Annals of DAAAM for 2010 & Proceedings of the 21st International DAAAM Symposium, Volume 21, No. 1, ISSN 1726-9679
ISBN 978-3-901509-73-5, Editor B. Katalinic, Published by DAAAM International, Vienna, Austria, EU, 2010
Make Harmony Between Technology and Nature, and Your Mind will Fly Free as a Bird
Annals of DAAAM International

EXERGETIC AND ENVIRONMENTAL ANALYSIS WHEN USING R 407C IN MARINE FERIGERATION

MEMET, F[eiza] & MITU, D[aniela] - E[lena]

Abstract: *Today the choice of refrigerant cannot be base exclusively on efficiency. Environmental considerations and the expected future regulation of the use must be considere, too. The two main factors that are of concern to the environment are Ozone Depletion Potential (ODP) and Global Warming Potential (The Greenhouse Effect) (GWP). Marine refrigeration often uses R22. International regulations impose the substitution of this refrigerant from existing plants. Researches focus on developing new more environmentaly friendly refrigerants. This paper carries out an exergy analysis of the marine refrigerating plant when R 407C is used. This kind of analysis might be use also for other green refrigerants. The environmental assessment reveals that R 407C is a quite good option considering the climate change awarness.*
Key words: *exergy, environment, marine refrigeration*

1. INTRODUCTION

A typical marine refrigerating plant works with a single stage-reciprocating compressor.
The single stage refrigeration plant has the purpose of removing heat from the cargo space (the container) in order to keep the temperature of the commodity at the desired temperature. The refrigeration plant consists of four basic components: The evaporator, the compressor, the condenser and the TXV.

There are currently 715 000 TEUs (Twenty-foot Equivalent Units) worldwide. In 1998, sales of TEUs reached a level of 96 500 (500 insulated containers and 96 000 refrigerated containers). The trend is towards self-contained refrigerated containers. They are technological wonders, which can transport perishable products for weeks, or even months, under very stable temperature, humidity and controlled atmosphere conditions.

In this sector, R1 34a dominates. This alternative is for chilled products, which are the most commonly transported products. For frozen products, R1 34a is used, either which is surprising having in view its very poor energy efficiency at low temperatures, or R404A can be employe.

On refrigerated ships (reefers), besides R22, the main refrigerants used are R410A, R407C and R404A. In 1993, five refrigerated ships using ammonia was built. Since then, ammonia has no longer been use, except on fishing boats. Indirect systems using brines such as calcium chloride, and plate exchangers, are the most commonly use.

2. EXERGY ANALYSIS. RESULTS

Exergy is the maximum amount of the work, which can be produce by a system, or a flow of matter as it comes to equilibrium with a reference environment. Exergy is consume or destroyed due to irreversibilities in any real process. The exergy consumption during a process is proportional to the entropy created due to irreversibilities associated with a process.

Exergy analysis, based on First and Second Law of Thermodynamics, offers the real measure of useful energy of each mass or energy stream, identifying and evaluating the real inefficiencies of the system. The exergy method is able to quantify locations, types and values of wastes and losses. More general, exergy is able to evaluate efficiencies, having in view that exergy efficiencies represent a measure of the approach to the ideal. In few words, exergy analysis offers the opportunity to design more efficient energy systems by diminishing inefficiencies.

Exergy is never in balance because total exergy input always exceeds the total exergy output. The exergy balance for each process component is use for the calculation of irreversibility, known as exergy destruction or exergy loss. Exergy losses are giving by exergy flowing to the surroundings, while exergy destruction shows the loss of exergy inside the process boundaries due to irreversibility (Mrema and Lawrence, 2001).

The exergy rate (Ex) connected with the heat rate (Q) is calculating as:

$$Ex = Q\left(1 - \frac{T_E}{T}\right) \tag{1}$$

In which T_E is the temperature of the environment.

The exergy stream of matter is give by its components: kinetic exergy (Ex_k), potential exergy (Ex_p), physical exergy (Ex_{ph}), chemical exergy (Ex_{ch}), like:

$$Ex = Ex_k + Ex_p + Ex_{ph} + Ex_{ch} \tag{2}$$

Physical exergy is the work obtainable by taking the substance, through a reversible process, from its initial state (given by temperature T and pressure p) to the state in equilibrium with the environment (given by T_E, p_E). Its formula is:

$$Ex_{ph} = H - H_E - T_E\left(S - S_E\right) \tag{3}$$

Above, total enthalpy is note as H and total entropy as S.
Chemical exergy is the maximum amount of work obtained when a substance is taken from environmental state (given by T_E, p_E), to the dead state through a process characterized by heat transfer and substance exchange only with the environment. Its formula involves the partial pressure of the component in the reference state (p_r):

$$Ex_{ch} = RT_a \ln\frac{p_a}{p_r} \tag{4}$$

From the exergy balance, exergy destruction, Ex_D, is give by:

$$\sum Ex_D = \sum Ex_{in} - \sum Ex_{out} \tag{5}$$

In order to estimate the quality of a process, is calculated the exergy efficiency, a rational measure of thermodynamic perfection of the analyzed process. It has defined as utilized exergy (given by all exergy output) divided by used exergy (given by exergy input), as:

$$\eta_{ex} = \frac{Ex_{out}}{Ex_{in}} \tag{6}$$

For the refrigerating cycle, the exergy efficiency depends on the exergy of the cooling load (Q_o) and exergy losses (Ex_{loss}):

$$\eta_{ex} = \frac{Ex_{Q_o}}{Ex_{Q_o} + Ex_{loss}} \tag{7}$$

The exergy flux for the refrigerated space is:

$$Ex_{Q_o} = \left(\frac{T_c}{T_o} - 1\right) \cdot Q_o \tag{8}$$

For the assessment of the exergy losses in the component parts of the refrigerating system, it is needed Figure 1, where the notations indicate: T_c – condensation temperature, T_o – vaporization temperature, *2r* – vapor state after adiabatic compression, *2ir* – vapor state after irreversible compression.

Exergy losses in the compressor:

$$\left(ex_{loss}\right)_{12} = T_E\left(s_2 - s_1\right) \quad \left[J/kg\right] \tag{9}$$

Exergy losses in the condenser:

$$\left(ex_{loss}\right)_{23} = h_2 - h_3 - T_E\left(s_2 - s_3\right) \tag{10}$$

Exergy losses in the throttling valve:

$$\left(ex_{loss}\right)_{34} = T_E\left(s_4 - s_3\right) \tag{11}$$

Exergy losses in the evaporator:

$$\left(ex_{loss}\right)_{41} = h_4 - h_1 - T_E\left(s_4 - s_1\right) \tag{12}$$

The exergy destruction in each component of the system depends on the refrigerant type. To illustrate, was considere a refrigerant often met in marine refrigeration, R 407 C.

Were assuming the following conditions:

- the cooling load was 100 kW,
- the evaporation temperature was 30^{o}C
- The isentropic compression efficiency was taking as 0.8.

Was obtaining a value of 0,45 for the exergy efficiency.

The exergy losses specific to the processes developed in the plant:

- Compression 35.4%,
- Condensation 11.2%,
- Throttling 4.3%,
- Evaporation 11.6%

It is seeing that the most significant part of the losses is meeting in the compressor.

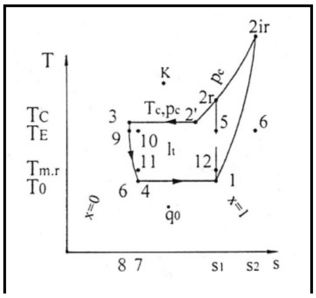

Fig. 1. Cycle in (T–s) diagram of a single stange refrigeration machine

3. ENVIRONMENTAL ASPECTS

The astrosphere is one of the most important bases of life on Earth. The environmental problems in connection with refrigerating and air-conditioning systems can be summarized as ozone depletion in the stratosphere, which has led to the regulation of the Montreal Protocol, and global warming, which has been under consideration for the last few years. These environmental effects are measure by the well-known definitions of Ozone Depletion Potential (ODP), Global Warming Potential (GWP) and Total Equivalent Warming Impact (TEWI). Marine engineer's refrigerant policy must be clear and unambiguous, focused on the use of natural refrigerants, which have no direct harmful impact on the environment, and the use of the new environmental friendly "green refrigerants".

R 407C is a zeotropic mixture (R 32/ 125/134a; 23/25/52). R 407C is mainly used for retrofitting, in marine refrigeration using R 22. R 407C doesn't harm the ozone layer, its ODP being 0 compared to the one of R 22, which is 0,055. When comparing R 22 with

R 407C based on their impact on global warming it is founded that GWP_{R22}= 1900 and $GWP_{R\ 407C}$ = 2000 (CO_2= 1,100 y).

4. CONCLUSION

R 407C is often used to replace R 22 in existing refrigerating plants on board the ships.

The selection of the best refrigerant is helpe by the exergy analysis. This method allows the design of more efficient systems by reducing inefficiencies. The calculus developed in the paper revealed that the most exergy losses are meeting in the compressor (35,4%). This observation is useful because if other refrigerants are discusse, the focus will be on the value of exergy losses in the compressor.

R 407C is not harmful for the ozone layer and its contribution to the greenhouse effect is slightly higher than that for R 22.

5. REFERENCES

Chiriac, F.; et. al., (2006). Machines and refrigerators, Ed. Agir, Bucharest

Dobrovicescu, A.; et.al., (2008). *Optimisation structurelle des cycles frigorifique au CO_2*, Ed. Agir, Thermotechnics, XII Years, no.1/2008, Bucharest

Hera, D., (2005). *Refrigerants and environmental management,* Ed. Conspress, Bucharest

Mrena, G.D., et.al. (2001). *Exergetic analysis of the acetylene gas production: case of the Tanzania oxygen limited in Tanzania*, Proc. of ECOS 2001, Vol. II, Istanbul

Morosuk, T. & Tsatsaronis, G., (2007). *Advanced thermodynamic evaluation of refrigeration machines using different working fluids*. Proc. of ECOS 2007, Vol. I, Padova