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# CALORIMETER PERFORMANCE TESTS OF HFC-245ca AND HFC-245fa AS CFC-11 REPLACEMENTS

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## Abstract

As an ozone-depleting chemical and a Class I substance under the Montreal Protocol, chlorofluorocarbon (CFC)-11 can no longer be manufactured in developed countries for use in those countries. This refrigerant was the main chemical used in low-pressure chillers. The phaseout of CFC-11 has led to the use of hydrochlorofluorocarbon (HCFC)-123 as the refrigerant of choice in new low-pressure chillers. However, HCFC-123 is a Class II substance under the Protocol and will eventually be phased out, too. Therefore there is a need to identify non-chlorine-containing alternatives for use in low-pressure chillers.

Early thermodynamic investigations indicated the potential of several hydrofluorocarbon (HFC) chemicals, including HFC-245ca and HFC-245fa, as non-chlorine-containing options. These investigations showed that HFC-245ca had lower volumetric capacity and cycle efficiency than CFC-11, while HFC-245fa had significantly higher volumetric capacity but slightly lower cycle efficiency.

The present work presents the results of compressor calorimeter tests with HFC-245ca and HFC-245fa as CFC-11 alternatives. Tests were performed in a semihermetic compressor at evaporating temperatures from 1 to 13°C and condensing temperatures from 40 to 60°C. In these ranges, the capacities and efficiencies of HFC-245ca were confirmed to be lower than CFC-11, while both capacities and efficiencies of HFC-245fa were significantly higher. The higher-than-expected efficiencies and capacities for HFC-245fa were a result of the higher compressor efficiencies. If the higher condensing pressures for HFC-245fa could be found to be acceptable to low-pressure chiller manufacturers, this refrigerant would be a viable alternative.

## Background

Under the Montreal Protocol and Clean Air Act Amendments of 1990, CFC-11 can no longer be manufactured in developed countries for their use in low-pressure chillers. The short-term alternative for this compound is HCFC-123, which itself is under the phaseout schedule since it is a Class II substance. In earlier studies, the search for non-chlorine containing alternatives for CFC-11 and HCFC-123 resulted in the identification of several potential alternatives, including HFC-245ca and HFC-245fa (1,2).

Preliminary analysis of material compatibility, toxicity, flammability, and atmospheric lifetime for HFC-245ca indicated favorable results in the absence of moisture (3). High moisture content resulted in some compatibility problems with the limited set of elastomers investigated.

In addition, HFC-245ca was observed to be flammable in air with high relative humidity, with the range of flammability sensitive to the moisture content.

Preliminary analyses of material compatibility, flammability, and atmospheric lifetime have also been performed with HFC-245fa(4). Of the 13 elastomeric materials tested, three gave satisfactory performance. Atmospheric lifetime was also found to be acceptable. As with HFC-245ca, HFC-245fa was found to be mildly flammable in the presence of moisture; however, based on the proposed modifications to ASTM E681-85 and ASHRAE Standard 34-1992 flammability tests, HFC-245fa is expected to be rated non-flammable(5).

The theoretical analysis of both HFC-245 isomers included thermodynamic evaluations in a vapor-compression cycle and calculations of centrifugal compressor characteristics(2). As with the short-term alternative, HCFC-123, isentropic compression of the HFC-245 isomers from saturated vapor was found to result in the potential for wet compression with HFC-245ca having the greatest potential of the three refrigerants. Comparison of performance in a cycle with throttling and dry compression indicated that the volumetric capacity of HFC-245ca was about 13% lower than for CFC-11, while the capacity of HFC-245fa was about 30% higher. Cycle efficiencies for HFC-245ca and HFC-245fa were, respectively, 5 and 4% lower than for CFC-11. It was also noted that, at 40°C, the condensing pressure for HFC-245fa was about 70 kPa higher than for CFC-11.

In an earlier study a calorimeter test was performed on HFC-245ca in an oil-free compressor at one test condition, 4.4°C evaporating and 40.6°C condensing temperatures(6).

**Equipment and Test Method**

Experimental evaluation of the CFC-11 alternatives was done on a compressor calorimeter test rig with a semihermetic compressor. The original calorimeter was modified for low-pressure refrigerants to eliminate excessive pressure drops. These modifications were detailed in an earlier publication(7). The semihermetic compressor had a 0.56 kW motor and delivered 1.329 L/s at 1750 RPM. The compressor was designed for use with HFC refrigerants and was lubricated by polyolester oil.

Tests were performed using ASHRAE Standard 23-1993(8) as a basis. The cooling capacity was determined by two methods: a primary method based on the quantity of electrically supplied heat to the calorimeter boiler and a secondary method based on the heat balance of the water-cooled condenser. Agreement between the two methods was acceptable. Each test condition was evaluated three times, and the resulting values were averaged. The standard deviation of the average value for any given parameter was never greater than 2%.

Tests were performed at evaporating temperatures from 1 to 13°C and condensing temperatures from 40 to 60°C. A few degrees of subcooling was achieved in the condenser to ensure liquid feeding to the expansion valve. Similarly some superheating was achieved in the evaporator to ensure that no liquid reached the compressor to avoid wet compression. All results were corrected back to conditions of saturated liquid leaving the condenser and saturated vapor leaving the evaporator.

**Experimental Results**

Table 1 shows typical compressor calorimeter results for HFC-245fa at 12.8°C evaporating and 40.6°C condensing temperatures. Similar tables were generated at all test conditions for both HFC-245fa and HFC-245ca. All graphical results for both refrigerants are presented relative to the results for CFC-11 in the same compressor.

Figures 1 and 2 show the results for relative cooling capacity of HFC-245ca and HFC-245fa, respectively. As expected from the theoretical analyses, the capacity of the ca-isomer is lower than that of CFC-11, while the fa-isomer has significantly higher cooling capacity with measured values ranging from 30 to 50% higher. The higher-than-expected capacities for HFC-245fa are a result of the higher compressor volumetric efficiencies, presented later. The compressor electrical input for the two refrigerants is shown in Figures 3 and 4. The required input for HFC-245ca was about the same as for CFC-11, while HFC-245fa required higher input.

Figures 5 and 6 present the compressor's energy efficiency ratio (EER) for the two refrigerants relative to CFC-11. The lower capacity for the ca-isomer results in EER values from 3 to 18% lower than for CFC-11. For the fa-isomer, as with the cooling capacity, the EER is significantly higher than CFC-11. Measured values ranged from 10 to 28% higher. Lower EER for HFC-245ca was expected from the theoretical analysis; however, the EER for HFC-245fa was higher than expected.

Compressor isentropic and volumetric efficiencies are shown in Figures 7 through 10. For HFC-245ca, the compressor isentropic energy efficiency is from 2 to 12% lower than for CFC-11, while volumetric efficiencies are close to those for CFC-11. For HFC-245fa, both compressor efficiencies are from 4 to 30% higher than for CFC-11. These higher efficiencies contribute to the higher-than-expected cooling capacity and EER.

Figures 11 and 12 present the compression ratios. Both isomers have higher compression ratios than CFC-11, with the ca-isomer averaging about 16% higher and the fa-isomer averaging about 8% higher.

**Conclusions**

1. Compressor calorimeter tests confirmed that both HFC-245ca and HFC-245fa are viable alternatives to replace CFC-11.

2. As expected, both the compressor cooling capacity and the EER with HFC-245ca were less than with CFC-11. With HFC-245fa, both parameters were significantly higher than with CFC-11 and higher than expected.

3. Compressor isentropic energy and volumetric efficiencies were lower than CFC-11 for HFC-245ca and higher for HFC-245fa.

4. With its superior performance, HFC-245fa could be a strong replacement candidate, if the higher condensing pressures could be accepted by chiller manufacturers.

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**ABLE 1: TEST CONDITIONS AND MAIN RESULTS FROM THE CALORIMETER TESTS OF A SEMI-HERMETIC COMPRESSOR WITH HFC-245fa:**

**ymbols**: **$p_1$** - suction pressure, kPa; **$p_2$** - discharge pressure, kPa; **$T_E$** - nominal evaporating temperature, °C; **$T_C$** - nominal condensing temperature, °C; **$T_{EI}$** - temperature at the evaporator inlet, °C; **$T_{Esat}$** - evaporating saturation temperature at suction pressure, °C; **$T_{EV}$** - temperature at the expansion valve inlet, °C; **$T_{Csat}$** - condensing saturation temperature at discharge pressure, °C; **$T_{CI}$** - temperature at the condenser inlet, °C; **$T_1$** - temperature at the compressor inlet, °C; **$T_2$** - temperature at the compressor outlet, °C; **$T_{OIL}$** - oil temperature at the sump bottom, °C; **$Q_E^P$** - cooling capacity from the primary method at the real conditions, W; **$\delta Q_E^{SC}$** - relative deviation of the secondary condenser method from the primary method, %; **$P_{el}$** - electrical input power into the compressor at the real conditions, W; **V** - Voltage, V; **$I_C$** - Compressor motor current, A; **EER** - Energy efficiency ratio, Btu/W.h; **PR** -Pressure ratio; $\lambda_C$ - Compressor volumetric efficiency, %; $\eta_C$ - Compressor energy efficiency, %; σ - standard deviation.

**emarks:**
1. Test conditions: $T_E$ = 12.8°C, $T_C$ = 40.6°C
2. Date of tests: 06/14/96
3. Oil circulation not measured.



| Test | $p_1$ | $p_2$ | $T_{EI}$ | $T_{Esat}$ | $T_{CI}$ | $T_{Csat}$ | $T_{EV}$ | $T_1$ | $T_2$ | $T_{OIL}$ | $Q_E^P$ | $\delta Q_E^{SC}$ | $P_{el}$ | V | $I_C$ | EER | PR | $\lambda_C$ | $\eta_C$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| C96-0043 | 90.52 | 250.5 | 11.4 | 12.6 | 57.4 | 40.5 | 19.2 | 18.1 | 59.7 | 46.9 | 1004.7 | 3.6 | 412.0 | 115.0 | 6.31 | 8.35 | 2.77 | 89.75 | 27.46 |
| C96-0044 | 90.73 | 251.2 | 11.4 | 12.7 | 57.8 | 40.6 | 19.1 | 18.8 | 60.1 | 47.2 | 1007.6 | 3.3 | 412.0 | 115.0 | 6.32 | 8.36 | 2.77 | 90.10 | 27.64 |
| C96-0045 | 90.39 | 251.2 | 11.3 | 12.6 | 58.0 | 40.6 | 19.2 | 18.8 | 60.3 | 47.2 | 1003.4 | 3.1 | 410.0 | 115.0 | 6.28 | 8.35 | 2.78 | 90.09 | 27.72 |
| | | | | | | | | | | | | | | | | | | | |
| Avg | 90.55 | 251.0 | 11.4 | 12.6 | 57.7 | 40.6 | 19.2 | 18.6 | 60.0 | 47.1 | 1005.2 | 3.3 | 411.3 | 115.0 | 6.30 | 8.35 | 2.77 | 89.98 | 27.61 |
| σ | 0.14 | 0.3 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.3 | 0.2 | 0.1 | 1.8 | 0.2 | 0.9 | 0.0 | 0.02 | 0.00 | 0.00 | 0.16 | 0.11 |

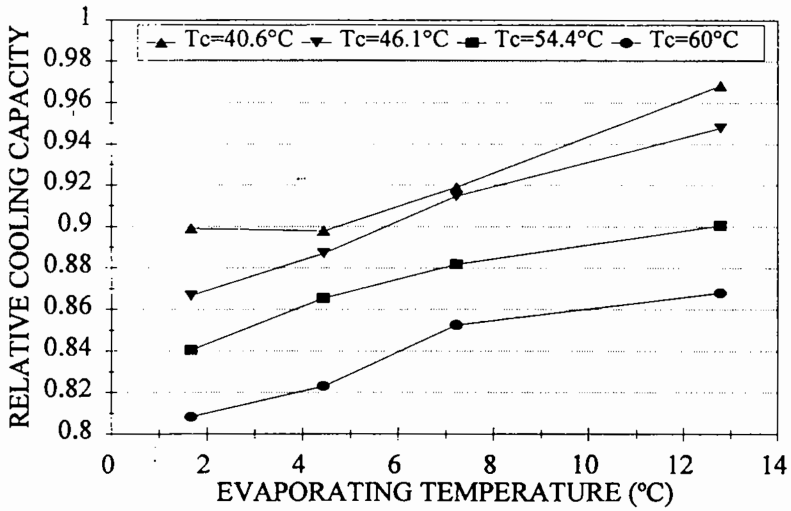


**Figure 1. Compressor Cooling Capacity with HFC-245ca Relative to CFC-11.**

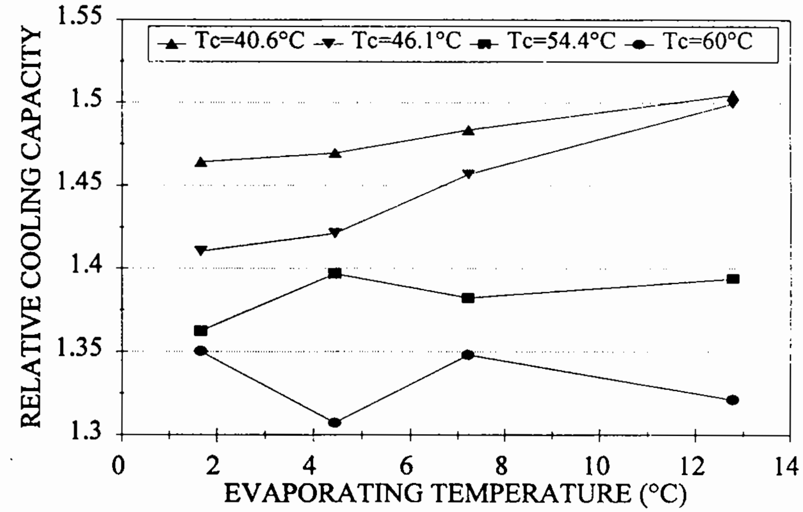


**Figure 2. Compressor Cooling Capacity with HFC-245fa Relative to CFC-11.**

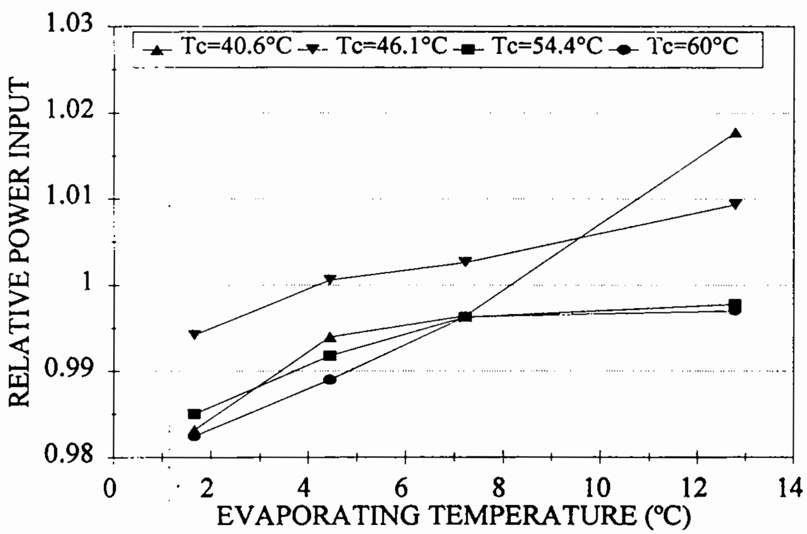


**Figure 3. Compressor Electrical Input with HFC-245ca Relative to CFC-11.**

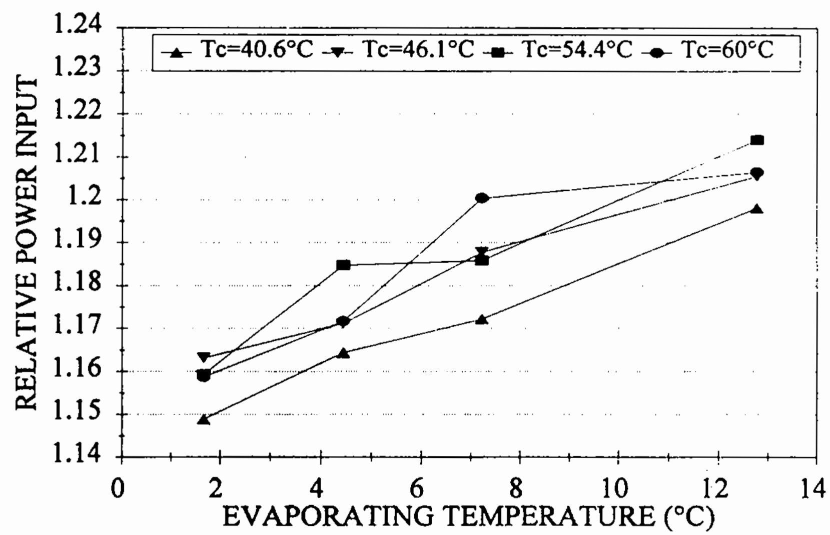


**Figure 4. Compressor Electrical Input with HFC-245fa Relative to CFC-11.**

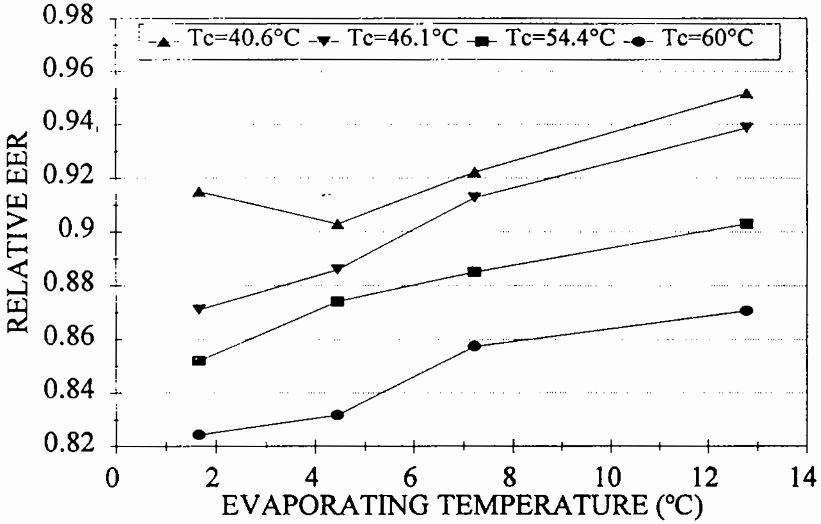


**Figure 5. Compressor Energy Efficiency Ratio (EER) with HFC-245ca Relative to CFC-11.**

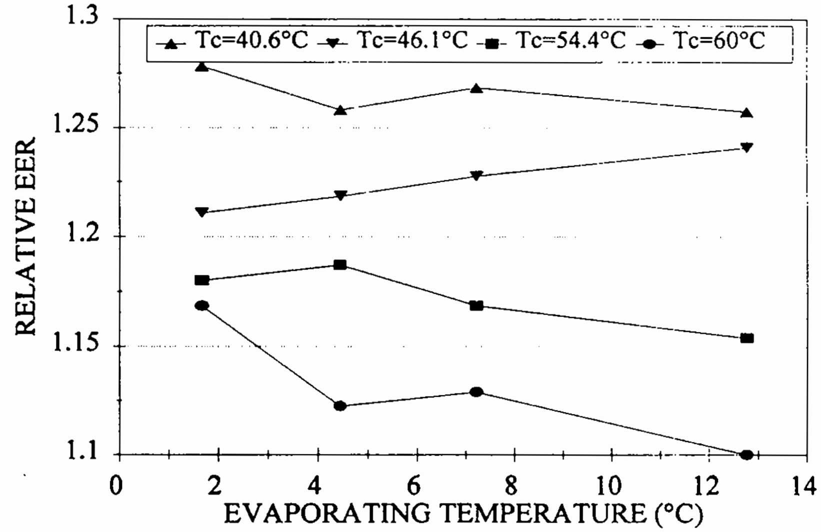


**Figure 6. Compressor Energy Efficiency Ratio (EER) with HFC-245fa Relative to CFC-11.**

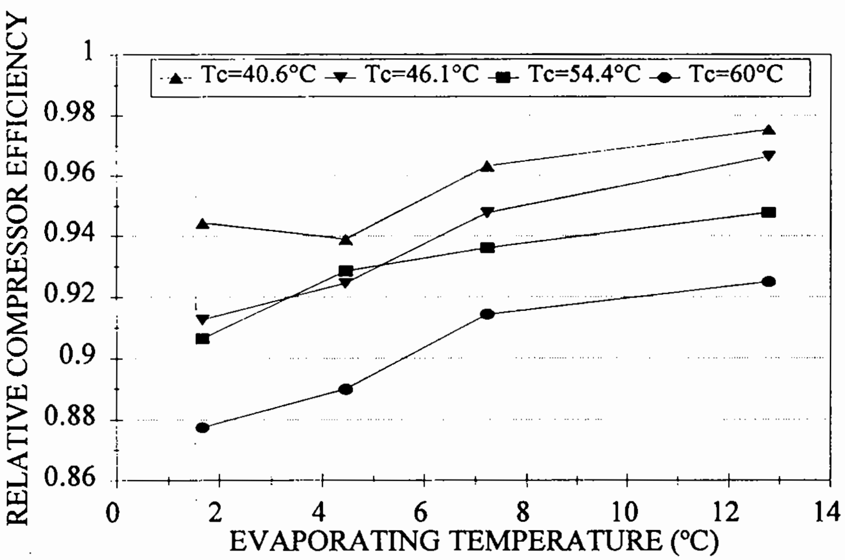


**Figure 7. Compressor Isentropic Energy Efficiency with HFC-245ca Relative to CFC-11.**

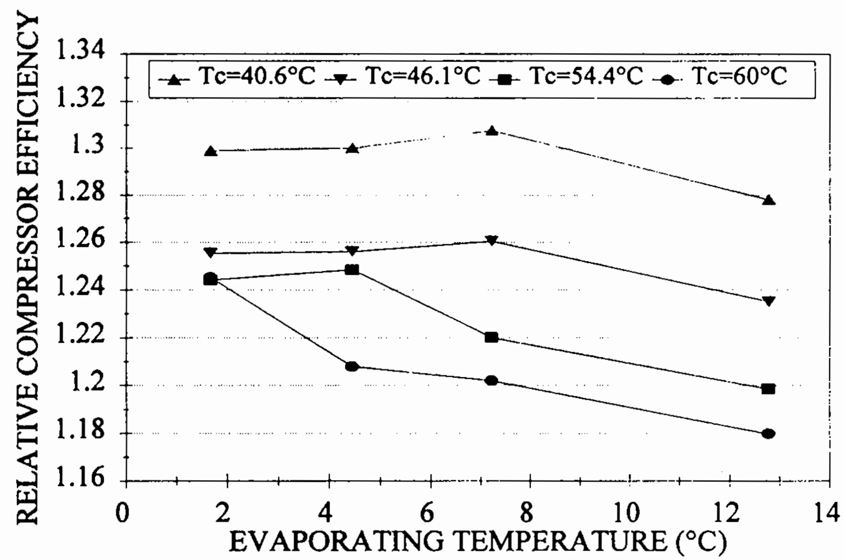


**Figure 8. Compressor Isentropic Energy Efficiency with HFC-245fa Relative to CFC-11.**

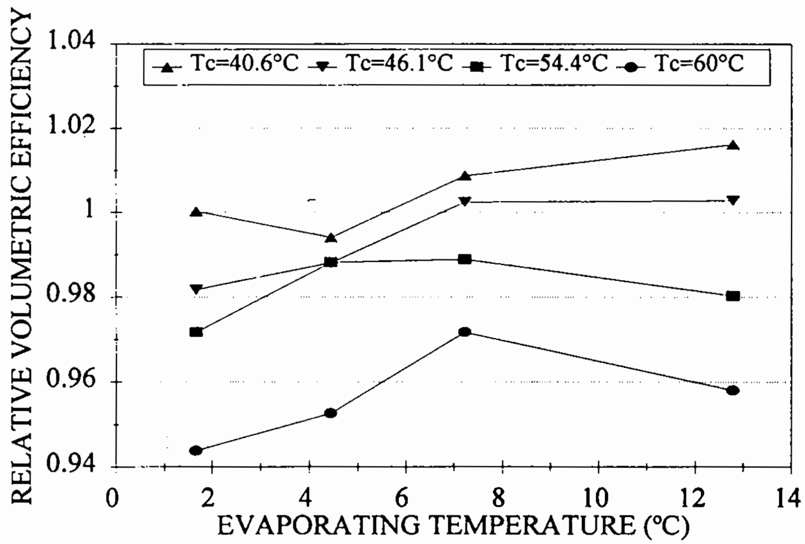


**Figure 9. Compressor Volumetric Efficiency with HFC-245ca Relative to CFC-11.**

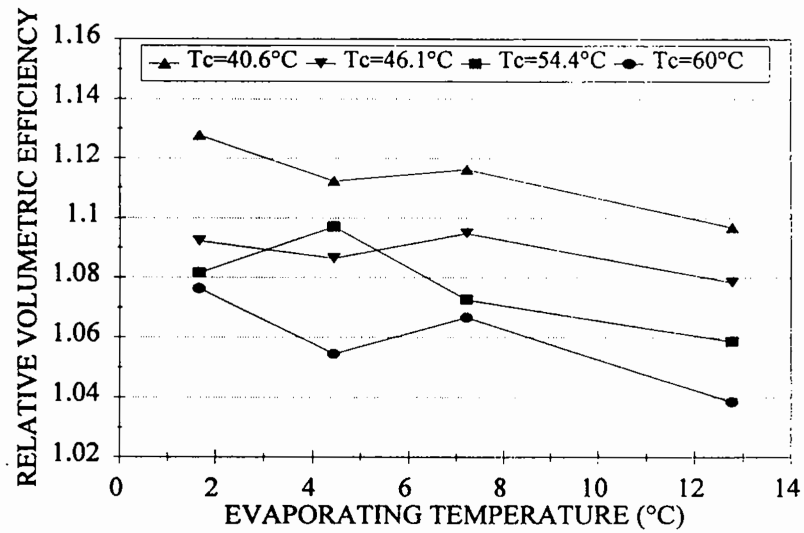


**Figure 10. Compressor Volumetric Efficiency with HFC-245fa Relative to CFC-11.**

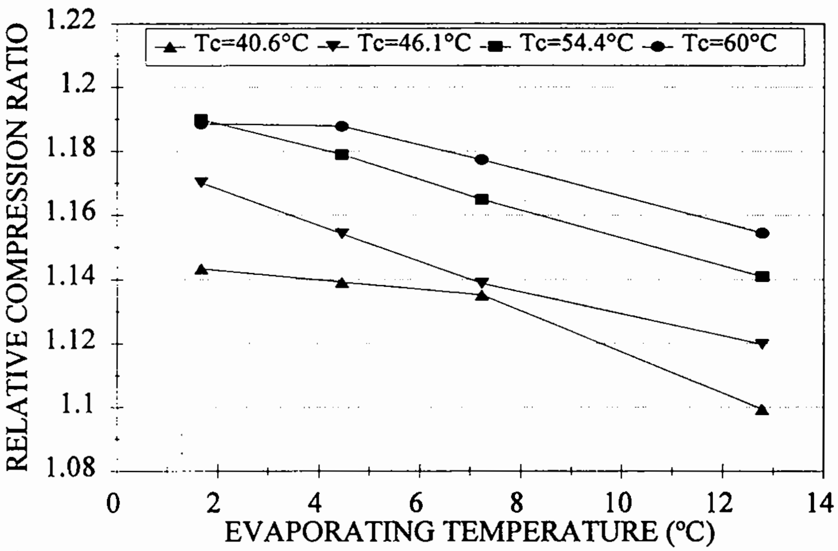


**Figure 11. Compression Ratio with HFC-245ca Relative to CFC-11.**

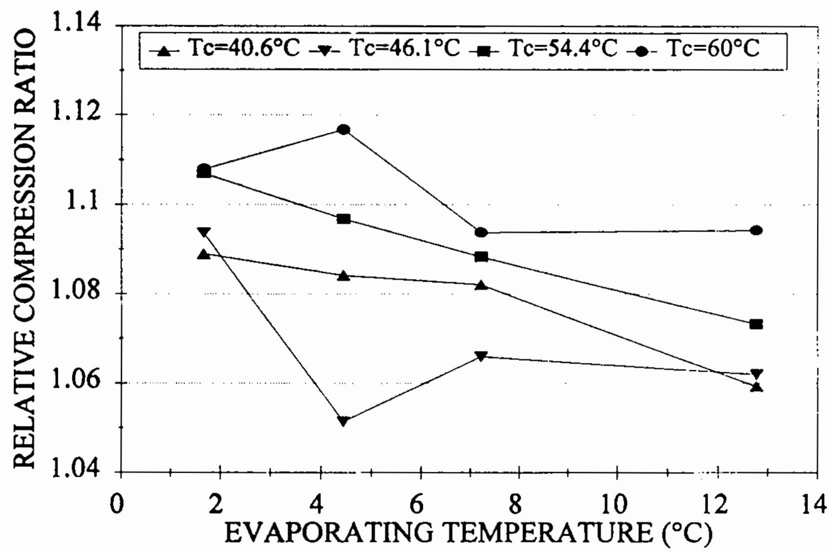


**Figure 12. Compression Ratio with HFC-245fa Relative to CFC-11.**

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16. ABSTRACT The paper gives results of compressor calorimeter tests with hydrofluorocarbon (HFC)-245ca and HFC-245fa as alternatives for the refrigerant chlorofluorocarbon (CFC)-11. Tests were performed in a semi-hermetic compressor at evaporating temperatures from 1 to 13 C and condensing temperatures from 40 to 60 C. In these ranges, the capacities and efficiencies of HFC-245ca were confirmed to be lower than of CFC-11, while both capacities and efficiencies of HFC-245fa were significantly higher. The higher-than-expected efficiencies and capacities for HFC-245fa were a result of the higher compressor efficiencies. If the higher condensing pressures for HFC-245fa could be found to be acceptable to low-pressure chiller manufacturers, this refrigerant would be a viable alternative.

17. KEY WORDS AND DOCUMENT ANALYSIS

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| Refrigerants | Stationary Sources | 13A |
| Halohydrocarbons | CFC-11 Replacements | 07C |
| Calorimeters | Hydrofluorocarbons | 14B |
| Compressors | Chillers | 13G |
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