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Aspects Regarding the Use of R-134a in Marine Refrigeration

In marine refrigeration and air conditioning, refrigerants like R-12, R-22 and R-502 are most commonly used.
Due to environmetal challenges, marine refrigeration plants on board of the old vessels have to be updated and designed in new terms. Recently, the global warming problem has put new pressure on possible alternatives, as R-134a for R-12, and drawn attention to energy efficiency.
Results and theoretical considerations concerning a retrofit project are discussed with respect to R-134a compared with R-12, a traditional refrigerant on board of old ships.

Keywords: *refrigerants, ozone, properties, ship*

1. Aspects regarding International Current Legislation

The ozone layer is vital to life on the Earth's surface. In the 1980's, it was discovered that it was vulnerable to damage by emissions into the atmosphere of particular industrial chemicals of which the most important was the family of CFC.

In the light of definition of legislation concerning the safeguarding of human health and environment from burdensome impacts resulting from human activities which deplete the ozone layer, the Vienna Convention was signed on March 22nd in 1985.

The Montreal Protocol (16th of September 1987) set the initial restrictive of production, trade and consumption of the most important CFC (R-11, R-12, R-113, R-114, R-115), as well as in certain substances containing bromine, halons (Annex A of the controlled substances, Montreal Protocol 1987). The Protocol was initially signed by 49 countries among which most European ones, the United States, Canada and Japan, countries that had highest percentage of production and consumption of the ODS.

As a results of the scientific, technological and economic revaluation of the annual data, certain reassessments and amendments of the Protocol were made necessary.

The most recent revision of the Protocol was made in Beijing in 1999, where it was decided:

- To improve the control measures on the production and consumption of CFC, halons, other fully halogenated CFC, carbon tetrachloride, methyl, chloroform, hydroflourcarbons, methyl bromide and bromochloromethane;
- To accelerate the phase out of consumption and production of bromochloromethane;
- To extend and complete the rules for calculation of control levels for all substances of Protocol Annexes;
- To ban the export of HCFC to non-Parties from 1-1-2004; and within one year of the date of entry force of this paragraph each Party shall ban export of bromochloromethane to any State not Party to this Protocol;
- To extend the special situation of developing countries for all controlled substances with an emphasis to bromochloromethane;
- To strengthen the procedure of reporting data to the Ozone Secretariat (United Nations Environment Program).

Specific regulations were also adopted by certain countries-parties, with a view limit ever more the measures as regard CFC and HCFC (Official Journal of the European Communities 1991, 1994, 1999, 2000).

One of the main duties of the Ozone Secretariat is to receive, analyze and provide information on the production and consumption of ODS. So the information concerning the annual reports of the Parties of the Protocol is very useful in order to check whether or not the Protocol Parties have complied with the imposed measures until now.

Charts are constructed illustrating not only the global reported production calculated levels (in ODP tons) for all controlled substances, but also the maximum permitted limits as they can be defined by the Protocol control measures. The calculation of the global maximum permitted production limits must include the corresponding sums permitted, so as to fulfill the basic domestic needs of Parties operating under Article 5 (developing countries). In addition, the entire production sums of developing countries which had the obligation of putting the control measures into practice by 1999 onwards (Status of ratification, UNEP 1997) were taken into account. So, in order to calculate these limits the following equalization is set out (Status of Agreements by UNEP 1997, Policy design by UNEP 1998):

Maximum permitted production limits of substances in a group=the production percentage of the base level amount permitted in the developed countries plus the whole production amount for the developing countries plus the production percentage of the base level amount permitted in developed countries concerning the fulfillment for the basic needs of developing countries as stated in Article 5.

As shown in Figures 1-4, information is generated on production and consumption with the maximum permitted limits for CFCs of Annexes A and B.

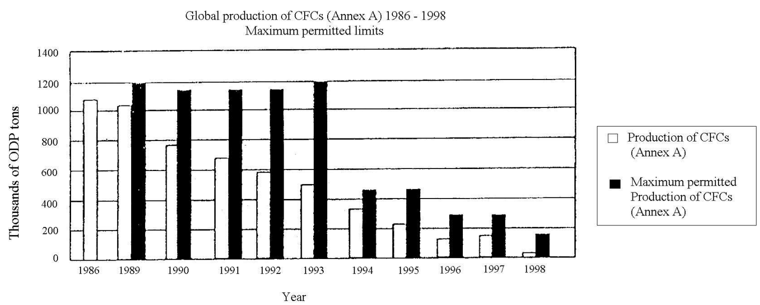

Figure 1. CFCs production (Annex A) for 1986-1998

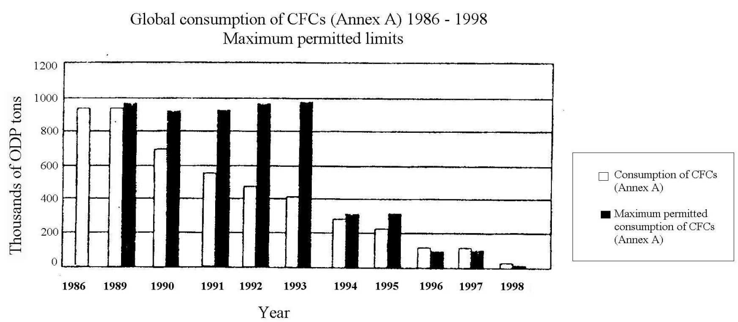

Figure 2. CFCs consumption (Annex A) for 1986-1998

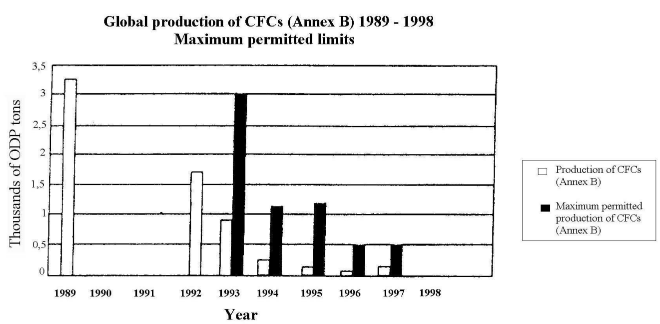

Figure 3. CFCs production (Annex B) for 1989-1998

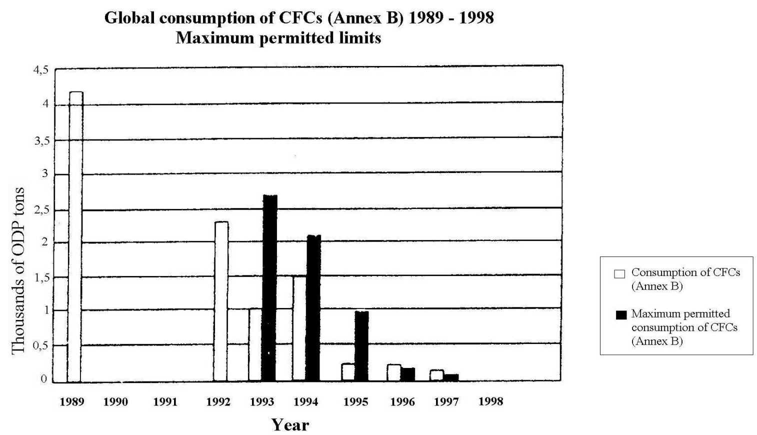

Figure 4. CFCs consumption (Annex B) for 1989-1998

2. About the conversion projects accomplished by UNIDO in Romania

Based on the Montreal Protocol Found, many projects have been approved during the last years to help Article 5 countries to convert their production of refrigeration equipment from using CFCs to non ozone depleting refrigerants. Romania belongs to the group of Article 5 countries entitled to request assistance from the Montreal Protocol Fund to convert the production of refrigeration equipment.

The company TRANSFRIGOTREN INTERNATIONAL from Buftea is operating 200 refrigerated carriages to transport frozen food. Each carriage is equiped on both ends of body with a self contained two-stage refrigeration machine. Originally, the company wanted to replace R-12 by R-22 (Nowortny, 1996). A short study has proven that this solution is not feasible as demonstrated in Table 1. Figure 5 shows the schema of refrigeration cycle.

Results shows that R-134a is the only alternative.

Considering the same temperature conditions as with R-12, the refrigeration capacity is being reduced and the COP as well, but the electric motor will not be overloaded. From this point of view, the conversion to R-134a is an acceptable solution. The lower capacity can be balanced by a longer running time of the refrigeration machine.

Table 1.Comparision between R-12 an R-134a and boundary conditions

Property	Symbol applied	Dimension	Cycle/Refrigerant	
			Original cycle/R-12	Original cycle/R-134a
Evap temp	t_0	^oC	-30	-30
Cond temp	t	^oC	+45	+45
Super heat temp	t_{0h}	^oC	-20	-20
Dens Suction Gas	r_{0h}	kg/m^3	6,06	4,2
Evap press	p_0	bar	1,03	0,84
Reduc suction pres	p_0^*	bar	1,03	0,84
Cond press	p	bar	11,0	11,6
Refrig cap	Q_0	kW	10,3	8,59
Cond cap	Q	kW	14,8	12,65
Electr power	P	kW	4,57	4,06
Coef of perfor	COP	-	2,25	2,12

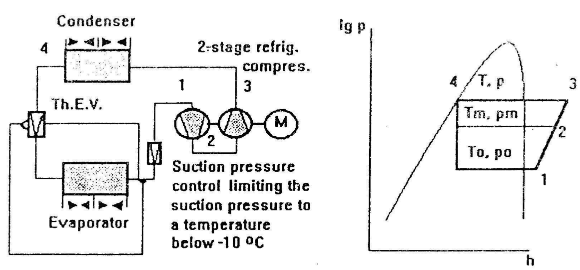

Figure 5. Refrigeration cycle of the equipment to be converted from R-12 to R-134a

3. R-134 for the existing marine refrigerating plants

R-12 is mainly used on older ships. Fleets of developing countries consist mostly of these kind of ships.

In 1991, the Ship-owners Refrigerated Cargo Research Association (SRCRA) carried out detailed assessment for the R134a retrofit of a clip-on refrigeration unit.

The equipment used was a Sea-Cold model – A machine, and the lubricant was Castrol Icematic – SW 22. Refrigeration capacity tests at ISO 1496/II conditions were carried out for a range of weights of charge and a range of expansion valve settings, and temperature control tests were carried out at several different ambient temperatures, with the unit attached to an insulated container.

For best performance on unit it was found necessary to close the expansion valve somewhat relative to the R-12 operating position, but no advantage was found in fitting a different valve. Optimum refrigerant charge was equal to that used for R-12.

At the optimum, refrigeration capacity at the ISO 38°C ambient/–18°C internal temperature condition was found to be reduced by about 10%, with a smaller reduction in power draw. In 30°C ambient, a temperature of below –20°C was achieved, albeit with a suction pressure well below atmospheric pressure. No temperature control problems were found.

The SRCRA has carried out tests on a range of container refrigeration equipment. Results shown that, overall, mean capacity loss at ISO conditions is 11%.

Whilst it is not possible to predict accurately the performance changes on any particular unit, some general principles must apply.

The real transfer characteristics of R-134a are advantageous, thus equipment with generously sized heat exhangers should benefit.

The selection of R-134a refrigerant as a substitute to R-12 is based on the fact that its thermodynamic properties are similar to the refrigerant that he is replacing.

R-134a heat transfer coefficients have been measured and these measurements have only been performed for evaporation and condensation occuring inside tubes (Kakac, 1998). There are no reports of shell side evaporation and condensation of R-134a.

A comparison of the properties for R-12 and its replacement R-134a are presented in Tables 2 and 3.

Table 2. Comparison of R-12 and R-134a Properties at t=40°C

Property	R-12	R-134a	Diffe-rence %	Effect on Heat Transfer
Liquid density, kg/m^3	1253	1147	–8,5	↑ Slightly
Vapor density, kg/m^3	55,0	50,0	–9,1	↓ Slightly
Enthalpy of vaporization, kJ/kg	128,0	163,1	+26,8	↑ Moderate
Saturation pressure, MPa	0,9607	1,017	+5,9	~ 0
Liquid viscosity, μPa s	195	163,4	–16,2	↑ Slightly
Vapor viscosity, μPa s	13,78	14,31	+3,8	↓ Slightly
Vapor thermal conductivity, mW/mK	11,0	15,56	+41,5	↑ Slightly
Liquid thermal conductivity, mW/mK	63,8	74,6	+16,9	↑ Strong
Liquid specific heat, kJ/(kg K)	1,01	1,514	+49,9	↑ Slightly
Vapor specific heat, kJ/(kg K)	0,7857	1,130	+43,8	↑ Slightly
Liquid Prandtl number	3,09	3,32	+7,4	↑ Slightly
Vapor Prandtl number	1,03	1,04	+0,9	↑ Slightly

t = condensation temperature

These tables provide to the designer information on the two refrigerants properties utilized in heat exchangers calculation, and also qualitative information useful when the designer asks design changes when time comes for implement the alternative refrigerant.

Table 3. Comparison of R-12 and R-134a Properties at t_0=–5°C

Property	R-12	R-134a	Diffe-rence %	Effect on Heat Transfer
Liquid density, kg/m^3	1417	1308	–7,7	↑ Slightly
Vapor density, kg/m^3	15,4	12,2	–20,8	↓ Slightly
Enthalpy of vaporization, kJ/kg	153,9	202,3	+31,4	↑ Moderate
Saturation pressure, MPa	0,261	0,243	–6,9	~ 0
Liquid viscosity, µPa s	284	3,01	+6,0	↓ Slightly
Vapor viscosity, µPa s	11,3	12,2	+7,9	↓ Slightly
Vapor thermal conductivity, mW/mK	8,01	11,77	+46,9	↑ Slightly
Liquid thermal conductivity, mW/mK	80,8	98,1	+21,4	↑ Strongly
Liquid specific heat, kJ/(kg K)	0,922	1,297	+40,6	↑ Moderate
Vapor specific heat, kJ/(kg K)	0,629	0,868	+38,0	↑ Slightly
Liquid Prandtl number	3,24	3,98	+22,6	↑ Slightly
Vapor Prandtl number	0,89	0,99	+11,2	↑ Slightly

t_0 = evaporation temperature

It can be observed that the liquid thermal conductivity, enthalpy of vaporization and liquid specific heat are all significantly higher for R-134a compared to R-12. That's why all three of these properties contribute to higher heat transfer coefficients.

Heat transfer coefficients have been measured during condensation and evaporation of R-134a, for a 3,67 m long smooth tube with an inner diameter of 8,0 mm. Average evaporation heat transfer coefficients for almost a full quality range are shown in Figure 6, for evaporation temperatures of 5, 10 and 15°C.

For similar mass fluxes, the heat transfer coefficients for R-134a are about 30% to 40% higher than values for R-12. Part of this transfer coefficient is due the fact that to obtain similar exit qualities for the same tube length, it was necessary to increase the heat flux for R-134a. The reason for this increase is that enthalpy of vaporization is higher by R-134a.

A comparison of R-134a and R-12 at condensation temperatures of 30, 40 and 50°C is shown in Figure 7. It can be observed that the in-tube condensation heat transfer coefficients are about 25% to 30% higher for R-134a.

The differences in heat flux for R-134a and R-12 does not have the same effect for condensation as it does for evaporation.

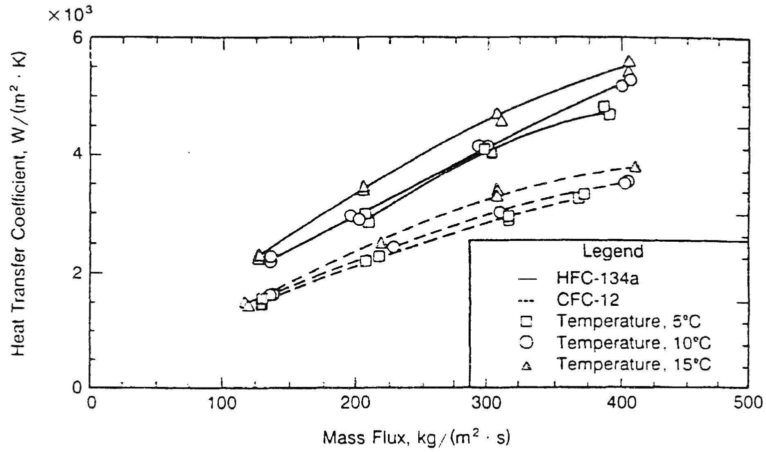

Figure 6. Evaporation heat transfer coefficients for R-134a and R-12 at t of 5°C, 10°C, 15°C

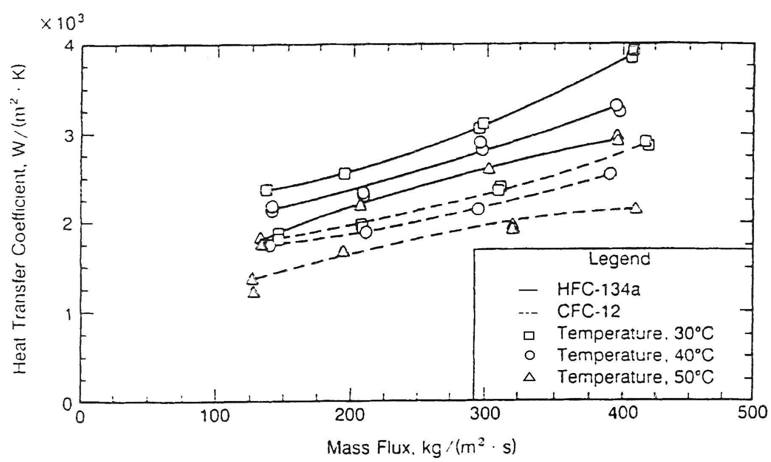

Figure 7. Condensation heat transfer coefficients for R-134a and R-12 at t of 30°C, 40°C, 50°C

It is important to mention that for low evaporating temperatures and pressures, suction line pressure drops are likely to be more critical for R-134a. Also, at any particular operating condition, the match between compressor valve characteristic and compression ratio will be important. This suggest that R-12 equipment with generously sized components and with a compressor which is efficient at higher compression ratios will be best suited to conversion to R-134a, other things being equal.

HFC refrigerants show higher polarity in comparison to CFC. Mineral and alkylene benzene oils are not polar and therefore not miscible with the alternative HFC refrigerants. Polyol ester oils are polar lubricants and show a good miscibility with the new refrigerants. It is important to remove the old oil from refrigeration system. If the residual old oil content is to high, it can accumulate in the evaporator, resucing the heat transfer and therefore lower the performance of the system.

Experiences obtained from retrofitting R-12 plants to R-134a have shown that two ester oil changes will suffice for all plants having an evaporating temperature of $-5^{o}C$ or higher. Heat pumps, water chillers, and air conditioning units that have been well maintained will not require a further oil change until scheduled maintenance period. The same applies to plants having lower evaporating temperatures, where the length of the piping is not great.

Oil sample analysis are recommended and the results will indicate the degree of contamination of the system. The combination of ester oils and polar refrigerants like HFC is known to be an excellent solvent for deposits of reaction products and oxidants of previously used oils and refrigerants. The deposits are partly dispersed. If the ester oil reaches saturation, deposits will precipitate in filters and dryers. Systems with very long piping are perticularly susceptible to accumulation of old oil and water residues, in additionto the deposits described above.

4. Conclusion

In this paper, a replacement refrigerant for R-12, mainly used on older ships have been presented. It treats about R-134a which shows promising results. It is a hydroflorocarbon that does not deplete the ozone layer.

On the basis of the EPA emission scenario for R-134a in the year 2010, this product would contribute to 0,6% of the effect of greenhouse gases from human activity. It can be assumed that total HFC contribution is likely to be less than 1%, a figure which will be further reduced by the actual trend in reducing leakage rates from refrigeration installations.

Based on UNIDO’s activities in Romania to convert the application of CFCs to environmentally friendly refrigerants, the process of conversion in marine refrigeration sector from developing countries is discussed.

R-134a can be used to replace R-12 in containers and clip-on units with few alternation to existing equipment.

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