DOE/CE/23810-60

EVALUATION OF HFC-245ca FOR COMMERCIAL USE IN LOW PRESSURE CHILLERS

TASK 1 REPORT: Preliminary Estimates of Chiller Performance

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30 April 1995

Prepared for:
The Air-Conditioning and Refrigeration Technology Institute
Under
ARTI MCLR PROJECT NO. 665-53300

This project is supported, in whole or in part, by U.S. Department of Energy, Office of Building Technology, grant number DE-FG02-91CE23810: Materials Compatibility and Lubricants Research (MCLR) on CFC-Refrigerant Substitutes. Federal funding supporting the MCLR program project constitutes 93.57% of allowable costs. Funding from the air-conditioning and refrigeration industry supporting the MCLR program consists of direct cost sharing of 6.43% of allowable costs, and significant in-kind contributions.

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ABSTRACT

HFC-245ca has been identified as a potential replacement for both CFC-11 and HCFC-123 in centrifugal chillers based on estimates of its thermodynamic properties, even though serious concerns exist about its flammability characteristics. The overall objective of this project is to assess the commercial viability of HFC-245ca in centrifugal chillers. This first report focuses on preliminary estimates of chiller performance only, while the next report will include laboratory performance data. The chiller performance estimates are based on early correlations of thermodynamic properties and predictions of compressor efficiency, with variations in heat transfer ignored until experimental data are obtained. Conclusions from this study include the following:

- The theoretical efficiency of HFC-245ca in optimized three stage chiller designs is very close to that for CFC-11 and HCFC-123 chillers.

- HFC-245ca is not attractive as a service retrofit in CFC-11 and HCFC-123 chillers because significant compressor modifications or dramatic lowering of condenser water temperatures would be required.

- Hurdles which must be overcome to apply HFC-245ca in centrifugal chillers include the flammability behavior, evaluation of toxicity, unknown heat transfer characteristics, uncertain thermodynamic properties, high refrigerant cost and construction of HFC-245ca manufacturing plants.

- Although the flammability of HFC-245ca can probably be reduced or eliminated by blending HFC-245ca with various inert compounds, addition of these compounds will lower the chiller performance. The chiller performance will be degraded due to less attractive thermodynamic properties and lower heat transfer performance if the blend fractionates.

- The experimental phase of the project will improve the accuracy of our performance estimates, and the commercial viability assessment will also include the impact of flammability, toxicity, product cost and product availability.

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SCOPE

Federal regulations ban the production of CFC-11 on January 1, 1996, currently limit the distribution of HCFC-123 to service applications on January 1, 2020 and eliminate service production by January 1, 2030. HFC-245ca has been identified as a potential replacement for both CFC-11 and HCFC-123 based on estimates of its thermodynamic properties even though serious concerns exist about its flammability characteristics. The overall project objective is to make a commercial viability assessment of HFC-245ca in centrifugal chillers, with this first report focusing on a preliminary estimate of chiller performance only. These estimates will be refined with laboratory data being collected over the next four months. In addition to chiller performance, the toxicity and flammability risks will also be included in the market assessment scheduled to be completed later this year.

SIGNIFICANT RESULTS

BACKGROUND

Low pressure centrifugal chillers have been available in single stage and multistage configurations for many years and large numbers of chillers of both designs are in use today. The Trane Company has built centrifugal chillers in multistage configurations only for more than 20 years, and this study will focus on the multistage direct drive configuration. While the performance trends described in this report will generally apply to both single and multistage chillers, this report does not quantify performance estimates for single stage chillers.

Before examining the chiller performance estimates, the theoretical performance of CFC-11, HCFC-123 and HFC-245ca will be compared in single and three stage cycles as illustrated on a temperature-enthalpy diagram in Figures 1 and 2. The processes portrayed in Figure 1 are typically described as shown in Table 1.

Table 1. Single Stage Process

Process Line	Process	Process Line	Process
1 - 2'	Isentropic Compression	1 - 2	Adiabatic Compression
2 - 3	Desuperheating	3 - 4	Condensing
4 - 5	Adiabatic Expansion	5 - 1	Evaporation
6 - 7	Condenser Water Temp	9 - 8	Evaporator Water Temp

The three stage cycle includes two economizers which separate the liquid and vapor refrigerant after partial expansion and direct the vapor into the compressor between the impellers. The processes portrayed in Figure 2 are typically described as shown in Table 2.

Table 2. Three Stage Process

Process Line	Process	Process Line	Process
1 - 2	Adiabatic Compression	7 - 8 & 5	Adiabatic Expansion
3 - 4	Adiabatic Compression	8 - 9 & 3	Adiabatic Expansion
5 - 6	Adiabatic Compression	9 - 10	Adiabatic Expansion
6 - 7	Desuperheat and Condensing	10 - 1	Evaporation

This process is more efficient than the single stage process because (1) the vapor separated by the economizers is recompressed from an intermediate pressure rather than from evaporator pressure and (2) the enthalpy of the liquid entering the evaporator is lower due to the latent heat of the vapor in the economizer. The theoretical performance of each cycle is shown in Table 3.

Table 3. Theoretical Performance for Single and Three Stage Cycles

Refrigerant	Single Stage	Ratio	Three Stage	Ratio
CFC-11	0.52 kW/ton	Base	0.50 kW/ton	0.95
HCFC-123	0.53 kW/ton	1.01	0.50 kW/ton	0.95

Boundary conditions: zero subcooling, zero superheat, 94% motors with liquid cooling, 83% impellers, 6.1C (43 F) saturated suction temperature, 35.6 C (96 F) saturated condensing temperature

Notice the performance difference between the two refrigerants diminishes going from single stage to three stage compression.

THERMODYNAMIC AND TRANSPORT PROPERTIES

Accurate estimates of the thermodynamic properties of refrigerants are critical for estimates of chiller performance and accurate reduction of laboratory data. Although we have much more experience with both CFC-11 and HCFC-123 and therefore more confidence in the accuracy of their property data, the HFC -245ca property data supplied by Allied Signal is suitable for making preliminary estimates of performance. Both Allied Signal and NIST continue collecting data with HFC-245ca and refining the correlations for the thermodynamic properties, and we will use improved correlations as we receive them, however the Allied Signal model is the only correlation we have permission to discuss at this time. Theoretical performance of HFC-245ca with the latest Allied Signal correlation is compared to that for CFC-11 and HCFC-123 in Table 4.

Table 4. Theoretical Performance of HFC-245ca

Refrigerant	Single Stage	Ratio	Three Stage	Ratio
CFC-11	0.52 kW/ton	Base	0.50 kW/ton	0.95
HCFC-123	0.53 kW/ton	1.01	0.50 kW/ton	0.95
HFC-245ca	0.53 kW/ton	1.01	0.50 kW/ton	0.95

The boundary conditions are the same as for Table 3. As shown in Table 4, calculations using the most recent improvements to the thermodynamic property data for HFC-245ca suggest theoretical efficiencies close to those for HCFC-123.

PERFORMANCE OF HFC-245CA IN SERVICE RETROFIT APPLICATIONS

The performance of HFC-245ca as retrofit substitutes for CFC-11 and HCFC-123 depends primarily on compressor and heat exchanger performance, with the assumption that the fixed orifices will be replaced with HFC-245ca selections. Since bundle performance data is not available and difficult to predict, the results described in this report are based entirely on compressor performance simulations and thermodynamic property variations between the refrigerants. Before examining the performance estimates, consider the compressor related thermodynamic properties of each refrigerant shown in Table 5.

Table 5. Compressor Performance Parameters

Property	CFC-11	HCFC-123	HFC-245ca
Displacement	.00684 m^3/s/ton (.242 ft^3/s/ton)	.00793 m^3/s/ton (.280 ft^3/s/ton)	.00727 m^3/s/ton (.257 ft^3/s/ton)
Isentropic Work	21.4 kJ/kg (9.18 Btu/lbm)	20.0 kJ/kg (8.60 Btu/lbm)	23.2 kJ/kg (9.96 Btu/lbm)

Boundary conditions: 4.44 C (40 F) saturated suction temperature, 37.8 C (100 F) saturated discharge temperature

Substituting either HCFC-123 or HFC-245ca into a chiller designed for CFC-11 will result in lower chiller capacity due to the higher compressor displacement requirements for HCFC-123 and HFC-245ca, about 16% for HCFC-123 and 6% for HFC-245ca. The lower work requirement for HCFC-123 can easily be accommodated by the CFC-11 impeller and motor, but the higher work requirement for HFC-245ca may cause serious performance problems including inability to achieve the desired lift (difference between saturated condensing and saturated evaporating temperatures) and significant reductions in capacity beyond those related to the refrigerant displacement. This problem is even worse when retrofitting HFC-245ca into an HCFC-123 optimized chiller where the differences in isentropic work are even larger. Thus, the chiller owner will need to install a new compressor which has been designed for the displacement and isentropic work requirements of HFC-245ca. Why not just reduce the lift on the compressor when using HFC-245ca? Because the compressor lift would have to be reduced about 2.8 C (5 F) in a CFC-11 chiller and 5.6 C (10 F) in an HCFC-123 chiller without any hardware changes. Reducing the lift 2.8 C (5F) to 5.6 C (10 F) requires extensive changes to the building's water side equipment and is usually not feasible. Increasing the evaporator leaving water temperature reduces the cooling capacity of the air conditioning system and increases the potential for indoor air quality problems due to significantly lower latent heat capacity. Reducing the condenser water temperature may be impossible due to local weather conditions.

HFC-245ca is a very poor candidate for service retrofit of either CFC-11 or HCFC-123 chillers with no hardware changes. A new compressor designed for use with HFC-245ca is needed to provide similar performance to either CFC-11 or HCFC-123.

PERFORMANCE OF HFC-245CA IN OPTIMIZED CHILLERS

The differences in compressor displacement and isentropic power between the refrigerants results in unique compressor designs for each refrigerant at the same chiller capacity. Compressor design parameters optimized for each refrigerant plus chiller performance estimates are shown in Table 6 for 200 and 800 ton capacities.

Table 6. Three Stage Optimized Compressor Designs

Refrigerant	Capacity Tons	Impeller Diameter m (ft)	Diffuser Diameter m (ft)	Compressor Adiabatic Efficiency	Power kW	Cycle Efficiency kW/Ton
CFC-11	200	.605 (1.98)	.953 (3.13)	0.73	132	0.66
HCFC-123	200	.292 (.958)	.922 (3.03)	0.73	130	0.65
HFC-245ca	200	.630 (2.07)	.993 (3.26)	0.72	133	0.67
CFC-11	800	.632 (2.08)	.996 (3.27)	0.74	518	0.65
HCFC-123	800	.625 (2.05)	.983 (3.23)	0.73	527	0.66
HFC-245ca	800	.652 (2.14)	1.03 (3.38)	0.74	513	0.64

Boundary conditions: 4.4 C (40 F) saturated evaporator temperature, 37.8 C (100 F) saturated condensing temperature, 95% motor at 3560 RPM

The impeller designs for the 200 ton compressor are characterized by relatively low inlet Mach numbers and low blade loading which provides stable operation over a wide capacity range (tendency not to surge). The HFC-245ca impeller is larger in diameter than both the CFC-11 and HCFC-123 impellers. The compressor adiabatic efficiency for HFC-245ca is slightly less than for either CFC-11 or HCFC-123 designs and the resulting chiller efficiency is slightly lower. This efficiency trend reverses in the 800 ton size due to compressor displacement differences between the refrigerants. Compressor performance suffers when the impeller passages become either too wide or too narrow, thus smaller capacity compressors favor lower density refrigerants like HCFC-123 and large capacity machines favor higher density refrigerants like CFC-11 or HFC-245ca.

Based on these preliminary results, HFC-245ca appears to be an attractive candidate for use in low pressure chillers. However, several hurdles must be overcome before HFC-245ca can become commercially viable, including:

- The flammability characteristics of HFC-245ca are expected to result in a class 2 flammability rating per ASHRAE Standard 34 and severely compromises HFC-245ca's commercial value. Mixing an inert chemical with HFC-245ca to give a class 1 flammability rating has been examined by several chemical companies, resulting in suggestions for azeotropic blends which resolve the flammability concern but may degrade the theoretical cycle efficiency by 2-4%.

- HFC-245ca is NOT commercially available and is forecasted to be a very expensive chemical to manufacture, with estimates as high as 3 to 4 times the manufacturing cost for HCFC-123.

- The heat transfer characteristics remain to be measured, and the thermodynamic properties are still unproven, and variation in these properties could have a large negative impact on the commercial viability assessment for HFC-245ca. These data will be gathered during the test phase of this project. In addition, the heat transfer performance of a nonflammable blend may suffer due to fractionation in the heat exchangers.

CONCLUSIONS

The following conclusions can be reached from this preliminary analysis:

- The theoretical efficiency of HFC-245ca in optimized three stage chiller designs is very close to that for CFC-11 and HCFC-123 chillers.

- HFC-245ca is not attractive as a service retrofit in CFC-11 and HCFC-123 chillers because significant compressor modifications or dramatic lowering of condenser water temperatures would be required.

- Hurdles which must be overcome to apply HFC-245ca in centrifugal chillers include the flammability behavior, evaluation of toxicity, unknown heat transfer characteristics, uncertain thermodynamic properties, high refrigerant cost and construction of HFC-245ca manufacturing plants.

- Although the flammability of HFC-245ca can probably be reduced or eliminated by blending HFC-245ca with various inert compounds, addition of these compounds will lower the chiller performance. The chiller performance will be degraded due to less attractive thermodynamic properties and lower heat transfer performance if the blend fractionates.

- The experimental phase of the project will improve the accuracy of our performance estimates, and the commercial viability assessment will also include the impact of flammability, toxicity, product cost and product availability.

COMPLIANCE WITH AGREEMENT

The results documented in this report do not deviate from the contracted scope of work.

PRINCIPAL INVESTIGATOR EFFORT

Ed Keuper as principal investigator for this project has spent half of his time on this project from the contractual start date through 31 May 1995.

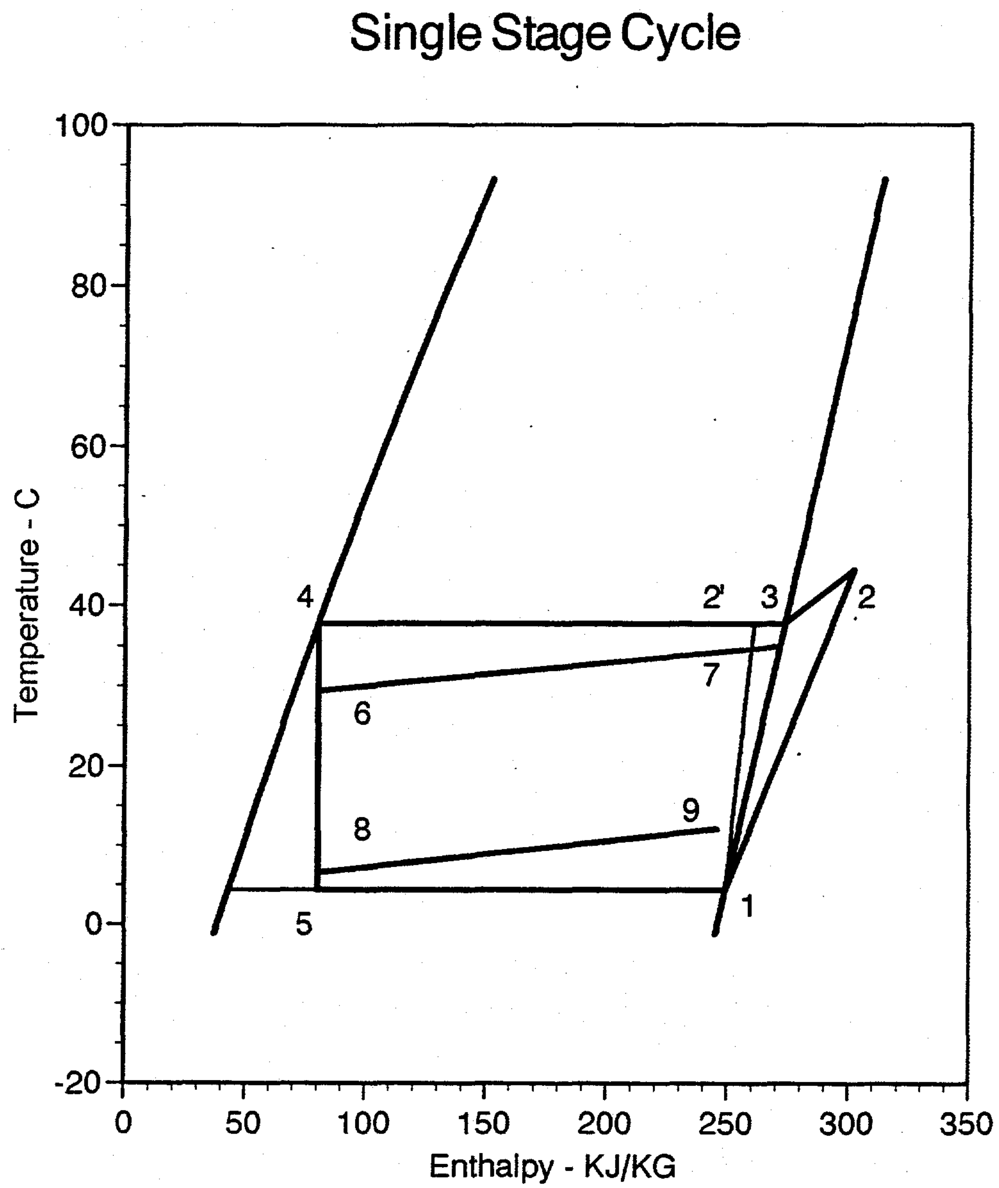
Single Stage Cycle
100
80
60
40
20
0
-20
Temperature - C
0
50
100
150
200
250
300
350
Enthalpy - KJ/KG
4
2'
3
2
7
6
9
8
1
5

Figure 1

Three Stage Cycle with Economizers

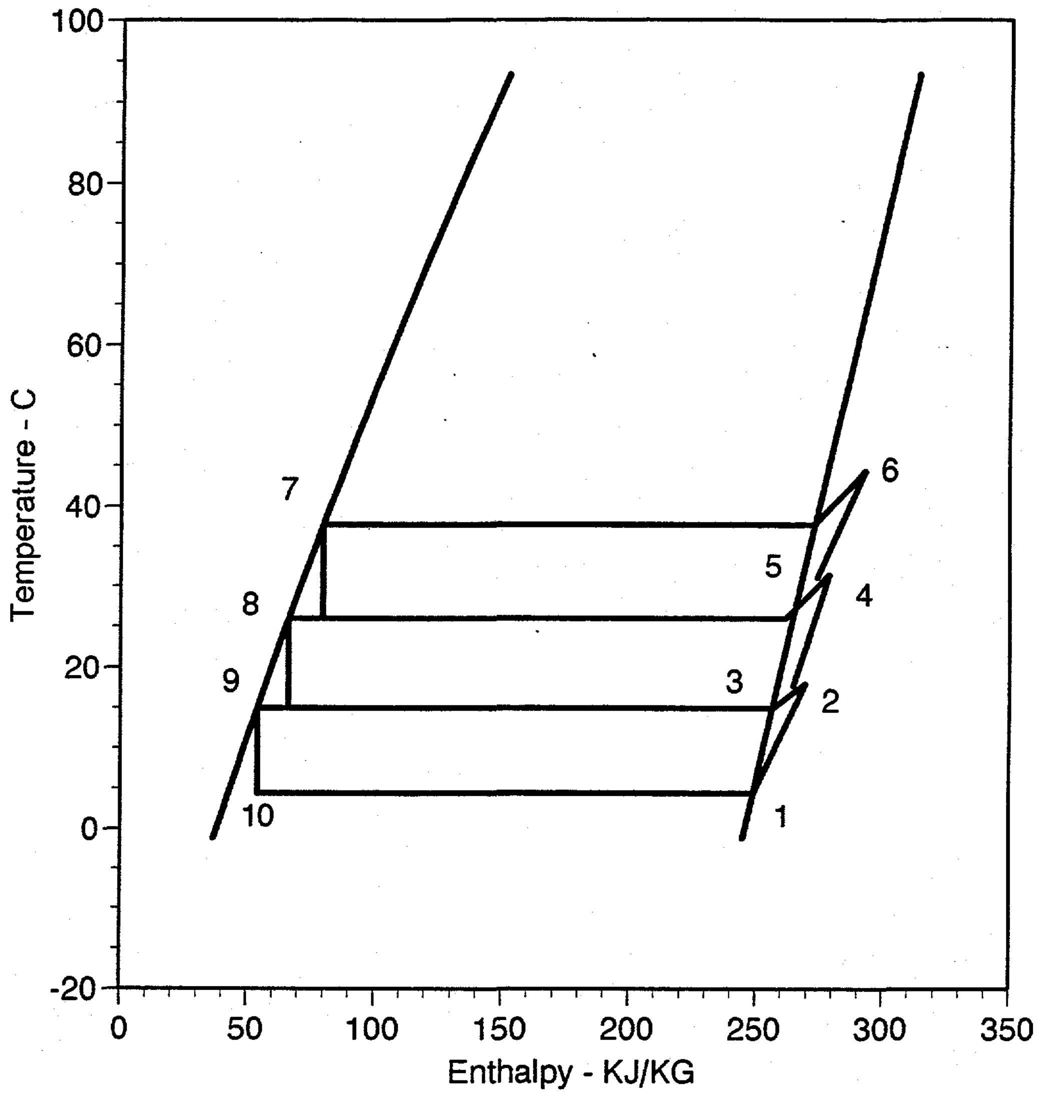

Figure 2