature is kept constant)

The performance of the cycle decreases with the increase of the condensation temperature, because of the fact that the difference between the evaporation pressure and the condensation pressure increases, leading to a higher energy consumption at the compressor.

In the next two figures, it is revealed the change in the performance, when the superheating degree varies.

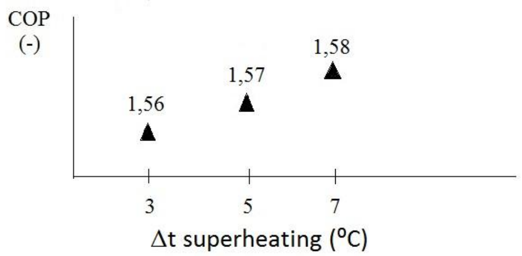

Figure 4 COP versus superheating degree

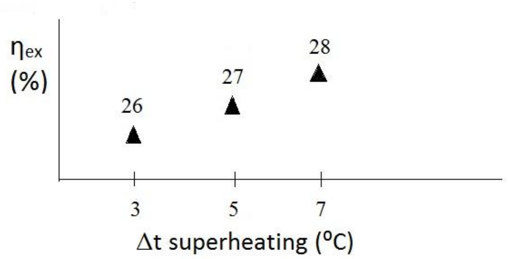

Figure 5 Exergy efficiency versus superheating degree

It is seen that superheating increase has a benefit influence on the performance of the cycle.

Same result it is obtained when we talk about sub cooling increase, as seen in Figures 6 and 7.

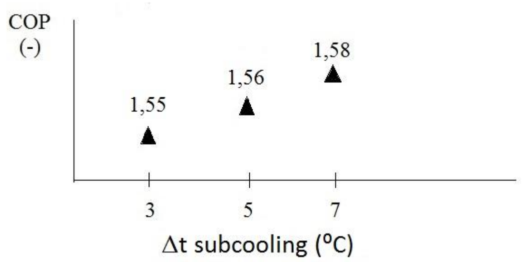

Figure 6 COP versus sub cooling degree

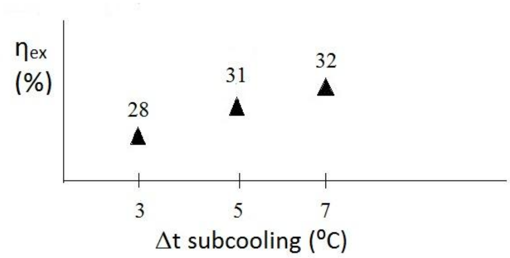

Figure 7 Exergy efficiency versus sub cooling

Best performance of the ammonia cycle results to be obtained for high levels of superheating and sub cooling.

5. CONCLUSIONS

Ammonia is an old refrigerant, successfully used in maritime refrigeration, but showing an increased interest for new refrigeration plants on board the ships.

By taking adequate safety measures, ammonia, as a natural refrigerant, is environment friendly and able to ensure high energy efficiency.

Being recognized the fact that vapour compression refrigeration systems exploitation requires high energy needs, the analysis of these systems is very important.

In this paper, the thermodynamic analysis relies on the first and second laws of thermodynamics.

By considering the both laws, a realistic image of the performance can be revealed; performance indicators were COP and exergy efficiency.

It was found that the cycle is more efficient when the difference between evaporation and condensation temperatures is lower.

Also, for an improved performance, the cycle should contain superheating and sub cooling processes. Higher superheating and sub cooling degrees will lead to higher performances.

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