Drop-In Substitutes for R502: The Role of HCFC22 and HC290

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ABSTRACT

R502 is due to be banned in the near future, and the need for an immediately available and easy-to-use alternative is becoming more and more urgent. Retrofitting refrigerating units can prove easier and less expensive if the mineral or alkylbenzene lubricants usually adopted with R502 have a certain miscibility in the drop-in mixtures. This paper examines the near-azeotropic mixture R143a/290/22 evaluating the influence of the R22 and of R290 mass fractions on the oil miscibility and on operating conditions in the refrigerating units.

INTRODUCTION

R502 is currently the most commonly used refrigerant in commercial cold storage; it is due to be banned worldwide by January 1st, 1996, according to the Copenhagen amendment of the Montreal Protocol, and by January 1st, 1995 within the European Union according to a 1992 EEC Regulation. Suitable alternatives for retrofitting refrigerating units should therefore become available very soon. Individual halogenated hydrocarbons have been investigated with poor results and more efforts are now being dedicated to binary or ternary mixtures.

The mixtures selected for replacing R502 can be divided into two categories:

- the zero Ozone Depletion Potential (ODP) mixtures, designed for original equipment manufacturers (OEMs);
- mixtures containing HCFC (mostly R22), which are immediately available and intended for retrofitting refrigerating units in the short term.

A few zero ODP mixtures have been developed and are now available. Their use as drop-in refrigerants raises some concern because polyol-ester lubricants are frequently required. The mineral or alkylbenzene oils usually adopted with R502 have to be replaced, and several charges of the refrigerant and lubricant are needed to achieve a satisfactory procedure. On the other hand, mixtures based on HCFCs can prove effective alternatives for retrofitting R502 units: a certain compatibility with mineral and alkylbenzene lubricants is their most important feature; their components are all well known and they also offer immediate availability and good performance.

The development of short-term mixtures containing HCFCs was suggested after the signing of the Montreal Protocol because no suitable substitute for R502 was known at the time. The Copenhagen amendment of the Montreal Protocol calls for the phase-out of HCFCs with a time schedule that allows for their use in drop-in mixtures replacing R502 in existing plants (up until January 1st, 2030). In December 1992, the European Communities Union defined a new phase-out schedule for HCFCs, setting the final ban at January 1st, 2015. In Germany and Italy the phase-out has been brought forward to January 1st, 2000. Nonetheless, R22 and all the other HCFCs have to be taken into consideration for the formulation of short-term substitutes of R502 in order to make retrofitting easier and less expensive.

Some R22-based mixtures are already available, and many have responded well to tests in refrigerating equipment without making any changes to the circuit or lubricating oil. The Institute for Refrigeration of the Italian National Research Council is involved in investigating refrigerant mixtures, and the Ausimont company intends to present a drop-in substitute for

R502. In this paper the R143a/290/22 mixture is analyzed as a typical of these short-term replacement mixture, evaluating the influence of the R22 and R290 mass fractions on oil miscibility and operating conditions in the refrigerating units.

LUBRICANT MISCIBILITY

The lubricant for the compressor in a refrigerating unit should have a certain miscibility in the refrigerant in order to ensure that the oil returns properly to the compressor. In refrigerating units charged with R502 a mineral or alkylbenzene oil is usually adopted; these lubricants have only partial miscibility in R502. Identifying alternative refrigerants with mineral or alkylbenzene lubricants having comparable miscibility can greatly simplify conversion of the refrigerating units. Mixtures containing R22 have a certain compatibility with these lubricants. Starting with the R143a/22 mixture, experimental measurements of critical solubility data were performed. Fig. 1 shows the miscibility of the Esso Zerice S46 alkylbenzene oil in R502 and in R143a/22 mixtures (50/50 and 29/71): the presence of the R22, in which the lubricant is highly soluble, was found very significant in improving miscibility in the mixture.

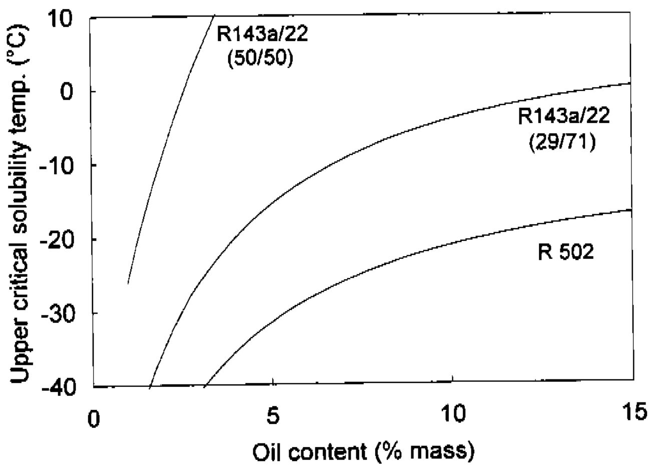

Fig. 1 - Miscibility of alkylbenzene oil in R143a/22 (50/50 and 29/71) and R502.

A further increase in the miscibility of the alkylbenzene oil in the R143a/22 mixture can be obtained by adding R290.

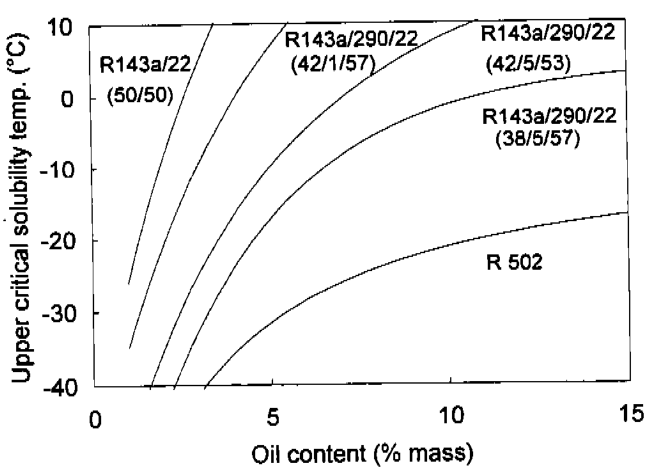

Fig. 2 - Miscibility of alkylbenzene oil in R143a/22(50/50), R143a/290/22 (various compositions) and R502.

Fig. 2 represents the miscibility of the alkylbenzene oil in the ternary mixture R143a/290/22 in different compositions, taking R502 and R143/22 (50/50) for reference. Comparison of the critical solubility data for the mixtures R143a/290/22 (42/1/57) and (38/5/57) demonstrates the remarkable effect of the hydrocarbon on the miscibility of the lubricant. The mixtures R143a/290/22 (38/5/57) and R143a/22 (29/71) are almost equivalent in terms of miscibility with the alkylbenzene oil.

The same tests were performed with the mineral oil Suniso 3GS. Fig. 3 illustrates the critical solubility data for this lubricant oil in the R143a/290/22 (42/1/57 and 38/5/57) mixture with R143a/22 (50/50) and R502 for reference.

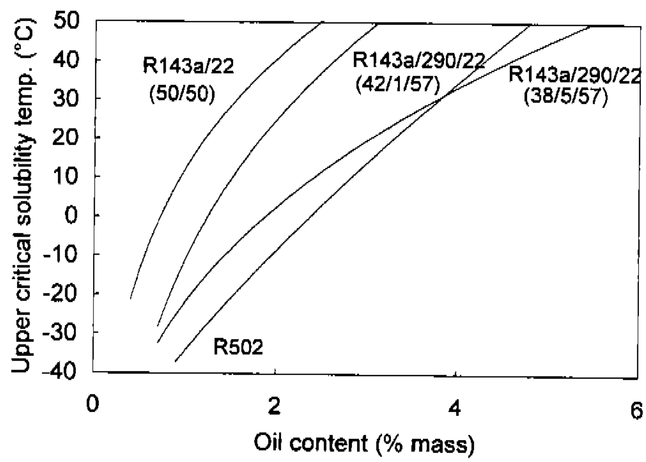

Fig. 3 - Miscibility of mineral oil in R143a/22 (50/50), R143a/290/22 (various compositions) and in R502.

The experimental data reveal the lower miscibility of the mineral oil in all the refrigerants: the influence of the R22 and R290 mass fractions always remains remarkable and their significance in the retrofit mixtures is emphasized.

IDEAL CYCLE PERFORMANCE

The performance of the ternary mixture R143a/290/22 was evaluated in the R22 mass fraction range 0.4-0.7 and in the R290 mass fraction range 0-0.05, referring to the ideal cycle in fig. 4. It is assumed for all the refrigerants that the dew-point temperature in the condenser and the refrigerant temperature at the evaporator inlet are kept the same.

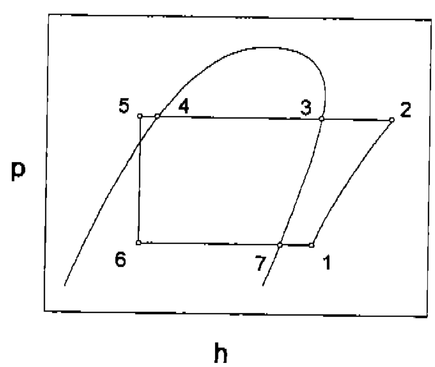

Fig. 4 - Reference cycle for refrigerant performance.

t_3	=	45	°C
t_6	=	-25	°C
t_4-t_5	=	5	°C
t_1-t_7	=	45	°C
h_{ie}	=	1	

The most significant results are summarized in figs. 5 to 9. The performance of a refrigerating unit is always enhanced by replacing R502 with the R143a/290/22 mixture. The refrigerating capacity is 7% to 12% higher than with R502, depending on the R290 mass fraction; the COP is 4% to 8% higher, particularly depending on the R22 mass fraction. As refrigerating capacity and efficiency are always enhanced, the performance of the unit is not significant in the choice of composition for the mixture. The condensing pressure increases slightly, but the difference in pressure ratio is negligible.

Serious problems may stem from the increase in the discharge temperature due to the R22 (fig. 9). At the R22 mass fraction of 0.7, the discharge temperature is 14°C higher than with R502, and adding R290 in the mass fraction of 0.05 can reduce the temperature by no more than 2°C. At the R22 mass fraction of 0.4, the increase in the discharge temperature is 4.5°C, an acceptable value for almost all applications.

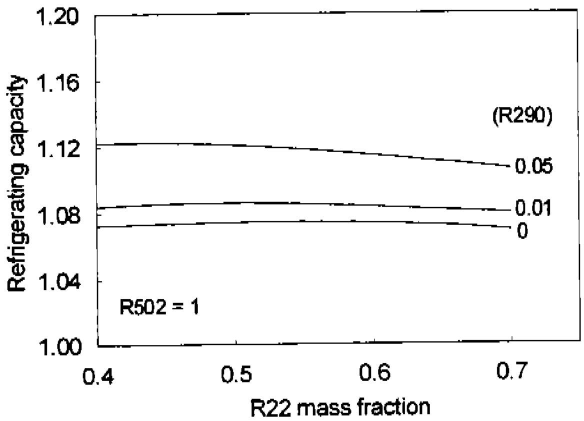

Fig. 5 - Refrigerating capacity of the R143a/290/22 mixture by comparison with R502 in an ideal cycle.

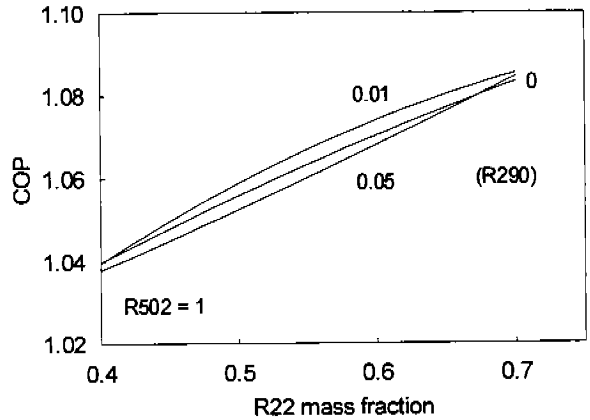

Fig. 6 - Coefficient of performance of the R143a/290/22 mixture by comparison with R502 in an ideal cycle.

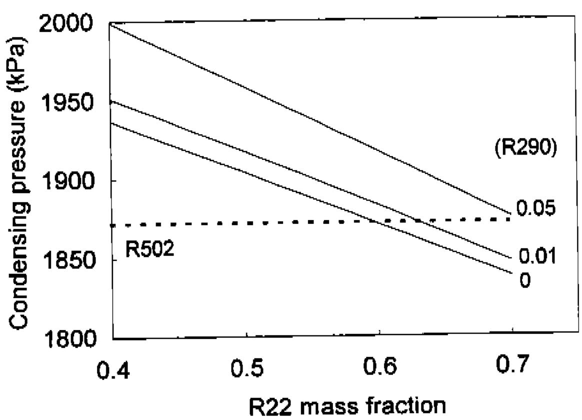

Fig. 7 - Condensing pressure of the R143a/290/22 mixture by comparison with R502 in an ideal cycle.

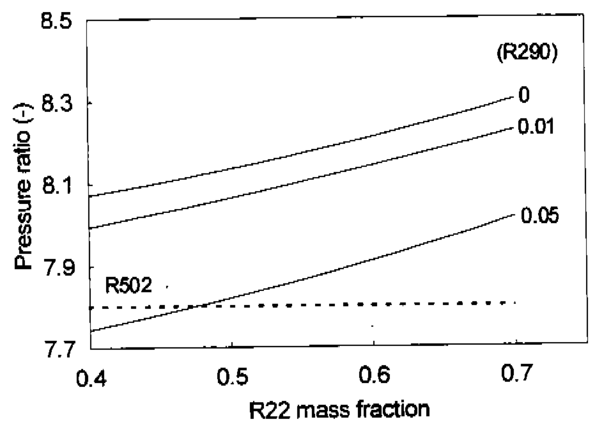

Fig. 8 - Pressure ratio of the R143a/290/22 mixture by comparison with R502 in an ideal cycle.

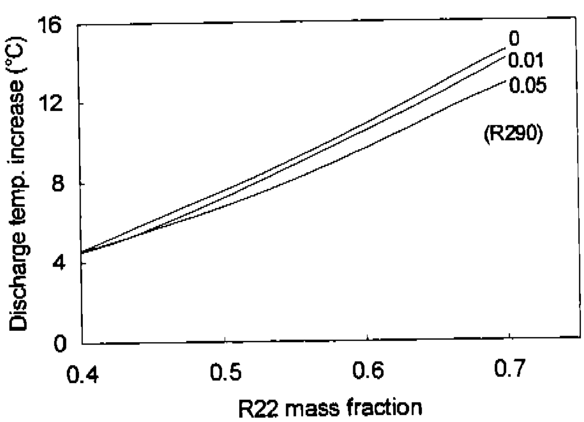

Fig. 9 - Discharge temperature increase of the R143a/290/22 mixture with respect to R502 in an ideal cycle.

The evaporating and condensing temperature glides always remain below 1°C for the mass fraction ranges of the mixture considered: this means that, in the event of any leakage of refrigerant, any change in the mixture's composition has little effect.

The Ozone Depletion Potential of R143a/290/22 is not zero due to the presence of R22 (ODP_{R22} = 0.05). Its ODP ranges between 0.02 and 0.035 for the mass fractions considered, and remains negligible compared to that of R502 (0.2). The Global Warming Potential is 15-20% of the value for R502. Due to the lower GWP and to enhanced efficiency, the Total Equivalent Warming Impact of the mixture is expected to be lower than for R502 in the applications considered.

Certain considerations emerge from analyzing the ideal cycle performance of the R143a/290/22 mixture as a substitute for R502 in relation to the oil miscibility measurements reported in the previous section. The R22 mass fraction in the mixture must be reduced as much as possible to avoid a significant increase in the compressor discharge temperature. A low mass fraction of R290 can be added to make currently-used lubricants more miscible in the mixture. The most suitable composition for general purposes is difficult to identify, as many important and conflicting requirements are involved. Assuming the need for a drop-in replacement for R502, a high R22 mass fraction could be acceptable for applications in which the original discharge temperature is low. For applications with a low evaporating temperature, oil miscibility can improve remarkably with the addition of R290 to a low R22 mass fraction mixture. One of the most important features of R502 - its low discharge temperature - can thus be maintained.

TESTING A REFRIGERATING UNIT

A closed frozen food display cabinet was tested to compare the performance of the R143a/290/22 mixture with that of R502. The main characteristics of the cabinet were as follows: net volume 1290 dm^3; hermetic compressor; original capillary tube replaced by an expansion valve to keep the same test conditions for all refrigerants. The cabinet was placed in a test room at 25 ± 1°C, the air inside the cabinet was maintained at -20°C by means of an electric heater and the refrigerant temperature at the evaporator outlet was kept at -20°C. Refrigerating capacity was measured using the calorimetric method in steady-state conditions. The original mineral oil was not changed.

Two mixtures were chosen for the tests: R143a/290/22 (28/2/70) and R143a/290/22 (38/5/57). No further tests on oil miscibility and transport or materials compatibility were performed on the unit. The most significant test results are listed in Table I.

Table I - Results of tests on a closed refrigerating cabinet with R502 and R143a/290/22.

		R502	R143a/290/22 (28/2/70)	R143a/290/22 (38/5/57)
refrigerant mass	(g)	990	876	871
compressor suction temperature	(°C)	-13.0	-11.7	-11.7
compressor discharge temperature	(°C)	102.2	114.7	109.7
condenser inlet temperature	(°C)	94.0	104.0	102.9
condenser outlet temperature	(°C)	32.0	32.0	32.3
expansion valve inlet temperature	(°C)	31.6	31.6	31.8
evaporator inlet temperature	(°C)	-24.5	-24.6	-24.7
evaporator outlet temperature	(°C)	-19.9	-20.0	-19.9
compressor suction pressure	(kPa)	185	191	205
compressor discharge pressure	(kPa)	1579	1600	1701
pressure ratio	(-)	8.53	8.38	8.30
evaporator inlet pressure	(kPa)	255	243	262
condenser outlet pressure	(kPa)	1521	1544	1636
refrigerant mass flow rate	(kg/h)	33.40	25.57	26.93
total electric power	(W)	1313	1336	1380
refrigerating capacity	(W)	858	984	1016
COP	(-)	0.65	0.74	0.74

The outcome of testing the R143a/290/22 mixture as a drop-in for R502 suggests the following considerations: operating pressures increase by 5-10% with respect to R502, but the pressure ratio is slightly lower; the unit's performance in terms of refrigerating capacity and efficiency increases, with a 2-5% higher electrical absorption; the discharge temperature increase is 12.5°C with the R143a/290/22 (28/2/70) mixture, and 7.5°C with the R143a/290/22 (38/5/57) mixture. Because efficiency is higher, the Total Equivalent Warming Impact of the mixture in this application is lower than that for R502.

CONCLUSIONS

Mixtures containing R22 are probably the most suitable refrigerants for the drop-in substitution of R502. Investigations carried out by the ITEF-CNR and Ausimont on the near azeotropic mixture R143a/290/22 show a considerable influence of R22 and an even greater effect of R290 on the miscibility of the mineral and alkylbenzene lubricants usually adopted with R502. Some concern may derive from the high discharge temperature with high R22 mass fractions, so the most suitable composition depends on the application. For low-evaporating-temperature applications - and providing that flammability is not a problem - adding an R290 mass fraction of 0.05 to the mixture ensures sufficient oil solubility with a 0.57 R22 mass fraction. Refrigerating capacity and efficiency are improved in the refrigerating unit tested here, and the TEWI of the mixture is always lower than that of R502 in all the compositions considered.

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