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Comparative Performances of HFA 134a and CFC-12 in a Reciprocating Water Chiller

D. Arnaud
ATOCHEM

J. P. Caillie
ATOCHEM

COMPARATIVE PERFORMANCES
OF HFA 134a AND CFC 12 IN A
RECIPROCATING WATER CHILLER

D. ARNAUD - J.P. CAILLIE

ATOCHEM Groupe ELF AQUITAINE
Centre d'Application de Levallois
95, rue Danton
92300 LEVALLOIS PERRET (FRANCE)

ABSTRACT

In order to compare the thermodynamic performances of HFA 134a and CFC 12 in a semi-industrial system, the authors have designed and tested an experimental 15 kW water chiller equiped with a semi-hermetic reciprocating compressor charged with naphtenic mineral oil.

Direct measurements have been made on :

. the total energy consumption of the compressor
. the frigorific energy produced at the evaporator

A good agreement was observed between these measures and the performances deduced from temperature, pressure and flow rate measurements on the refrigerant circuit.

. comparative thermodynamic performances of the unit
. efficiency of the compressor
. global heat transfert coefficient of the evaporator

were reported and discussed for both refrigerant HFA 134a and CFC 12 over a cold water temperature range of - 10°C to + 5°C and for a constant condensation temperature of + 32.5°C.

The influence of the charge of refrigerant on the performances of the unit has also been studied and is discussed.

After 500 hours of continuous operations it was not observed any mechanical or performances disfunctioning of the system due to the non miscibility of HFA 134a with the oil.

1 - INTRODUCTION

The use of Hydrofluoroalcane (HFA) 134a has been investigated in recent years for replacing CFC 12 in reciprocating compressors.

Several research and development activities are presently in progress for developping this new refrigerant, especially a lot of work is done to develop new synthetic oils miscible with HFA 134a. Polyalkylene glycols basis have been proposed [1-3] but seem not to meet all refrigeration industry requirements because of their high hygroscopy and thermal instability in contact with some materials present in the refrigeration system.

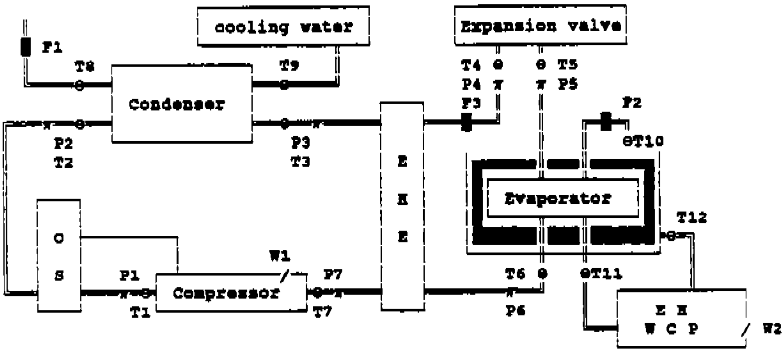
Few experimental results have been presented till now on the behaviour of HFA 134a in contact with standard mineral oil used today with CFC 12.

The objectives of this work was to evaluate the new refrigerant HFA 134a in an existing installation defined for CFC 12 and to show that it was possible in some cases, to use HFA 134a with standard naphtenic mineral oil, especially in an industrial system equiped with an oil separator.

2 - TEST INSTALLATION

The 15 kw water chiller used in these series of tests was developped and constructed by a french OEM, according our schedule.

A schematic diagram of the system is shown in figure 1.



<u>Sensors</u>

F : Flowmeters
T : Temperature gauges
P : Pressure gauges
W : Wattmeters

EHE : External heat exchanger
OS : Oil separator
EH : Electric heater
WCP : Water circulation pump

figure 1

<u>Compressor</u>

. reciprocating (3 pistons)

. displacement : 49.5 m^3/h at 1 450 rpm

. lubricant : original 150 SUS naphtenic mineral oil.

<u>Oil separator</u> :

. Oil capacity 770 cm^3

Condenser :

. horizontal multitubes

. 12 tubes of 1.2 m length each

. condensation of refrigerant outside tubes

Evaporator :

. coaxial tube-in-tube

. evaporation of refrigerant inside tube

Expansion valve

. thermostatic expansion valve with external pressure equalization

. R 22 bulbe (in the case of HFA 134a tests)

. R 12 bulbe (in the case of CFC 12 tests)

Calorimeter box

165 liters of a monoethylene glycol solution

The water chiller and calorimeter box include 25 sensors (flowmeters, wattmeters, temperature and pressure gauges) as shown in figure 1 which are connected to a computer.
Integration of the data were instantaneously made to generate a thermal assess of the system and follow directely the evolution of every crucial parameters.

3 - TESTS CONDITIONS

In this study, the condensation temperature has been maintained constant and equal to 32.5°C by adjusting the flow rate of the cooling water at the condenser.

For both refrigerant, the evaporator superheat was controlled and maintained constant equal to 3-4°C by adjusting the opening and closing of the thermostatic expansion valve.

The temperatures of the chilled water loop at the evaporator calorimeter were varied between - 10°C to + 5°C by adjusting the value of the electric heater.

Direct measurements of the evaporator capacity have been made at thermal equilibrium by measuring the total heat input (electric heater + water circulating pump + through - the-wall heat loss) at the calorimeter box containing the chilled water loop where the evaporator is merged.
Secondary estimation of the evaporator capacity has been obtained from the temperature, pressure and flowrate measurements on the refrigerant circuit ; good agreement (within 3-5 %) has been observed with the direct measurements and has permitted to check the validity of the theoretical thermodynamic properties of refrigerants tested.

Direct estimation of the condenser capacity has been made through the measurements of temperature rises and flowrate on the cooling water side.
A second estimate of the same evaporator capacity has been obtained from temperature, pressure and flowrate measurements on the refrigerant circuit and was also in good agreement with the first estimation.

The input power of the compressor was directly measured from a wattmeter.

Analysis of the efficiencies of the compressor for both refrigerant has been obtained from known (enthalpies, vapor density [4]) or measured (flowrate, temperature pressure) thermophysical properties of the tested refrigerant at working temperatures and pressures.

4 - PERFORMANCES TESTS RESULTS

Results presented here were extracted from the test data and are plotted in a serie of graphs comparing the evolution of some important parameters of the water chiller with both refrigerants CFC 12 and HFA 134a.

Thermodynamic data correspond to direct measurements made on the calorimeter box.

Frigorific capacity : Figure 2

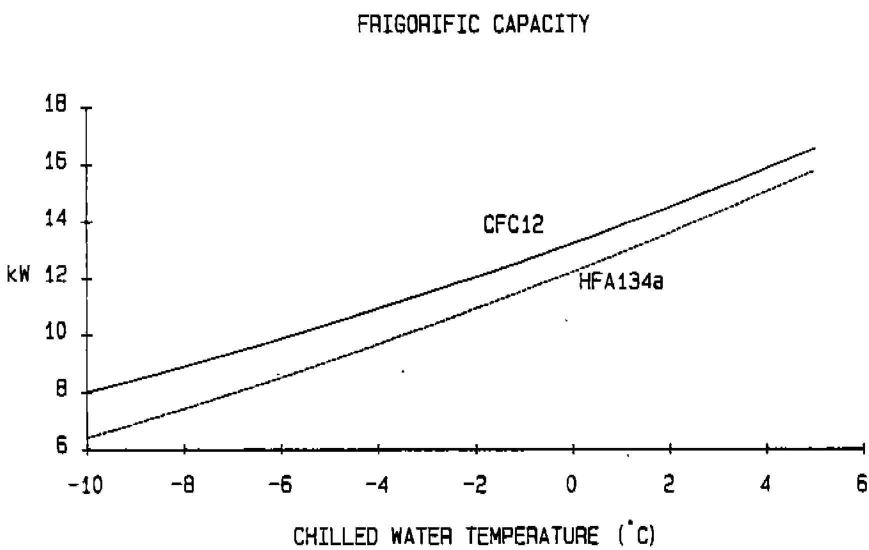


FIGURE 2

Results observed correspond to expected values deduced from theoretical thermodynamic properties of refrigerants CFC 12 and HFA 134a.

The frigorific capacity of the water chiller is 4 % to 15 % lower for HFA 134a over the range of cold water test temperatures.

However it is interesting to note that the difference becomes lower as the cold temperature increases, as at lower temperature, the volumetric efficiency of the compressor penalizes in greater extent HFA 134a because of its much more higher compression ratio (figure 3).

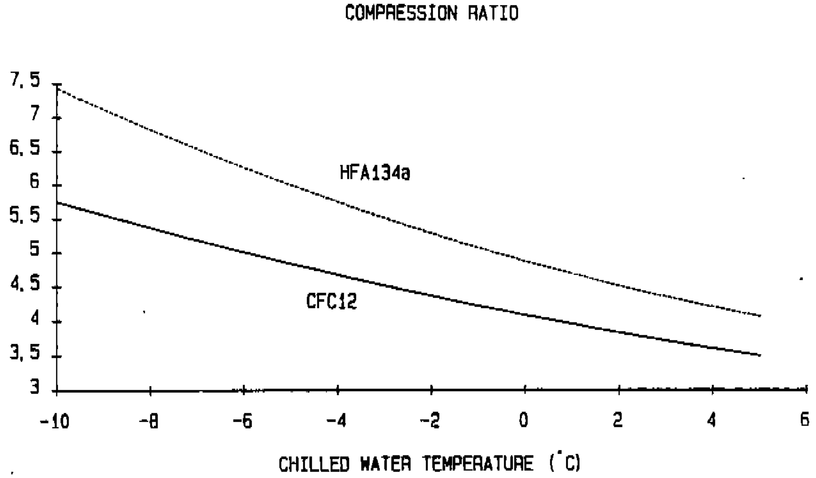


FIGURE 3

<u>Input power of the compressor</u> : **figure 4**

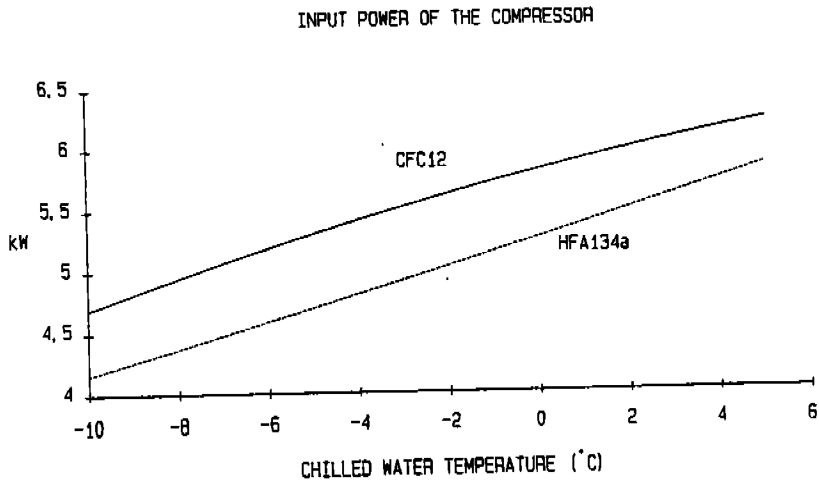


FIGURE 4

It has been observed that the difference of measured input power at the compressor between the two refrigerants tested remains constant, equal to 0.5 kW over the range of cold water tested temperatures, lower values being observed with HFA 134a (about 10 % comparing to CFC 12).
This difference is probably due to the lower density of HFA 134a vapors at given inlet temperatures.

<u>Coefficient of performance</u> : figure 5

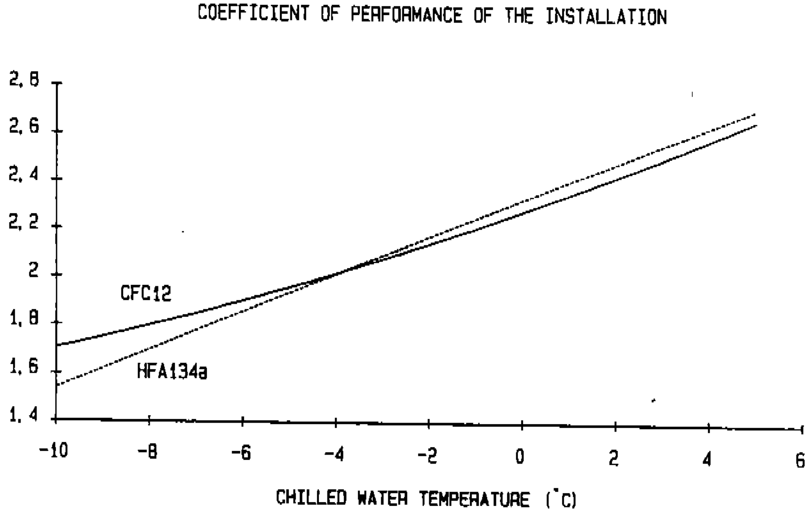


FIGURE 5

Compared to CFC 12, the coefficient of performance (COP) of the installation charged with HFA 134a varies between - 8 % and + 5 %, lower values being observed at low temperatures.
From - 4°C to + 5°C chilled water temperature the COP of the installation becomes greater in the case of HFA 134a, indicating better compressor yields.

<u>Compressor yields</u>

- <u>Isentropic efficiency</u> : figure 6

Isentropic efficiency of the compressor has been estimated from direct measurements of temperatures and pressures at the inlet and outlet of the compressor.
Because of reequilibration of temperature inside the compressor and measurements of temperature not precisely at the head cylinder, direct estimation was not possible for each refrigerant.

However for the same levels of temperatures measured, relative comparison was possible and is presented in figure 6.
It can be seen that isentropic efficiency is about 5 % higher for HFA 134a denoting a greater non adiabaticity of the compressor in the case of CFC 12.

RATIO OF THE ISENTROPIC EFFICIENCIES CFC12 / HFA134a

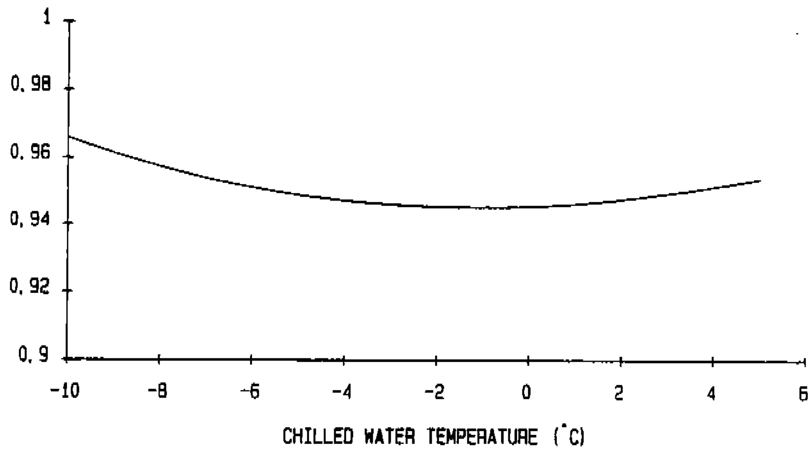


FIGURE 6

. <u>Volumetric yield</u> : figure 7

VOLUMETRIC YIELD OF THE COMPRESSOR

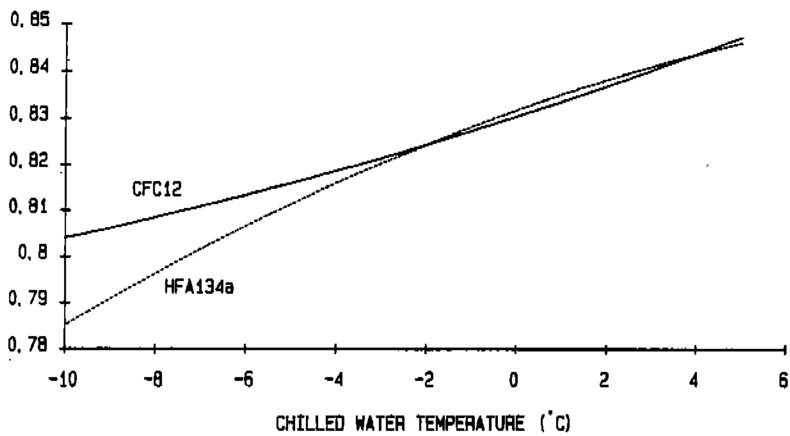


FIGURE 7

Volumetric yield has been estimated from the ratio of the actual volume swept by the compressor (directely deduced from measurements of refrigerant flowrate and temperature at the inlet) over the theoretical swept volume (given by the constructor).
From - 10°C to - 2°C this yield is slightly lower in the case of HFA 134a (2 % in the extreme conditions) corresponding to a greater compression ratio for HFA 134a.

· Overall heat transfer coefficient at the evaporator : figure 8

The overall heat transfer coefficient at the evaporator has been estimated from temperature and frigorific capacity measurements.

Refrigerants flowrates varied from :

- 4.5 to 8 kg/mn in the case of CFC 12
- 3 to 4.5 kg/mn in the case of HFA 134a

Experimental results show a lower (about 20 %) overall heat transfert coefficient for HFA 134a.

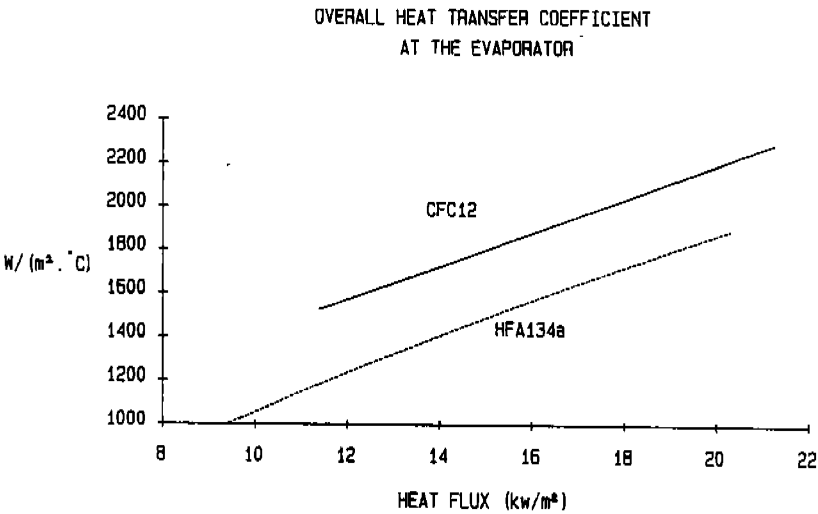


FIGURE 8

5 - INFLUENCE OF THE CHARGE OF REFRIGERANT

The influence of the charge of refrigerant on the variation of frigorific capacity at the evaporator has been studied in the same conditions as performances tests, at a constant cold temperature of - 2.5°C, by discharging the system.

Results on figure 9 show that the minimal refrigerant charge is lower of about 18 % for HFA 134a in the system, due to the greater heat of vaporization of HFA 134a comparing to CFC 12 at a given temperature.

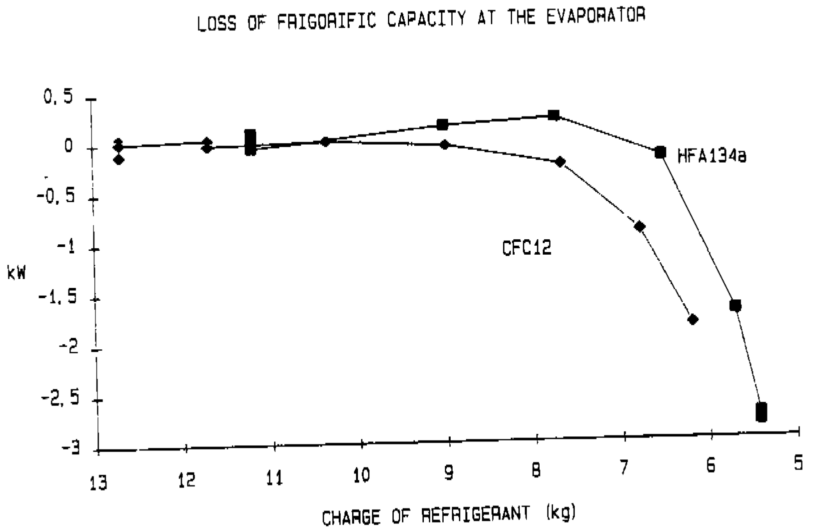


FIGURE 9

6 - STABILITY OF REFRIGERANT AND LUBRICATING OIL

Both refrigerants CFC 12, HFA 134a and lubricating oil were sampled and analysed before trials and after 500 hours of continuous operations.

Results of analysis are shown in table 1 and 2. It was not observed any significant changes in composition of oil and refrigerants due to a disfunctioning of the system : both refrigerants and oil are quite stable in the conditions of the tests. In similar condition, HFA 134a seems even more stable than CFC 12.

TABLE 1 : ANALYSIS OF REFRIGERANTS

	Operating hours with CFC 12		Operating hours with HFA 134a	
	0	500	0	500
Global purity of refrigerant % weight	99.9	99.9	99.9	99.9
by products (ppm weight)	-	R 22 : 500	No significant evolution	

TABLE 2

Operating hours	0	500 hours with CFC 12	500 hours with HFA 134a
Color	yellow	yellow	yellow
Water content (ppm weight)	30	45	40
Total acid number (mg KOH/g)	0.001	0.020	0.020
Viscosity at 40°C (centistocks)	30.0	32.0	32.0
Spectroscopy analysis (ppm w.)			
Fe	-	1	-
Cu	-	2	2
halogens	-	2	-
NMR analysis			
. ratio $\frac{CH_3 \text{ group}}{CH_2+CH \text{ group}}$ %	0.64	0.65	0.64
. ratio $\frac{\text{aromatic}}{\text{aromatic + aliphatics}}$ %	2.7	2.6	2.7

7 - CONCLUSION

This is an example of using HFA 134a in an existing installation defined for CFC 12.

These tests have permitted to verify that :

. it is possible to use HFA 134a in existing CFC 12 industrial or semi-industrial installations by only adapting the expansion valve.

. loss of performances of the system are in accordance with theoretical performances of HFA 134a and may be acceptable in some existing applications.

. HFA 134a and standard naphtenic mineral oil are chemically compatible ; in particular it was not observed any chemical reaction between the oil and the refrigerant at such high operating temperatures as 90°C.

. After 500 hours of operation, with the configuration of the system tested (presence of oil separator and the compressor below) It was not observed any accumulation of oil at the evaporator or any mechanical disfunctioning of the compressor due to the non miscibility of HFA 134a with the oil.

This has to be confirmed on longer period tests and other configurations.

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