Aspects of using Unicool R417 A instead of R 22 in the reefer transport

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Abstract: - International regulations impose that after January 1, 2015, the use of R 22 in marine refrigeration plants is strictly banned on Europe Union flagged vessels. R417A presents very close working parameters in marine applications to R 22 and the changeover does not ask expensive system modifications.
This paper deals with the exergetic analysis of a single stage reciprocating compressor plant working with R22 and R 417 A, the non-ozone depleting long term replacement for R 22. The exergetic analysis offers indications on the refrigerating system improvement. It is seen that when using R 417 A, the exergy destroyed is higher than that when using R 22, in each component part of the plant. Also, the highest value of the exergy destroyed is obtained in the compressor, meaning that this component part of the plant has priority in the improvement process.

Key-Words: - refrigerant, exergy analysis, exergy destroyed, compressor.

1 Introduction

Reefer transport is defined as the maritime transport of perishable cargo that asks climate control during transport in order to reduce product deterioration. Reefer transport has significantly increased over the last decade and is predicted to grow in the future.

Emitted CFC and HCFC refrigerants have been directly connected to the destruction of stratospheric ozone. International regulations have been adopted in order to phase out the production and consumption of the refrigerants for the protection of the stratospheric ozone layer.

Looking after green refrigerants, the preoccupations are that substitutes and refrigerating systems might have lower energy efficiency, higher GWP and more important environmental impact than the Ozone Depleting Substance refrigerants and systems that they replace.

In 2007, the Montreal Protocol Parties approved the acceleration of the phase-out process of HCFCs, gases with low Ozone Depletion Potential, which were nominated as replacements for CFCs. Traditionally, on board the ships is met R 22, a refrigerant belonging to the HCFC family.

According to the REGULATION (EC) No 2037/2000 of the EUROPEAN PARLIAMENT OF THE COUNCIL of 29 June 2000 on substances that deplete the Ozone layer, from 1 January 2010 the use of virgin hydrochlorofluorocarbons shall be prohibited in the maintenance and servicing of refrigeration and air conditioning equipment existing at that date; all hydrochlorofluorocarbons shall be prohibited from 1 January 2015.

These regulations are available for all European Union flagged vessels. All marine refrigerating systems working with R22 cannot be maintained, serviced or topped up with new refrigerant after January 1, 2010. Between January 1, 2010 and January 1, 2015, recycled HCFC may be used. After January 1, 2015, the use of HCFCs is completely banned on E.U. flagged vessels.

Research activities focused on finding new marine refrigerants. In refrigerating systems on board reefer ships, HFC – 410 A is an interesting option. Lately, ammonia indirect systems are used both for reefer ships and fish boats. Other refrigerant belonging to the HFC family, R 134 A is commonly used in the intermodal refrigerated container market, having in view that the vast majority of transported products are fresh foods. Transcritical CO_2 systems are also considered, but ammonia and HCs are not permitted in containers with reference to IMO.

The criteria for choice of refrigerant can be summarised as follows:

1. Environmental Issue (Ozone Depletion) – addressed by the Montreal Protocol and European legislation.
2. Environmental Issue (Global Warming) – by far the largest component of TEWI (Total

Equivalent Warming Index) is the indirect CO2 emissions from power generation, making the refrigerant direct GWP insignificant.

3. Cost – refers to the refrigerant cost together with the system applied costs.
4. Efficiency – can be expressed in terms of running cost and is linked closely to global warming, but very much secondary to the chlorine-free legislation-driven move away from R22.
5. Pressure level – refers to component availability and ability to use existing system designs; there is also a cost associated with implementing new designs and cost variances associated with component sizes which may be smaller for higher pressure systems, and so this criterion is closely linked to cost.
6. Temperature Glide – Fractionation in flooded chillers, premature frosting and perceived serviceability problems will count against glide refrigerants such as R407C. In some designs of system glide can be utilized.
7. Safety – Includes the investment cost associated with special installation and maintenance requirements for system safety.
8. Standards and Building Codes – this may be linked to the safety criterion.
9. Availability of compressors and other components.
10. Harmonization – Cost savings arising from simplification is the result of using one or a limited number of refrigerants in the manufacturing location and for the markets (countries) served. Also there are broader advantages in maintenance from standardizing on certain refrigerants in the field.
11. Marketing Image.

2 An overview on R 22 and R 417 A

R 22 contains chlorine, which if released, destroys the Ozone layer within the stratosphere. Despite efforts done to maintain leak free systems, the specific movement of a ship might cause pipe fractures. In order to be eliminate any possibilities of Ozone depletion, R 22 is being phased out from marine refrigeration systems. Strong recommendations indicate that the most economical solution to stay compliant with the regulations is substitute the existing R 22 with a suitable, non ozone – depleting alternative, such as Unicool R417A.

R 417 A is a ternary blend of HFC 125, HFC134a and HC 600. R 417 A has very similar working parameters in marine applications to R 22, so there is no need for change of gauges, safety valves, condenser etc. This means that the changeover does not require costly system modifications. R 417 has also the following advantages: lower temperature glide of 5,6 K compared to 7,4 K of Unicool R 407 C, lower discharge temperature leads to less possibilities of system oil decomposition, compatible with all oil types including mineral oil, so negates the need for a thorough and long drawn out process to clean out the old oil. R 417 A is a non ozone depleting replacement for R 22: ODP for R 417 A is zero and GWP for R 417 A is 0,49.

R 417 A is an adequate refrigerant for cold store applications. R 417 A works in good conditions for margarine or fruit storage (at +3°C), but also for temperature storage of –30°C.

3 The exergetic analysis

A better energy utilization is possible if we focus on the quantity and quality of energy, by applying the laws of thermodynamics.

The First Law of Thermodynamics shows that energy cannot be created nor destroyed and its quantity remains constant in all processes. In a steady state process, energy quantity is expressed by the use of the thermodynamic function named "enthalpy".

The Second Law of Thermodynamics shows that energy is degraded in all processes and its quality decreases. Exergy quality is expressed by the thermodynamic function called "exergy".

Exergy is the maximum amount of 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 all real processes. The exergy consumption during a process is proportional to the entropy created due to irreversibilities associated with a process. Exergetic analysis, based on First and Second Law of Thermodynamics, is a tool able to measure the useful energy of each mass or energy stream, finding and assessing the real inefficiencies of the system. Using this method, specialists may evaluate locations, types and values of wastes and losses.

Generally speaking, exergy is able to assess efficiencies, due to the fact that exergy efficiencies are a measure of the approach to the ideal. So, exergetic analysis give the chance to design more efficient energy systems by reducing inefficiencies. The exergy balance for each process component is used for the evaluation of irreversibility, known as exergy destruction or exergy loss.

Exergy losses are produced by the exergy flowing to the surroundings. Exergy destruction indicates the loss of exergy inside the process boundaries due to irreversibility.

For the assessment of the quality of a process, is calculated the exergy efficiency as the ratio between utilized exergy and used exergy:

$$\eta_{ex} = \frac{\dot{E}x_{out}}{\dot{E}x_{in}} = 1 - \frac{\dot{E}x_{des}}{\dot{E}x_{in}} \quad (1)$$

A typical marine refrigeration plant works with a single stage reciprocating compressor. A single vapor compression refrigeration system includes a compressor, condenser, throttling valve and an evaporator (See figure 1).

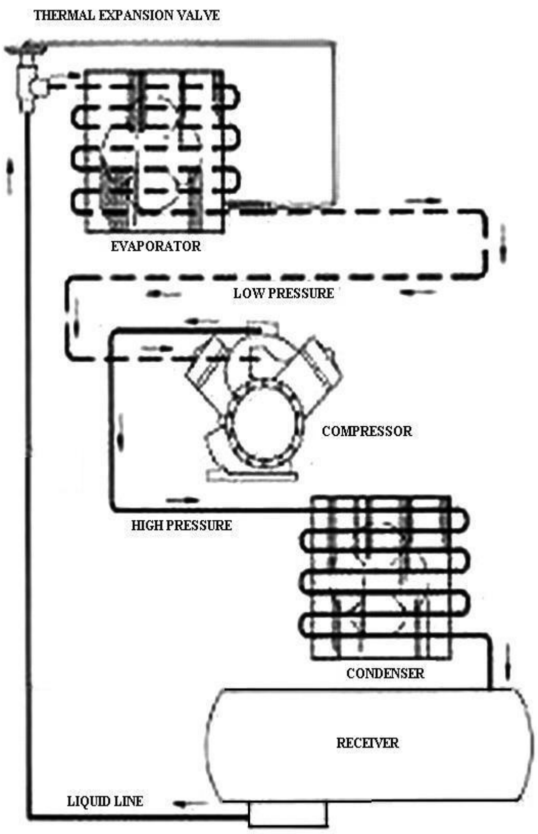

Fig. 1 Typical single-stage vapor compression refrigeration scheme.

For the refrigerating cycle, the exergy efficiency depends on the exergy of the cooling load (Q_0) and exergy losses ($\dot{E}x_{loss}$):

$$\eta_{ex} = \frac{\dot{E}x_{Q_0}}{\dot{E}x_{Q_0} + Ex_{loss}} \quad (2)$$

The following equations are used for the calculation of the exergy flow destroyed in the condenser, evaporator, compressor and throttling valve. Are involved the mass flow rate of the refrigerant ($\dot{m}_{ref}$, kg/s), the specific exergy (ex, J/kg), the thermal power exchanged ($\dot{Q}$, W), the dimensionless exergetic temperature (τ), the compressor power input ($\dot{L}_{cp}$, W).

$$\dot{E}x_{des,co} = \dot{m}_{ref}\left(ex_{in,co} - ex_{out,co}\right) - \dot{Q}_{co}\tau_{co} \quad (3)$$

$$\dot{E}x_{des,ev} = \dot{m}_{ref}\left(ex_{in,ev} - ex_{out,ev}\right) - \dot{Q}_{ev}\left|\tau_{ev}\right| \quad (4)$$

$$\dot{E}x_{des,cp} = \dot{m}_{ref}\left(ex_{in,cp} - ex_{out,cp}\right) + \dot{L}_{cp} \quad (5)$$

$$\dot{E}x_{des,tv} = \dot{m}_{ref}\left(ex_{in,tv} - ex_{out,tv}\right) \quad (6)$$

$$\tau = 1 - \frac{T_0}{T_{mt}} \quad (7)$$

Where T_0 is the temperature specific to the dead state and T_{mt} in properly evaluated for the evaporator and condenser.

4 Results and discussions

It is considered a refrigeration plant that has the evaporator placed in a cold store destinated to the food preservation, when the air temperature in the cold store varies in the range (–5÷5)^{o}C (Aprea et al, 2004).

The values of exergy destroyed in each component of the plant, for a temperature inside the cold store of 0^{o}C and for a temperature outside the cold store of 32^{o}C, are given in Table 1. It is seen that when R417 A is used as a refrigerant, the values of exergy destroyed in component parts of the plant are higher then R 22 is used as a working fluid.

The exergy analysis shows that for the refrigerant R417 A, the highest values of exergy destruction are obtained for the compressor. In this situation, the improvement of the refrigerating plant should continue with the improvement of the processes in the condenser, evaporator and then in the throttling valve.

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Table 1 Values of exergy destroyed in the component parts of the plant

Component of the refrigerating plant	Exergy destroyed when using R 22, W	Exergy destroyed when using R 417 A, W
Compressor	185	240
Condenser	127	143
Evaporator	92	122
Throttling valve	67	73

The compression process might be improved by choosing a new design for the compressor, more exactly by selecting a new design for the piston, or a new type of compressor, new lubricants etc. [Morosuk and Tsatsaronis, 2007].

6 Conclusion

The vast majority of the reefers have R 22 as refrigerant, but this Hydroclorofluorocarbon cannot be maintained, serviced or topped up with new refrigerant after January 1, 2010. In this paper, Unicool R417 A was considered as a replacement refrigerant for R 22, due to the fact that R417 A has very similar working parameters in marine applications to R 22 and the changeover does not require costly system modifications.

Exergetic analysis plays an important role in the evaluation of energy conversion systems. The results of this analysis revealed the priorities related to the improvement of the marine refrigerating plants. The hierarchy in the improvement process is: compression, condensation, evaporation and throttling.

This point of view is given by the values obtained for the exergy destructions calculated in the component parts of the refrigerating plant.

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