MARITIME TRANSPORT OF FOOD: EXERGETIC AND ENVIRONMENTAL ANALYSIS

Feiza Memet*, Osman Kamil Sag**
*Constanta Maritime University, Mircea cel Bătrân Street, 104, 900663, Constanţa, România,
e-mail: feizamemet@yahoo.com
**Piri Reis University, Istasyion Cad. Hacioglu SK 34940 Tuzla, Istanbul/Turkey,
e-mail: osmankamilsag@ *pirireis.edu.tr*

Abstract: *Almost 90% of the EU's external trade is carried by sea. The 1200 ports throughout the continent represent an extremely valuable economic asset. The maritime transport sector is faced by many challenges relating to technological development, climate change, but also financial and economic crisis.*
Refrigerated freight shipped worldwide mainly consists in meat, fish, dairy products, fruits and vegetables. Having in view the financial importance of the financial importance of the maritime transport of food, this paper deals with two major issues connected with a refrigeration machine on board the ship: the exergy analysis and the environmental issue related to marine refrigerants.
The exergy analysis is presented as an instrument used to define the performance of the marine refrigerating machine, able to show the way of its improvement. On the other hand, marine refrigeration specialists were aware about the need of use green refrigerants in this sector.
Accordingly, are discussed results of exergy analysis when R407C is used as a working fluid. The major part of exergy losses are encountered in the compressor (35,4%).

Keywords: *marine refrigeration, exergy losses, environment.*

Introduction

Marine transportation of goods doesn't refer only to non-perishable products, perishable commodities need also to be transported on board the ships. These might get spoiled during voyage if proper measures are not taken in terms of temperature control. Mentioned products could be anything like meat, fish, vegetables, fruits, dairy products and so on.

Marine transport of refrigerated goods may be one of the two types: containerized transport and conventional refrigerated shipping.

Ship refrigeration may be used for different application. A ship may transport a perishable refrigerated product for trade, but also frozen food. Marine refrigerating equipment is also for shipboard air conditioning needed by passengers and crew.

Shipboard refrigeration is necessary for the preservation of perishables in transit and foodstuffs to be used by passengers and crew. Marine refrigeration is also used for maintaining certain cargo products in liquid form that would otherwise evaporate when stored at ambient conditions.

Another application refers to preserving fish caught at sea. If the ship is out of the sea only for a few days, ice might be bought from shore. Auxiliary refrigeration is also used to aid the ice in refrigerating the load, in order to avoid excess melting. If the ship operates at sea for a few months, the catch needs to be frozen for preservation. In order to preserve flavor and color, fishing vessels should be able to deliver a quick freezing to the fish.

Refrigerated freight may be carried in containerized compartments loaded on the specialized ship. These containers may have their own electric refrigeration system that may be operated at the dock and can be plugged into the ship's electrical system.

A typical marine refrigerating plant works with a single stage reciprocating compressor. A simple vapor compression refrigeration system includes a compressor, condenser, throttling valve and an evaporator.
In marine refrigeration systems must operate refrigerants that are not considered dangerous to the environment and show good thermodynamic properties.

Experimental
Exergy. Exergy analysis
Exergy is the maximum amount of the work which can be produced by a system or a flow of matter as it comes to equilibrium with a reference environment. Exergy is consumed 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 used for the calculation of irreversibility, known as exergy destruction or exergy loss. Exergy losses are given 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 calculated as:

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

In which T_E is the temperature of the environment.
The exergy stream of matter is given by its components: kinetic exergy (Ex_k), potential exergy (Ex_p), physical exergy (Ex_{ph}), chemical exergy (Ex_{ch}), like:

$$Ex = Ex_k + Ex_p + Ex_{ph} + Ex_{ch} \qquad (2)$$

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:

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

Above, total enthalpy is noted 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):

$$Ex_{ch} = RT_a \, ln \frac{p_a}{p_r} \qquad (4)$$

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

$$\sum Ex_D = \sum Ex_{in} - \sum Ex_{out} \qquad (5)$$

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 is defined as utilized exergy (given by all exergy output) divided by used exergy (given by exergy input), as:

$$\eta_{ex} = \frac{Ex_{out}}{Ex_{in}} \quad (6)$$

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

$$\eta_{ex} = \frac{Ex_{Q_o}}{Ex_{Q_o} + Ex_{loss}} \quad (7)$$

The exergy flux for the refrigerated space is:

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

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.

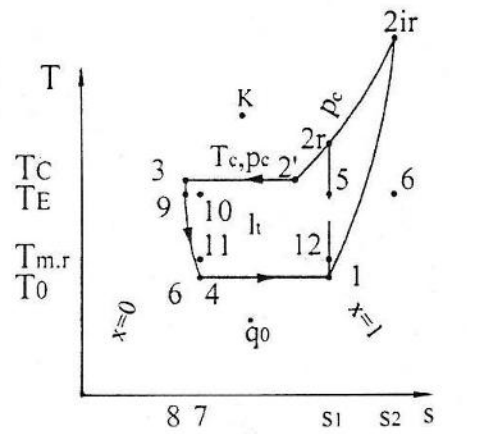

Figure 1. Cycle in (T–s) diagram of a single stange refrigeration machine.

Exergy losses in the compressor:

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

Exergy losses in the condenser:

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

Exergy losses in the throttling valve:

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

Exergy losses in the evaporator:

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

Environmental issue

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 measured by the well know 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 the new environmental friendly "green refrigerants", which have no direct harmful impact on the environment.

In the marine refrigeration, R134a dominates, for the transport of chilled products. For frozen products, R134a may also be used, even if it shows poor energy efficiency at low temperatures, or R 404 A can be employed.

On reefers (refrigerated ships), besides NH_3, the main refrigerants used are R410A, R 407 C and R 404 A.

Results and discussion

Exergy analysis is a method based on the first and second law of thermodynamics, which shows the thermodynamic imperfection of a process, including all

quality losses of materials and energy that are omitted when using first law analysis.
The exergy destruction in each component of the system depends on the refrigerant type. To illustrate, was considered a refrigerant often met in marine refrigeration, R 407 C.
Were assumed the following conditions:
- the cooling load was 100 kW,
- the evaporation temperature was 30°C
- the isentropic compression efficiency was taken as 0,8.

Was obtain 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 seen that the most significant part of the losses is met in the compressor.
Considering the environmental aspect of the use of the ternary zeotrope R 404 C (R32 – 23%, R125 – 25%, R134 a – 52%), its environmental effects are given by the values: ODP = 0 and GWP = 0,32.

Conclusions

Marine refrigeration specialists had to face the challenge raised together with the growth of the market for refrigerated perishables and the one raised by the environmental problems.
The process of the best refrigerant selection for the refrigerating system on board the ships is helped by the energy analysis.
This method allows the design of more efficient systems by reducing inefficiencies.
By calculating exergy losses in the component parts of the refrigerating machine, it is possible to select the best refrigerant among different green refrigerants.
In this study, was taken in discussion R407C, an environmental friendly refrigerant, often used on board of reefers.
Results have shown that the major part of losses are met in the compressor. These exergy losses can be reduced by taken special measures like: a larger design of valves, a more intensive cooling of the compressor, the choosing of two stage compression, in same cases, etc. There are specific measures of exergy losses reduction for each component part of the machine.

References

FLOREA CHIRIAC et. al., Maşini şi instalaţii frigorifice, Ed. Agir, Bucureşti, 2006, 297 pp.
ALEXANDRU DOBROVICESCU et. al., Optimisation structurelle des cycles frigorifique au CO_2, in Termotehnica, Anul XII, nr. 1/2008, Ed. Agir, Bucharest, 2008, pp.64-70
TATIANA MOROSUK, GEORGE TSATSARONIS, Advanced thermodynamic evaluation of refrigeration machines using different working fluids, in Proc. of ECOS 2007, Vol. I, Padova 2007, pp. 397-405
G. D. MREMA et. al., Exergetic analysis o fthe acetylene gas production: case of the Tanzania oxygen limited in Tanzania, in Proc. of ECOS 2001, Vol. II, Istanbul, 2001, pp. 689-696