A WAY TO INCREASE SAFETY IN MARINE REFRIGERATION WHEN USING AMMONIA AS A WORKING AGENT

Assoc. prof. Ph.D. Feiza Memet[x]

Constanta Maritime University[x]

ABSTRACT

Trade with perishables, especially food, has always been a successful business, marine refrigeration being a vital part of the specific international trade since it can cause economic losses and environmental fatalities.

In order to meet ozone depleting substances phase-out targets, ammonia (R717) in frequently meet in many applications. R717 is a natural refrigerant, with very good thermodynamic features. Despite of these, R717 is not a perfect refrigerant, one of its drawbacks being that it causes health problems to personnel exposed to concentrations over safe limit.

This paper analysis the possibility of decreasing the amount of R717 by mixing it with dimethyleter (DME). Two mixtures (20% DME, 80% R717) and (40% DME, 60% R717) are compared with pure ammonia, based on the fulfillment of the selection criteria of a refrigerant.

The comparison will reveal the fact that the first mentioned mixture satisfies in a more convenient way these criteria, replacement of R717 with this mixture being a good option in improving safety, by not affecting the thermodynamic aspect of the problem, or its environmental aspect.

Keywords: *ammonia, dimethyleter, marine refrigeration, safety.*

1. INTRODUCTION

Perishable goods are goods for which their value decay fast over time. For this reason, vendors willing to obtain an optimum profit should sell these products immediately they are available on the market.

Trade liberalizing facilities and advanced transportation technologies allow food and agricultural exports to intensify between continents.

When it is about meat, fish, fruits or vegetables export, ship board transportation is highly attractive. Thus, it is possible to offer to worldwide consumer’s perishable goods a high level of freshness and quality, at convenient costs.

U.S. perishable goods, such as beef, pork, broccoli, avocados, mangos, nectarines, are exported to Asia mainly, and less to Europe [1].

The demand for frozen and chilled fish products, is constantly increasing, resulting the intensification of fishing in open seas and oceans on adequately equipped fishing vessels [2].

Refrigeration, freezing, ice making systems are vital for the cold chain integrity. This equipment should address not only to the energy efficiency aspect of marine refrigeration, but also to the mandate of Montreal Protocol.

An important part of the global fishing fleet still uses HCFC 22 in existing marine refrigeration plants, while HFCs are widely spread in applications on board the ships.

HCFC usage should be addressed in order to comply with exigency for a healthy ozone layer. So, marine refrigeration is facing the challenge of HCFCs phase out and the use of high GWP HFCs.

The selection of refrigerants for marine refrigeration (and not only) is driven by the fact that no perfect refrigerant is known, that fully ensure an environmental friendly design and plant layout together with energy efficiency.

In the international concern framework of slowing down the global warming effect and ozone depletion phenomenon, refrigeration industry turns back its attention to the use of natural refrigerants, such as ammonia–refrigerant presenting very good thermodynamic features and environmental behaviour [3].

Despite these advantages, ammonia is a refrigerant asking for special safety measures, due to its toxicity and flammability, for some of its concentrations.

A modern approach of refrigeration systems working with ammonia as a refrigerant consists in the decreasing of the ammonia amount in the plant, in order to reach a higher safety level on board the ship.

Thus, this paper deals with a comparison between single stage refrigeration cycles working with ammonia and with mixtures between ammonia and dimethyleter, in different mass fractions.

It is aimed to be revealed if these mixtures not only solve the problem of ammonia amount decrease, but also provide good efficiency of the system.

2. ENVIRONMENTAL COMPONENT OF THE DISCUSSION

Twenty-four nations plus European Community were motivated to sign the Montreal Protocol in 1987, because of the damaged ozone layer and as a result, in January 1996, CFCs were banned in developed countries and their production and usage were fully forbidden worldwide in January 2010; HCFCs will be phased out differentially, by 2030 in developed countries and 2040 in developing countries [4].

Substitution of hydro chlorofluorocarbons and chlorofluorocarbons with hydrofluorocarbons has significantly diminished the concentration of chlorine in the atmosphere, but the optimization of refrigeration systems should continue with the use of refrigerants showing low or null GWP (Global Warming Potential) [5].

The environmental impact of refrigeration assessment continues with greenhouse warming aspect, addressed by Kyoto Protocol.

Ammonia (R717) is not affecting the environment, having null GWP and ODP. Showing environment friendly properties and good thermodynamic characteristics, this refrigerant is very efficient in vapour compression systems, being widely used although it is toxic [6].

Dimmethyleter (DME) is also an old refrigerant, recurred due to its also null GWP and ODP and good behaviour in vapour compression refrigeration systems [7].

The mixture of these two refrigerants will lead to the obtaining of an ecological mixture which might be use in marine vapour compression systems.

3. COMPARATIVE ANALYSIS – RESULTS AND DISCUSSION

In Figure 1 one can see the working refrigeration cycle, with superheating of vapours and sub cooling of liquid refrigerant, in p–h diagram and below are given formulas specific for the thermal calculus of the single stage vapour compression [8].

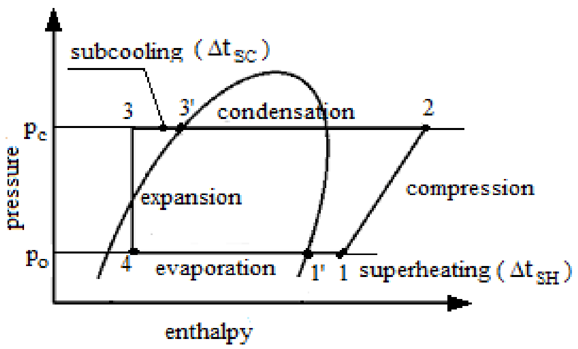

Figure 1 Working cycle of a single stage vapor compression refrigeration sistem with superheating and subcooling, in p–h

Temperature of subcooled liquid refrigerant:

$$t_3 = t_c - \Delta t_{SC} \quad (1)$$

where:

t_c – condensation temperature
Δt_{SC} – subcooling degree

Temperature of superheated vapours:

$$t_1 = t_0 - \Delta t_{SH} \quad (2)$$

where:

t_0 – evaporation temperature
Δt_{SH} – superheating degree
Specific cooling load:

$$q_0 = h_{1'} - h_4 \quad (3)$$

Specific volumetric cooling load:

$$q_{0V} = q_0 / v_1 \quad (4)$$

Specific work input:

$$l_c = h_2 - h_1 \quad (5)$$

Specific condenser load:

$$q_c = h_2 - h_{3'} \quad (6)$$

Specific superheating load:

$$q_{SH} = h_1 - h_{1'} \quad (7)$$

Specific sub cooling load:

$$q_{SC} = h_{3'} - h_3 \quad (8)$$

Thermal balance equation:

$$q_0 = q_{SH} + l_c = q_c + q_{SC} \quad (9)$$

Coefficient of performance:

$$COP = \frac{q_0}{l_c} \quad (10)$$

Refrigerant mass rate and volumic rate at the compressor inlet:

$$\dot{m}_r = \dot{Q}_o / q_o \quad (11)$$

$$\dot{V}_r = \dot{m}_r \cdot v_1 \quad (12)$$

where:

$\dot{Q}_o$ – refrigeration load.

Result are obtained for the following input data: refrigeration load 28.5 kW, condensation temperature 39ºC, evaporation temperature –10ºC, –5ºC, 0ºC, superheating degree 18ºC, sub cooling degree 10ºC.

The cases in study refer to three mass rates of DME (see Table 1).

Table 1. Refrigerants working in the analysed cycle

Refrigerant	DME (%)	R717 (%)
Pure ammonia	0	100
Mixture 1	20	80
Mixture 2	40	60

The influence of evaporation temperature variation on the specific cooling load (Table 2), on the temperature at the end of the isentropic compression (Table 3), on the saturation pressure (Table 4) on the Coefficient of Performance (Table 5), on the volumetric cooling load (Table 6) and on the volumic rate at the compressor inlet (Table 7) will be revealed.

Table 2. Influence of t_0 on q_0

evaporation temperature: –10ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
q_0 (kJ/kg)	1198	890	710
evaporation temperature: –5ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
q_0 (kJ/kg)	1198	890	710
evaporation temperature: 0ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
q_0 (kJ/kg)	1198	890	710

Table 3. Influence of t_0 on t_2

evaporation temperature: –10ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
t_2 (ºC)	160	145	130
evaporation temperature: –5ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
t_2 (ºC)	145	130	125
evaporation temperature: 0ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
t_2 (ºC)	131	124	110

Table 4. Influence of t_0 on p_{sat}

evaporation temperature: –10ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
p_{sat} (bar)	3	3.2	3.4
evaporation temperature: –5ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
p_{sat} (bar)	3.5	3.7	4
evaporation temperature: 0ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
p_{sat} (bar)	4	4.7	5

Table 5. Influence of t_0 on COP

evaporation temperature: –10ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
COP (–)	3.7	3.5	3.3
evaporation temperature: –5ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
COP (–)	4.1	3.9	3.6
evaporation temperature: 0ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
COP (–)	4.9	4.5	4.3

Table 6. Influence of t_0 on q_{0v}

evaporation temperature: –10ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
q_{0v} (MJ/m^3)	2.48	2.39	2.31
evaporation temperature: –5ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
q_{0v} (MJ/m^3)	3.11	2.87	2.69
evaporation temperature: 0ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
q_{0v} (MJ/m^3)	4.49	4.39	4.21

Table 7. Influence of t_0 on $\dot{V}_r$

evaporation temperature: –10ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
$\dot{V}_r$ (m^3/h)	0.013	0.014	0.016
evaporation temperature: –5ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
$\dot{V}_r$ (m^3/h)	0.01	0.012	0.014
evaporation temperature: 0ºC			
Refrigerant	Pure ammonia	Mixture 1	Mixture 2
$\dot{V}_r$ (m^3/h)	0.0090	0.0093	0.0096

When assessing the obtained results, it is useful to have in view refrigerant selection criteria, that might be summarise as:

– specific cooling load should have high values in order to get small values for the mass flow rate of the refrigerant;

- the temperature of the superheated vapours leaving the compressor should have low values, in order to ensure a good chemical stability for the refrigerant and the oil, for a long run life of the compressor; this temperature should not be more than 140ºC;
- the saturation pressure should show low values;
- the Coefficient of Performance should present high values, since this is an indicator of the performance of the system;
- the specific volumetric cooling load should have high values, since it affects the values of diameters of pipes and apparatus;
- the volumic rate of the refrigerant at the compressor inlet should present low values, in order to get small size compressors.

Mixture 1 shows better values for specific cooling load, the coefficient of performance, the specific volumetric load and for the volumic rate of the refrigerant in comparison with mixture 2; these values are closer to the ones obtained when using pure ammonia in the system.

Both mixtures present a higher saturation pressure, but values for mixture 1 are closer to the ones of pure ammonia.

4. CONCLUSIONS

Optimization of a refrigeration cycle working with ammonia may consist in finding of a solution for which the amount of ammonia is decreased. This solution will offer an increament in the safety on board the ship.

By diminishing the quantity of ammonia and replacing it with DME, two mixtures were obtained. The analysis done on the basis of the refrigerant's selection criteria values revealed that the mixture composed by 80% R717 and 20% DME is more convenient than the second mixture since values for:

- specific cooling load are lower in comparison with pure ammonia, but higher in comparison with the other mixture,
- the temperature at the exit of the compressor is lower in comparison with pure ammonia
- the saturation pressure is slightly higher in comparison with R717
- COP is slightly lower in comparison with R717
- values for specific Volumetric cooling load and volumic rate of the refrigerant at compressor's inlet are comparable with the ones obtained when pure ammonia is the working agent.

Mixture 1 shows thermodynamic properties similar with pure ammonia but the amount of this single refrigerant is decreased by replacing it with such a mixture.

5. REFERENCES

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