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ABSTRACT

The mixture R290-R134a is analyzed as a short-term substitute of R12 for the retrofit of the refrigerating units where refrigerating capacity plays an essential role. The vapour-liquid equilibria and the thermodynamic properties of the mixture are predicted by the Soave equation of state. The performances of this semi-azeotropic mixture are calculated for evaporating temperatures in the range -20 ÷0°C and are compared with those of the pure refrigerants R12, R134a and R152a. A series of tests was carried out on a refrigerating unit for perishable goods delivery vehicles: the results show that the mixture R290-R134a (0.1/0.9) assures the same refrigerating capacity of R12 without any modification in the components of the circuit and with a COP close to that of R134a.

INTRODUCTION

The selection of the refrigerant for the mid-term substitution of R12 favoured R134a. This selection did not disregard some flammable refrigerants, having first-rate thermodynamic performances like R152a, which was considered a replacement of R12 in small refrigerating equipments with hermetic compressor [1]. R134a is not flammable but has both a lower coefficient of performance and volumetric refrigerating than those of R12 (table 1).

Appropriate design of the new systems running with R134a may improve their actual COP so as to reach that of R12. In the case of the retrofit, consisting in substituting only the refrigerant and the lubricant oil, the COP of R12 seems to be hardly achievable with R134a; surely it is impossible to achieve the refrigerating capacity of R12. One of the means to increase the refrigerating capacity could be the addition of a high performance refrigerant like R22 or R290 to R134a. The addition of R22 seems to give some troubles since it is going to be banned by German laws in new systems by the end of 1999 [2]. On the other hand, the addition of R290 is supported by the following considerations [3]:

- it has no ODP and a very low GWP;
- it is non-toxic and has non-toxic products of combustion;
- its thermophysical and thermodynamic properties are well known;
- it has a good compatibility with the materials used in R22, R502 and R12 systems;
- in the presence of moisture it does not hydrolyse to form acids;
- it is a by-product of natural gas and is already widely used as a fuel;
- its cost is very low.

In spite of its flammability range (2.1 - 9.6 vol % in air) [4] R290 is nowadays suggested as a component of refrigerant mixtures. The risk due to flammability may be restricted by avoiding high mass fractions of R290 in the mixture.

Table 1 - Comparative performances of R12, R134a, R152a. Superheating 3 K, subcooling 0 K, isentropic efficiency 0.7.

		R12	R134a	R152a	R12	R134a	R152a
evaporating temperature	(°C)	-17.0	-17.0	-17.0	-7.0	-7.0	-7.0
evaporating pressure	(bar)	1.70	1.51	1.42	2.44	2.26	2.11
condensing temperature	(°C)	35.0	35.0	35.0	35.0	35.0	35.0
condensing pressure	(bar)	8.47	8.87	8.05	8.47	8.87	8.05
pressure ratio	(-)	4.99	5.87	5.65	3.47	3.93	3.85
discharge temperature	(°C)	65.6	59.7	77.4	58.6	54.2	67.7
suction vapour density	(kg/m^3)	9.99	7.46	4.54	14.05	10.90	6.56
refrigerating effect	(kJ/kg)	111.77	140.64	233.63	116.57	147.31	241.51
vol. refrigerating effect	(kJ/m^3)	1117	1050	1060	1638	1606	1584
COP	(-)	2.67	2.60	2.75	3.61	3.51	3.69

We are trying to find a means to increase the refrigerating capacity in the application of the retrofit. In this work we take into consideration the mixture R290-R134a. The results of a series of tests performed on a refrigerating unit for perishable goods delivery vehicles are also presented. The unit, which had been designed to operate on R12, was modified to serve as a test rig for the mixture.

PERFORMANCES OF THE MIXTURE R290-R134a

The performances of the mixture R290-R134a were predicted with some uncertainties due to the lack in vapour-liquid equilibria experimental data. The VLE were calculated at the following temperatures: -20, 0, 20, 40, 60 °C [5]. On the basis of these results we calculated the thermodynamic properties of the mixture by means of the Soave equation of state (1) together with the quadratic mixing rules (2):

$$p = \frac{RT}{v - b_m} - \frac{a_m}{v(v + b_m)} \tag{1}$$

$$a_m = x_1^2 a_1 + 2x_1x_2(1 - k_{12})\sqrt{a_1 a_2} + x_2^2 a_2 \qquad b_m = x_1^2 b_1 + 2x_1x_2\frac{b_1 + b_2}{2} + x_2^2 b_2 \tag{2}$$

$$a_i = a_{c_i}\left[1 + \left(1 - \frac{T_i}{T_{c_i}}\right)\left(m_i + n_i\frac{T_{c_i}}{T_i}\right)\right] \tag{3}$$

k_{12} is the binary interaction parameter, x_1 and x_2 are the molar fractions of the low and high boiling component respectively [6], [7], [8].

Table 2 - Critical pressure, critical temperature and Soave equation coefficients for R290 and R134a. The interaction parameter of the mixture R290-R134a is $k_{12} = 0.01232$.

	p_c (bar)	T_c (K)	a_c ($N\ m^4kg^{-2}$)	b (m^3kg^{-1})	m (-)	n (-)
R290	42.47	369.85	489.055	0.001421	0.6199	0.1429
R134a	40.66	374.25	97.770	0.000649	0.7870	0.2516

Figures 1 and 2 show vapour-liquid equilibria at pressures of 1 and 10 bar. At the pressure of 1 bar the maximum temperature glide of the mixture is 2.8 K at the mass fraction 0.47 and therefore the mixture can be classified as semi-azeotropic [9].

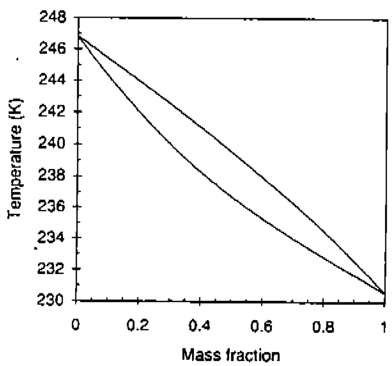

Figure 1 - Vapour-liquid equilibria of the mixture R290-R134a at 1bar.

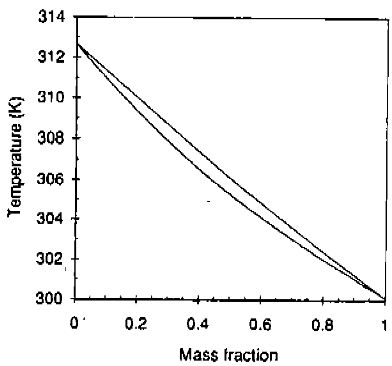

Figure 2 - Vapour-liquid equilibria of the mixture R290-R134a at 10 bar.

In order to compare the performances of the mixture and those of pure refrigerants, we set the temperature of the mixture at the inlet of the evaporator and its dew point in the condenser equal to the evaporating and condensing temperatures of table 1.

Table 3 - Performances of the mixture R290-R134a at various mass fractions. Superheating 3 K, subcooling 0 K, isentropic efficiency 0.7.

		R290-R134a			R290-R134a		
		(0.1/0.9)	(0.2/0.8)	(0.3/0.7)	(0.1/0.9)	(0.2/0.8)	(0.3/0.7)
evaporator inlet temp.	(°C)	-17.0	-17.0	-17.0	-7.0	-7.0	-7.0
evaporating pressure	(bar)	1.76	1.96	2.13	2.59	2.86	3.07
condenser dew point	(°C)	35.0	35.0	35.0	35.0	35.0	35.0
condensing pressure	(bar)	9.52	10.07	10.54	9.52	10.07	10.54
pressure ratio	(-)	5.41	5.13	4.96	3.68	3.53	3.44
discharge temperature	(°C)	59.8	59.9	60.0	54.3	54.4	54.5
suction vapour density	(kg/m^3)	7.69	7.71	7.59	11.10	10.99	10.73
refrigerating effect	(kJ/kg)	154.29	166.49	178.74	161.49	174.10	186.80
vol. refrigerating effect	(kJ/m^3)	1190	1280	1360	1790	1910	2000
COP	(-)	2.66	2.66	2.66	3.60	3.61	3.60

The results reported in table 3 show that a small addition of R290 to R134a produces a COP comparable to that of R12 and even a higher volumetric refrigerating effect than that of R12. The pressure ratio and the discharge temperature are not particularly affected by the mass fraction of R290. Since even a minimum quantity of R290 increases the performances of R134a, an experimental test for the mixture R290-R134a at the mass fractions 0.05, 0.10, 0.15 sounds reasonable.

TESTS: METHOD AND CONDITIONS.

The refrigerating unit chosen for our tests is a split unit for perishable goods delivery vehicles. In fact the loss of the refrigerating capacity in this kind of application makes the conversion from R12 to R134a troublesome, mainly at low evaporating temperatures.

The evaporating unit was installed inside a calorimeter (1400x1000x1100 mm), and both the calorimeter and the condensing unit were placed inside a temperature controlled room. The original thermostatic valve was replaced by a manually operated expansion device, in order to keep the same internal superheating for the all tested refrigerants. The superheating was measured as the difference between the internal temperature of the refrigerant leaving the evaporator and the evaporation temperature for pure refrigerants or the dew point temperature for mixed refrigerants, both calculated from the measured value of the evaporating pressure. Figures 3 and 4 show the results of a preliminary series of tests aiming to select the most suitable superheating. A 3 K superheating was chosen for all the tests.

The refrigerating capacity was measured by the calorimetric method; the temperature of the air entering the condenser was kept at 30 ± 1 °C, and for each refrigerant the temperature of the air into the calorimeter was 0 ± 1 °C, -3.3 ± 1 °C, -6.6 ± 1 °C, -10.0 ± 1 °C. For the COP measurement only the power input of the electric motor driven compressor was considered.

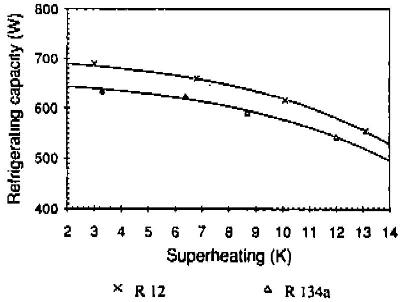

Figure 3 - Measured refrigerating capacity. Temperature of the air entering the evaporator: 0 °C.

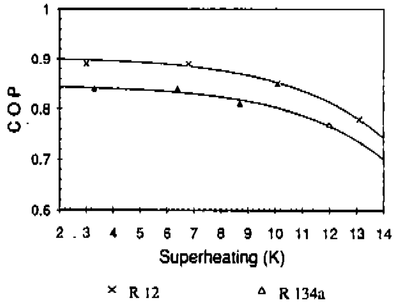

Figure 4 - Measured COP. Temperature of the air entering the evaporator: 0 °C.

TEST RESULTS

The most significant test results are shown in figs. 5,6,7,8,9, in which the refrigerating capacity, the electric power, the COP, the condensing and evaporating pressures are plotted against the temperature of the air entering the evaporator.

The replacement of R12 with R134a produces a decrease both in the refrigerating capacity (-8 % at 0°C air entering the evaporator and -16 % at -10 °C air entering the evaporator) and in the COP (-6 % at 0°C air entering the evaporator and -12 % at -10 °C air entering the evaporator).

These decreases are higher than the predicted values, and this is probably due to the fact that the unit was designed for R12 and not for R134a. The original performances of the unit

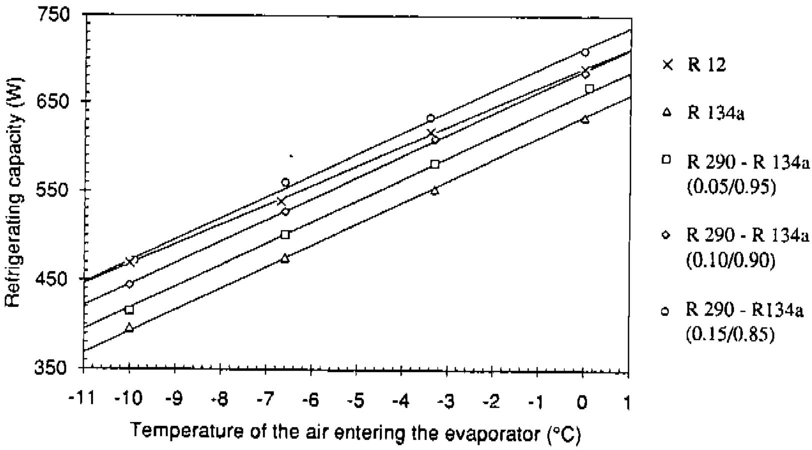

Figure 5 - Refrigerating capacity of the tested unit. Superheating: 3 K.

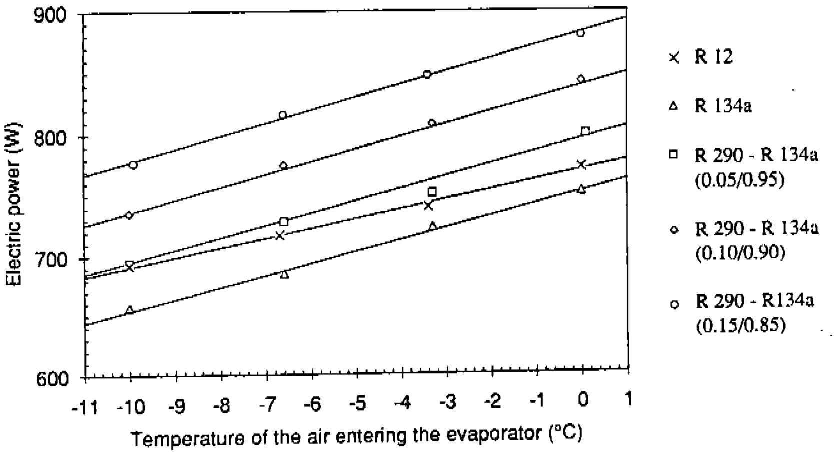

Figure 6 - Electric power consumption of the tested unit. Superheating: 3 K.

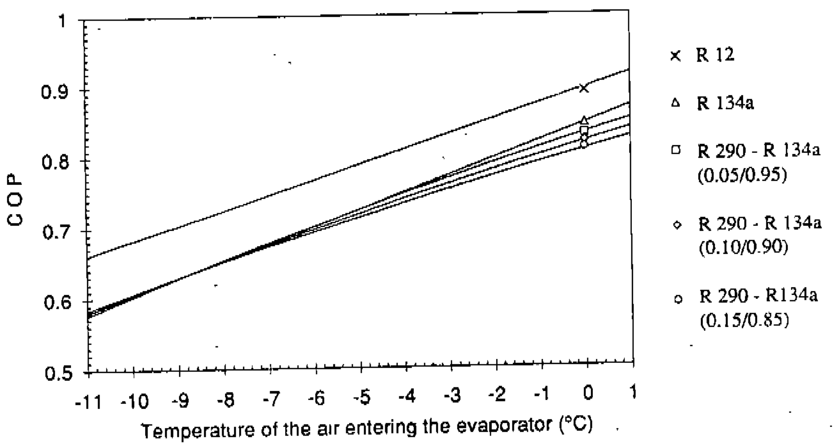

Figure 7 - Coefficient of performance of the tested unit. Superheating: 3 K.

seem to be hardly achievable unless changes in the components of the circuit are made.

A small addition of R290 to R134a results in an increase of the refrigerating capacity roughly proportional to the mass fraction of R290. At the lower evaporating temperatures the COP is unaffected by the mass fraction of R290 and, at higher evaporating temperatures, the COP decreases as the mass fraction of R290 increases.

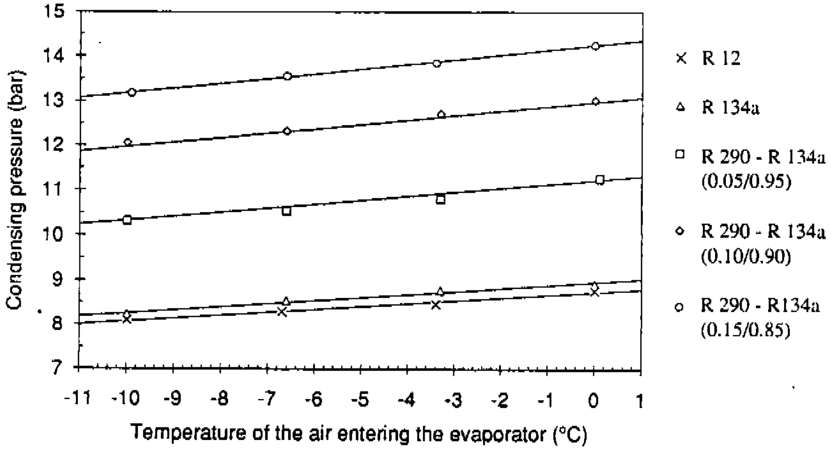

Figure 8 - Condensing pressure of the tested unit. Superheating: 3 K.

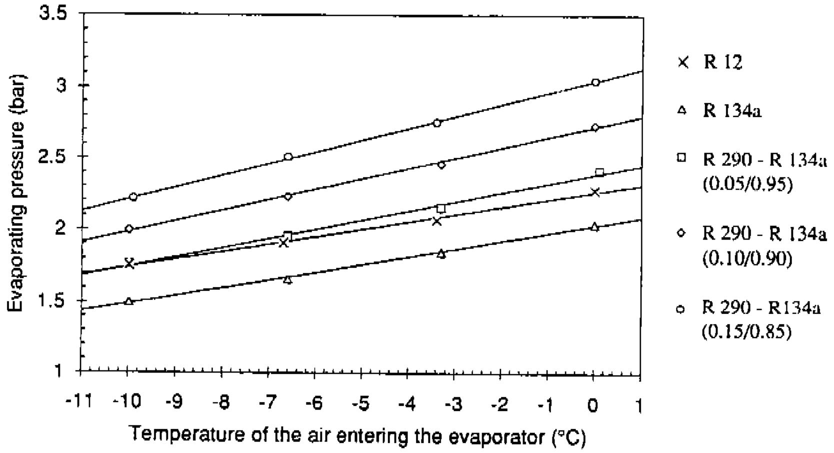

Figure 9 - Evaporating pressure of the tested unit. Superheating: 3 K.

An increase of the condensing and evaporating pressures is to be expected by mixing R134a with a low boiling refrigerant like R290.

At 0 °C air entering the evaporator the unit filled with the mixture R290-R134a (0.1/0.9) achieves the refrigerating capacity of the unit filled with R12 and its COP is similar to that of the unit filled with R134a.

CONCLUSIONS

R134a is a substitute of R12 both for new and existing refrigerating systems.

New systems may be properly designed to match the properties of this HFC in order to reach the performances obtained with the outdated CFC.

When R12 is no more available, the retrofit will become necessary in existing equipments and R134a may be charged after the lubricant change without modifying any component of the circuit, but resulting in a refrigerating capacity loss. However, there are some units like those used for refrigerated transports, which absolutely need to keep the refrigerating capacity so as to satisfy the ATP [10]. In this case mixing R134a with R290 or R22 would easily overcome this obstacle. The results reported in this work refer only to the mixture R290-R134a and show that the mixture R290-R134a (0.1/0.9) can improve the performances of R134a as short-term substitute of R12. The first results of our tests on the mixture R22-R134a show that also the mixture R22-R134a (0.2/0.8) is able to reach the same refrigerating capacity of R12.

Both the two low boiling refrigerants have unfavourable features: R290 is flammable but the little mass fraction in the selected mixture may mitigate the risks due to the flammability; R22 contains chlorine and has a high GWP.

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