United States Environmental Protection Agency
Research and Development

National Risk Management Research Laboratory
Research Triangle Park, NC 27711

EPA/600/SR-95/157 April 1996

EPA

Project Summary

Testing of Refrigerant Mixtures in Residential Heat Pumps

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The report gives results of an investigation of three possibilities for replacing the refrigerant HCFC-22 (hydrochlorofluorocarbon-22) with the non-ozone-depleting new refrigerants R-407D and R-407C in residential heat pumps. (A fourth option investigated--suction-line heat exchange--did not show any performance improvement.) The first and simplest scenario was a retrofit with no hardware modifications (drop-in). When R-407C was used in this scenario, it resulted in a 0-3% higher cooling capacity, a 4-9% lower cooling COP (Coefficient of Performance, a measure of energy efficiency), a 4-21% lower heating capacity, a 9-24% lower heating COP, an 8.3% lower SEER (Seasonal Energy Efficiency Ratio, a climate-adjusted yearly measure of efficiency), and a 7.2% lower HSPF (Heating Seasonal Performance Factor). Retrofit test results with R-407D show a 5% higher cooling capacity, a 4% higher cooling COP, a 3% lower heating capacity, and an 8% lower heating COP. The second possibility investigated required altering the refrigerant path to attain a near-counterflow configuration in the indoor coil for the heating mode. The third and most complex possibility was optimization consisting of adjusting the refrigerant charge and expansion devices. Each modification progressively improved refrigerant performance. Study results show that the system should be optimized, rather than simply dropping in the new refrigerant, because dropping in R-407D or R-407C to replace HCFC-22 degrades performance.

This Project Summary was developed by EPA's National Risk Management Research Laboratory's Air Pollution Prevention and Control Division, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Overview

Hydrochlorofluorocarbons (HCFCs), used as refrigerants in residential heat pumps and air conditioners, are recognized as contributing to the depletion of the protective stratospheric ozone layer of Earth. International agreement and U.S. law have called for phaseout of the production of HCFCs, requiring that non-ozone-depleting replacements be found for these refrigerant fluids. HCFC-22, the most common refrigerant used in heat pumps and air conditioners, is scheduled for gradual phaseout in the U.S. so that it cannot be used in new equipment after 2010 and full phaseout of production in 2020.

To contribute to finding a substitute for HCFC-22, a test facility was designed and built to measure the steady state and cyclic performance of air-to-air heat pumps in sizes up to approximately 5 refrigeration-tons (RTs). The performance of heat pumps was evaluated based on ASHRAE Standard 116-1983, “Method of Testing for Seasonal Efficiency of Unitary Air-Conditioners and Heat Pumps.” This standard includes six steady state tests: three cooling tests (A, B, and C) and three heating tests [High Temperature (47S), Frost Accumulation (35F), and Low Temperature (17L)]. The standard also includes two cyclic tests: a cyclic cooling test (D) and a cyclic heating test (47C). The results of these tests are used to evaluate the seasonal performance of a heat pump. In the work presented here, two heat pumps (test units) were used. Test unit 1 was a 2-RT split heat pump system with a reciprocating compressor, a short tube restrictor for cooling, and a thermostatic expansion valve for heating. Test unit 2 was a 3-RT split heat pump system with a scroll compressor and thermostatic expansion valves for both heating and cooling.

This study investigated the replacement of HCFC-22 with two ternary mixtures of HFC-32 (hydrofluorocarbon-32), HFC-125, and HFC-134a. Mixture 1 was in the proportion 30/10/60 weight percent. Mixture 2 had a reduced amount of HFC-32 to ensure a nonflammable mixture and was in the proportions 23/25/52 weight percent. The first and simplest possibility tested was retrofit with no hardware modifications. The second possibility investigated was path modification that requires altering the refrigerant path to attain a near-counterflow configuration in the indoor coil for the heating mode. The third and most complex possibility was soft optimization, consisting of maximizing the Coefficients of Performance (COPs) of the refrigerant in both heating and cooling modes by optimizing refrigerant charge and expansion devices. The fourth option investigated was use of a suction line heat exchanger (SLHX).

In test unit 1, Mixture 2 was tested in the retrofit, path modification, and soft optimization modes and the performance compared to baseline HCFC-22 performance. Initially, the baseline HCFC-22 performance was determined by optimizing the refrigerant charge to maximize the performance in American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) cooling test A, which is the procedure used to optimize the refrigerant charge in a heat pump using a short tube restrictor when delivered to a home. However, performance using HCFC-22 improved when the combination of refrigerant charge and short tube restrictor size was selected to optimize both cooling and heating modes. It was decided to use this second method, called “soft optimization of HCFC-22,” as the baseline for HCFC-22 performance because it more realistically portrayed the best all around performance of HCFC-22. The results of the steady state tests for test unit 1 are shown in Table 1. Table 2 compares the Seasonal Energy Efficiency Ratio (SEER), a calculated index of overall cooling season performance, and the Heating Seasonal Performance Factor (HSPF), a calculated index of overall heating season performance, for the scenarios tested in test unit 1. For comparison, the results of the steady state performance of Mixtures 1 and 2 in a similar study performed by an industry-sponsored Alternative Refrigerant Evaluation Program (AREP) are included in Table 1. In test unit 2, Mixture 1 was tested in the retrofit mode and Mixture 2 was tested in the retrofit mode and in the SLHX mode and compared to HCFC-22 performance. In this case, with two expansion valves to automatically adjust flow of refrigerant to optimize in both cooling and heating modes, the baseline HCFC-22 performance was determined by optimizing the refrigerant charge to maximize performance in ASHRAE cooling test A. Tables 3 and 4 show steady state and seasonal performance, respectively, for the scenarios tested in test unit 2. The AREP results are presented in Table 3 for comparison.

Table 1. *Steady State Performance of Mixture 2 Relative to HCFC-22 for Test Unit 1*

Option	*Cooling Capacity*		*Cooling COP*		*Heating Capacity*		*Heating COP*	
	A	*B*	*A*	*B*	*47S*	*17L*	*47S*	*17L*
Retrofit	*1.05*	*0.97*	*0.92*	*0.85*	*0.95*	*0.97*	*0.81*	*0.81*
Path Modification	*0.98*	*0.97*	*0.91*	*0.90*	*0.98*	*1.12*	*0.89*	*0.95*
Soft Optimization	*1.01*	*0.98*	*0.96*	*0.92*	*0.97*	*0.99*	*0.95*	*0.92*
AREP Soft Optimization	*0.93-1.01*		*0.90 -0.97*		*0.98 -1.02*		*0.93-1.02*	

[Note] The above data are the ratio of Mixture 2 performance to HCFC performance when soft optimized. Cooling data include results of ASHRAE tests A and B. Heating data include results of ASHRAE tests 47S and 17L. AREP = Alternative Refrigerant Evaluation Program.

Table 2. *Seasonal Performance of Mixture 2 and HCFC-22 for Test Unit 1*

Option	*SEER (Btu/kWhr)*	*HSPF*
HCFC-22 Soft Optimization	*11.7*	*1.70*
Mixture 2 Retrofit	*9.9*	*1.65*
Mixture 2 Path Modification	*10.5*	*1.68*
Mixture 2 Soft Optimization	*10.8*	*1.63*

[Note] SEER: Based on the climate data for U.S.A. national average in ASHRAE Standard 116-1983. HSPF: Based on the climate data for Region 5 in American Refrigeration Institute Standard 210/240.

When comparing the performance of the different modes and refrigerants, it must be kept in mind that the test results have an uncertainty of ±3% and that the results may be different for other test units. The tests showed that Mixture 1 performed nearly equal to HCFC-22 in both cooling and heating tests as a retrofit. However, due to the flammability of Mixture 1, this mixture is not likely to be used in a commercial heat pump. Mixture 2, while non-flammable, has a lower performance as a retrofit when compared to Mixture 1. Since Mixture 2 is more likely to be used in commercial applications because it is not flammable, the emphasis in this test program was to evaluate operating modes in which the performance of Mixture 2 could be improved to be more nearly equal to that of HCFC-22. These tests showed that modifying the refrigerant path to enable countercurrent flow in the heat exchangers improved performance as did adjusting the amount of charge and the size of the short tube restrictor to optimize performance for both cooling and heating. A combination of these methods can bring Mixture 2 performance to nearly that of HCFC-22. The tests also showed that use of a suction line heat exchanger has little effect on Mixture 2 performance. The test results are consistent with similar tests using these same mixtures performed by industry under the AREP program.

The test results reported here are only part of the data base needed to identify refrigerant alternatives to HCFC-22. Additional information is needed on the performance of other alternative refrigerants, performance in other types of equipment, performance over longer periods of time, compatibility of fluids and lubricants with materials used in heat pumps, costs of various alternatives, and many other issues.

Table 3. *Steady State Performance of MIxtures 1 and 2 Relative to HCFC-22 for Test Unit 2*

Option	*Cooling Capacity*		*Cooling COP*		*Heating Capacity*		*Heating COP*	
	A	*B*	*A*	*B*	*47S*	*17L*	*47S*	*17L*
Mix. 1 Retrofit	*1.05*	*1.03*	*1.03*	*1.02*	*0.98*	*0.99*	*0.92*	*0.92*
Mix. 1 AREP	*0.95-1.05*		*0.90 -1.02*		*0.96-1.05*		*0.87 -1.00*	
Mix. 2 Retrofit	*0.98*	*0.99*	*0.91*	*0.92*	*0.93*	*0.96*	*0.88*	*0.87*
Mix. 2 SLHX	*1.00*	*1.01*	*0.92*	*0.94*	*n/a*	*n/a*	*n/a*	*n/a*
Mix. 2 AREP	*0.93-1.01*		*0.90 -0.97*		*0.98-1.02*		*0.93-1.02*	

[Note] The above data are the ratio of mixture performance to HCFC-22 baseline performance. Cooling data include results of ASHRAE tests A and B. Heating data include results of ASHRAE tests 47S and 17L.
n/a = Not applicable. No heating tests were made in this mode.

Table 4. *Seasonal Performance of Mixture 2 and HCFC-22 for Test Unit 2*

Option	*SEER (Btu/kWhr)*	*HSPF*
HCFC-22 without SLHX	*12.2*	*2.02*
HCFC-22 with SLHX	*12.2*	*-*
Mixture 2 without SLHX	*11.7*	*1.96*
MIxture 2 with SLHX	*11.9*	*-*

[Note] SEER based on the climate data for U.S. A. national average in ASHRAE Standard 116-1-1983. HSPF based on the climate data for Washington, D.C. area in ASHRAE Fundamentals.

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The complete report, entitled "Testing of Refrigerant Mixtures in Residential Heat Pumps," (Order No. PB96-113 733; Cost: $31.00, subject to change) will be available only from:
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