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Alternatives for CFC-12 Refrigerant in Automotive Air Conditioning

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Abstract

Ten refrigerants including CFC-12, HFC-134a, and eight refrigerant blends were tested in an instrumented automotive air-conditioning system designed for CFC-12. The refrigerants were compared at three test conditions for refrigeration capacity, coefficient of performance, compressor discharge pressure, compressor discharge temperature, and evaporator outlet pressure. Due to limitations of the testing, test results should not be used as conclusive evidence of the performance of refrigerants. However, the results were obtained by testing all the refrigerants in the same system under the same conditions, and the results provide an indication of the comparative performance of the refrigerants. Refrigeration capacities for CFC-12 substitutes ranged from 9 percent lower to 9 percent higher than capacities for CFC-12. Capacities for refrigerant blends containing HCFC-22 tended to be higher than capacities for CFC-12 and other substitutes for CFC-12. Evaporating pressures for HFC-134a closely matched those for CFC-12. Compressor discharge pressures for HFC-134a ranged from 4 to 8 percent higher than those for CFC-12. Compressor discharge pressures for refrigerant blends containing HCFC-22 were 17 to 34 percent higher than those for CFC-12. Discharge temperatures for two of the four blends that contained HCFC-22 were more than 5C° higher than temperatures for CFC-12. Further laboratory and field testing would be required to adequately evaluate performance and other important refrigerant characteristics including materials compatibility, chemical stability, fractionation, and long-term durability.

Introduction

Title VI of the 1990 Clean Air Act Amendments requires the U.S. EPA (Environmental Protection Agency) to regulate substitutes for ozone depleting substances, including CFC (chlorofluorocarbon)-12 [1]. Title VI, Section 612 mandates "that it shall be unlawful to replace any class I or class II [ozone-depleting] substance with any substitute substance which the [EPA] Administrator determines may present adverse effects to human health or the environment.... The Administrator shall publish a list of (A) the substitutes prohibited under this subsection for specific uses and (B) the safe alternatives identified under this subsection for specific uses."

EPA implemented the Title VI, Section 612 requirements with the SNAP (Significant New Alternatives Policy) Program in 1994[2]. Under the SNAP Program, EPA evaluates substitutes for effects on human health or the environment including toxicity, flammability, ozone depletion, and global warming. Under the SNAP Program, EPA does not evaluate performance characteristics such as refrigeration capacity, efficiency, materials compatibility, miscibility with lubricants, and thermodynamic properties. As of June 3, 1997, 10 substitutes for CFC-12 in motor vehicle air conditioning were listed as "acceptable subject to use conditions." Use conditions include a requirement for unique fittings to prevent cross-contamination, a requirement for labeling to identify refrigerants in each vehicle, a prohibition against topping off one refrigerant with another, and a prohibition against recycling of refrigerant blends. Additionally, refrigerant blends containing HCFC (hydrochlorofluorocarbon)-22 require the use of barrier hoses to reduce permeation.

The substitutes listed as acceptable subject to use conditions under the SNAP Program include HFC (hydrofluorocarbon)-134a, three refrigerant blends containing HFC-134a, five blends containing HCFC-22, and a blend with a composition claimed as confidential business information by the manufacturer. Compositions of nine substitute refrigerants that were tested for performance are shown in Table 1. Since the testing was completed, another blend called GHG-X5 (0.41 HCFC-22 / 0.15 HCFC-142b / 0.04 isobutane / 0.40 HFC-227ea) has been listed as acceptable under the SNAP program. Only pure HFC-134a has been endorsed as a substitute for CFC-12 by the automotive OEMs (original equipment manufacturers). However, many of the refrigerant blends are currently available or will be available in the U.S. market.

EPA's National Risk Management Research Laboratory performed the testing described in this paper to provide information to EPA's regulatory office and the automotive air-conditioning industry. Testing was conducted at the Air Pollution Prevention and Control Division located in Research Triangle Park, North Carolina. This EPA laboratory has had prior experience in testing automotive air-conditioning systems and refrigerants[3,4,5].

Table 1. Refrigerant Composition (Percent by Weight)

Name	HCFC-22	HCFC-124	HCFC-142b	HFC-134a	Butane (R-600)	Iso-butane (R-600a)	Propri-etary lubricant
HFC-134a				100			
R-406A/GHG/McCool	55		41			4	
GHG-X4/Autofrost/Chill-It	51	28.5	16.5			4	
GHG-HP	65		31			4	
Hot Shot/Kar Kool	50	39	9.5			1.5	
FREEZE 12			20	80			
FRIGC FR-12		39		59	2		
Free Zone/RB-276			19	79			2
Ikon-12	Composition claimed as confidential business information						

Description of Testing

Refrigerants were tested in an instrumented, OEM, automotive air-conditioning system designed for CFC-12. The 1993 passenger car system had an orifice tube expansion device and a suction line accumulator. The evaporator and housing were located inside an insulated calorimeter chamber. Refrigeration capacity was determined by measuring the power input to electric heaters, heater fans, and evaporator fan inside the chamber. The capacity was determined with an uncertainty of approximately ±100W and a repeatability of ±30W. COP (coefficient of performance) was determined from the measured power input to the compressor with an uncertainty of approximately ±75W and a repeatability of ±50W. Pressures were measured with capacitive pressure transducers with an uncertainty of ±0.1 psia (±0.7 kPa) for 0-100 psia (0-689 kPa) and ±0.6 psia (±4.1 kPa) for 100-250 psia (689-1724 kPa). Refrigerant temperatures were measured with an uncertainty of ±0.9 F° (0.5 C°) with thermocouple probes inserted into the fluid. Instrumentation was similar to that described in a previous paper[3].

A new compressor was broken in for 40 hours with CFC-12 refrigerant and mineral oil lubricant. Following the break-in period, baseline tests were performed with CFC-12 and mineral oil.

Refrigerant blends were mixed in the laboratory using an electronic scale with an accuracy of ±0.2 gram. The Free Zone/RB-276 blend was not mixed in the laboratory because it contains a proprietary lubricant. A 30-pound (13.6 kg) cylinder of the Free Zone/RB-276 was obtained and the blend was charged into the system as a liquid from the cylinder. For all the refrigerant blends, manufacturer or supplier recommendations on charging the system were followed if they were available. Before each refrigerant was charged, the system was triple-flushed with dry nitrogen and evacuated until the system held a vacuum of less than 25 μm Hg for 15 minutes to ensure that no significant amount of residual refrigerant or moisture remained in the system. For all tests, minimal superheat at the compressor inlet indicated the presence of some saturated liquid in the suction line accumulator and confirmed that the system was fully charged.

Refrigerant manufacturer recommendations on lubricants were also followed if they were available. The four refrigerant blends that contained HCFC-22 were tested with the same mineral oil used with CFC-12. FREEZE 12 and FRIGC FR-12 were tested with 3 ounces (89 cm^3) of POE (polyolester) lubricant added to the existing mineral oil. The POE lubricant had a viscosity reported by the manufacturer to be 134 cSt at 40°C and 25 cSt at 100°C. Free Zone/RB-276, containing 2 percent of a proprietary lubricant, was tested with the mineral oil used with CFC-12. Ikon-12 was tested with a POE lubricant that had previously been tested for compatibility with the refrigerant[5]. HFC-134a was tested with PAG (polyalkylene glycol) lubricant added to the mineral oil used with CFC-12, as recommended by the OEM. When lubricants were changed, residual lubricant was removed from the system by repeatedly flushing with a solvent followed by evacuation to remove the solvent. The accumulator/drier was removed each time before the system was flushed and was replaced with a new unit after flushing. Heptane was used as a solvent to remove mineral oil and POE lubricant, and methanol was used to remove PAG lubricant. Solvents were not used to flush the compressor, but the compressor was repeatedly flushed with heated lubricant.

Conditions for the three tests performed with each refrigerant are shown in Table 2. Evaporator air inlet temperatures were set high enough to provide sufficient load to prevent cycling of the compressor. Steady-state operation enabled measurement and comparison of performance characteristics including refrigeration capacity, COP, pressures, and temperatures. Although a significant part of the refrigeration load on an air-conditioning system can result from moisture condensing on the surface of the evaporator, in the test system, air inside the evaporator chamber was not humidified to simplify the measurement of refrigeration capacity. Relative humidity was maintained at a low level during testing to prevent any condensation of water vapor. Electrical potential applied to the evaporator fan motor was regulated and maintained at 10.6VDC to obtain consistent air flow through the evaporator.

Table 2. Test Conditions

	1	2	3
Compressor rotational speed (rpm)	1000	2000	3000
Evaporator air inlet temperature, °C (°F)	37.8 (100)	43.3 (110)	48.9 (120)
Condenser air inlet temperature, °C (°F)	46.1 (115)	35.0 (95)	35.0 (95)
Condenser air inlet velocity, m/s (ft/min)	1.02 (200)	1.78 (350)	1.78 (350)
Compressor ambient temperature, °C (°F)	54.4 (130)	54.4 (130)	54.4 (130)

At each test condition, data were recorded at 30-minute intervals during a 2-hour period to ensure steady-state operation. After initial baseline tests with CFC-12 and tests with the nine substitutes were completed, tests were repeated with CFC-12 to ensure that system performance had not degraded during the course of the testing. Comparisons of the final tests with the initial CFC-12 tests are shown in Table 3. Refrigeration capacity remained within ±2 percent. At the 1000, 2000, and 3000 rpm test conditions, COP increased by 1.5, 5.4, and 3.9 percent, respectively. This increase in COP may have resulted, in part, from additional break-in of the compressor during the testing.

Table 3. Comparison of Final Tests with CFC-12 to Initial Baseline Tests With CFC-12

	1	2	3
Refrigeration capacity (percent change)	+1.0	-0.4	-2.0
COP (percent change)	+1.5	+5.4	+3.9

Limitations of Testing

Tests results described in this paper contribute to the information available in the open technical literature on alternative refrigerants. However, results should not be used as conclusive evidence of any refrigerant's relative merits for the following reasons:

1. All tests were performed with one automotive air-conditioning system. Performance may vary between different vehicle air-conditioning systems.

2. Only three tests were performed for each refrigerant. Automotive air conditioners operate over a greater range of conditions than represented by the test conditions.

3. Tests were performed under steady-state conditions. Automotive air conditioners usually operate under transient conditions with changing rotational speed, changing load conditions, changing capacity, or on/off cycling of the compressor.

4. In the laboratory, refrigerant blend composition was carefully controlled for the tests. In the field, composition can change due to leakage or fractionation during servicing. Performance may vary with changing blend composition.

5. Tests were performed to evaluate only air-conditioning system performance. Other important factors involved in refrigerant evaluation include materials compatibility, chemical stability, fractionation, and long-term durability. Extensive laboratory and field testing is required to adequately evaluate these factors.

Discussion of Results

Refrigeration capacities for the ten refrigerants are compared at the three test conditions in Figure 1. Of the ten refrigerants tested, HFC-134a had the lowest capacities with values ranging from 8 to 9 percent lower than the capacities for CFC-12. Capacities for the four blends that contained HCFC-22 were 0 to 9 percent higher than those for CFC-12 at the three test conditions. Capacities for the three blends that contained HFC-134a were 3 to 9 percent lower than those for CFC-12. Refrigeration capacities for Ikon-12 were 2 to 6 percent lower than those for CFC-12. Comparison of refrigeration capacities for Ikon-12 with those for HFC-134a is consistent with results obtained in a previous evaluation[5].

COPs are compared in Figure 2. COPs for HFC-134a ranged from 7 to 9 percent lower than those for CFC-12. COPs for HFC-134a and the four blends that contained HCFC-22 tended to be lower than the COPs for Ikon-12 and the three blends that contained HFC-134a. Comparison of the COPs for Ikon-12 with those for HFC-134a is consistent with results obtained in a previous evaluation[5].

Evaporator outlet pressures are compared in Figure 3. HFC-134a evaporator pressures most closely matched those of CFC-12 at the three test conditions. The four blends that contained HCFC-22 had evaporator pressures that were notably higher than the pressures for CFC-12. Ikon-12 and the three blends that contained HFC-134a had evaporator pressures that were lower than those for CFC-12.

Compressor discharge pressures are compared in Figure 4. Discharge pressures for HFC-134a were 4 to 8 percent higher than those for CFC-12. Compressor discharge pressures for the four blends that contained HCFC-22 were 17 to 34 percent higher than the pressures for CFC-12. The three blends that contained HFC-134a had discharge pressures that were lower than those for CFC-12.

Compressor discharge temperatures are compared in Figure 5. Discharge temperatures for HFC-134a and for two of the blends that contained HFC-134a were more than 5C° lower than temperatures for CFC-12. Discharge temperatures for two of the four blends that contained HCFC-22 were more than 5C° higher than temperatures for CFC-12.

Conclusions

Due to the limitations of testing, test results should not be used as conclusive evidence of the performance of refrigerants, as discussed above. However, the results do provide some useful indications of performance. Results from this evaluation indicated that the refrigeration capacities for all the refrigerants tested are likely to be adequate compared to the capacity for CFC-12. Although HFC-134a had the lowest capacity, its capacity was within 10 percent of that for CFC-12. The four refrigerant blends that contain HCFC-22 had the advantage of somewhat higher capacities than those of the other substitutes for CFC-12. Higher refrigeration capacity can improve occupant comfort during certain operating conditions when the refrigeration load is high compared to the available capacity.

However, the blends that contain HCFC-22 had the disadvantage of higher evaporating and condensing pressures. Higher pressures can increase the stress on air-conditioning system components and can have a negative effect on control systems with pressure sensing devices. Compressor discharge temperatures for two of the four blends that contained HCFC-22 were more than 5C° higher than temperatures for CFC-12. Higher discharge temperatures can cause the lubricant to break down at a faster rate and may cause a reduction of the time before failure of the system. Discharge temperatures for HFC-134a and for two of the blends that contained HFC-134a were more than 5C° lower than temperatures for CFC-12. Lower discharge temperatures may increase the durability of the system.

Results indicated that the COPs for all the refrigerants tested are likely to be adequate compared to the COP for CFC-12. Refrigerants with lower COPs may cause a slight increase in vehicle fuel consumption.

Ikon®-12 and the refrigerant blends that contain HFC-134a had the advantage of lower condensing pressures than those of HFC-134a. Ikon®-12 and the refrigerant blends that contain HFC-134a also had the advantage of slightly higher refrigeration capacities than those of HFC-134a. However, all zeotropic blends have the disadvantage of potential fractionation during installation, operation, and servicing. Performance may decline with changing blend composition. Pure HFC-134a has no fractionation and has had more extensive testing for materials compatibility and system durability.

Notice

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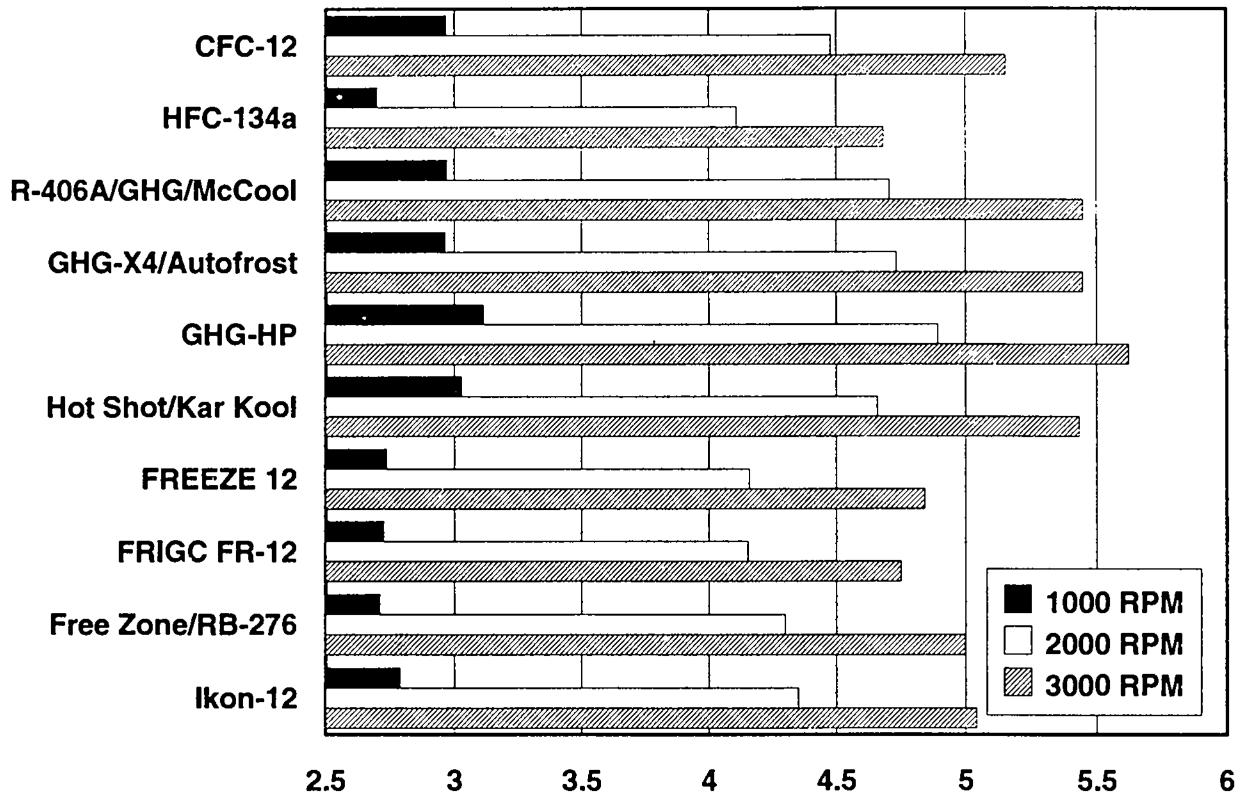

Figure 1. Refrigeration Capacity (kW)

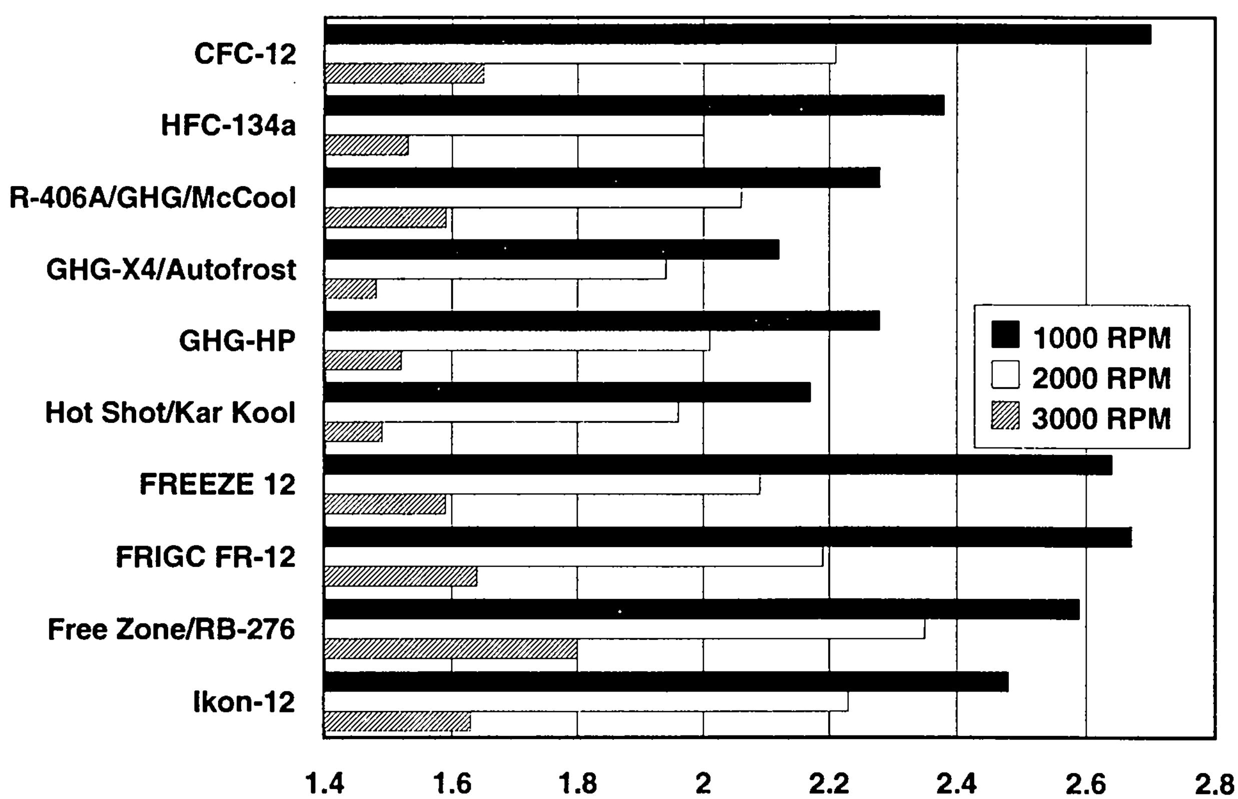

Figure 2. Coefficient of Performance

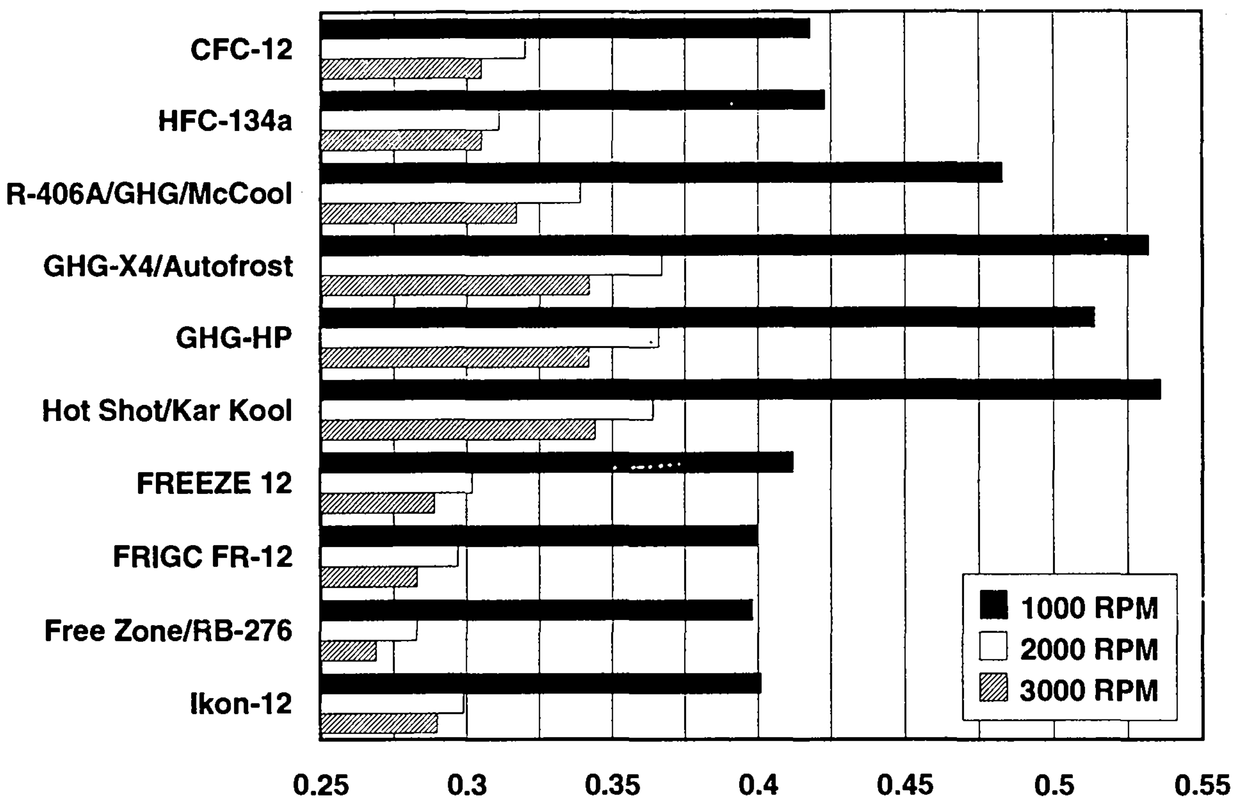

Figure 3. Evaporator Outlet Pressure (MPa)

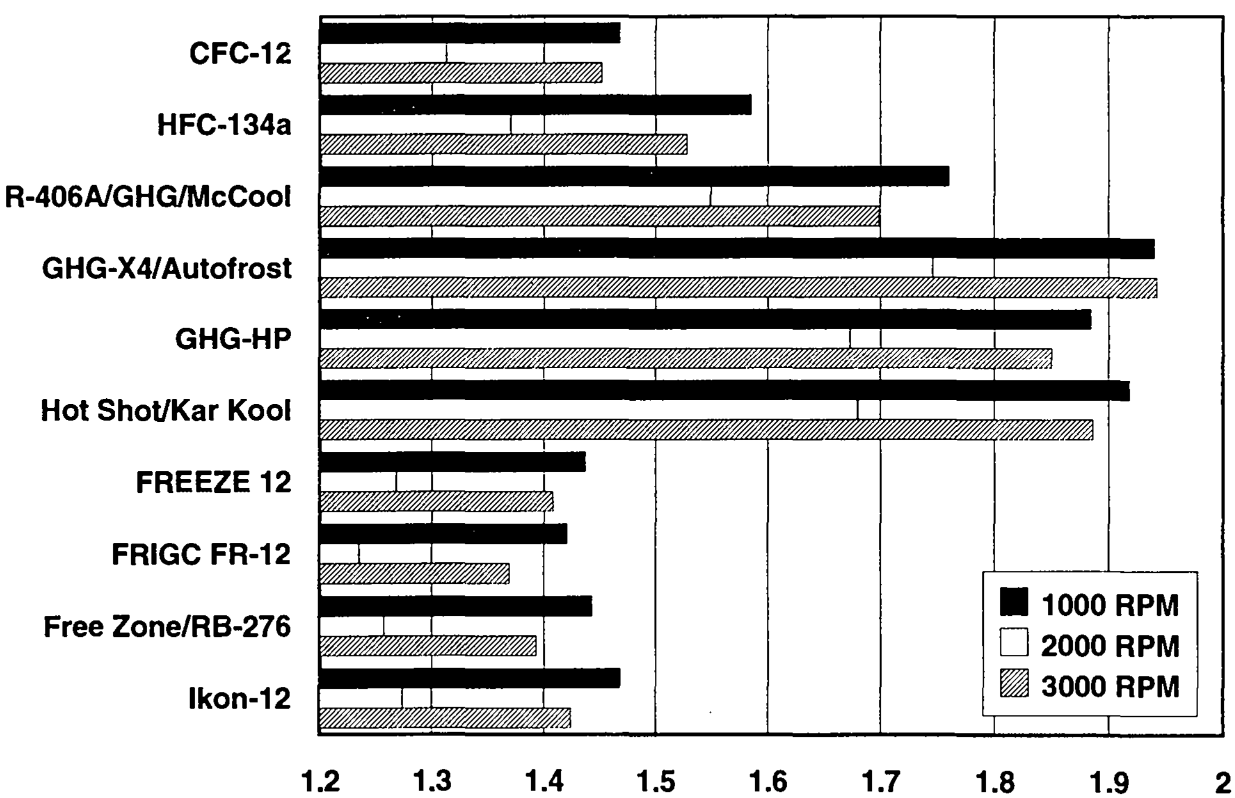

Figure 4. Compressor Discharge Pressure (MPa)

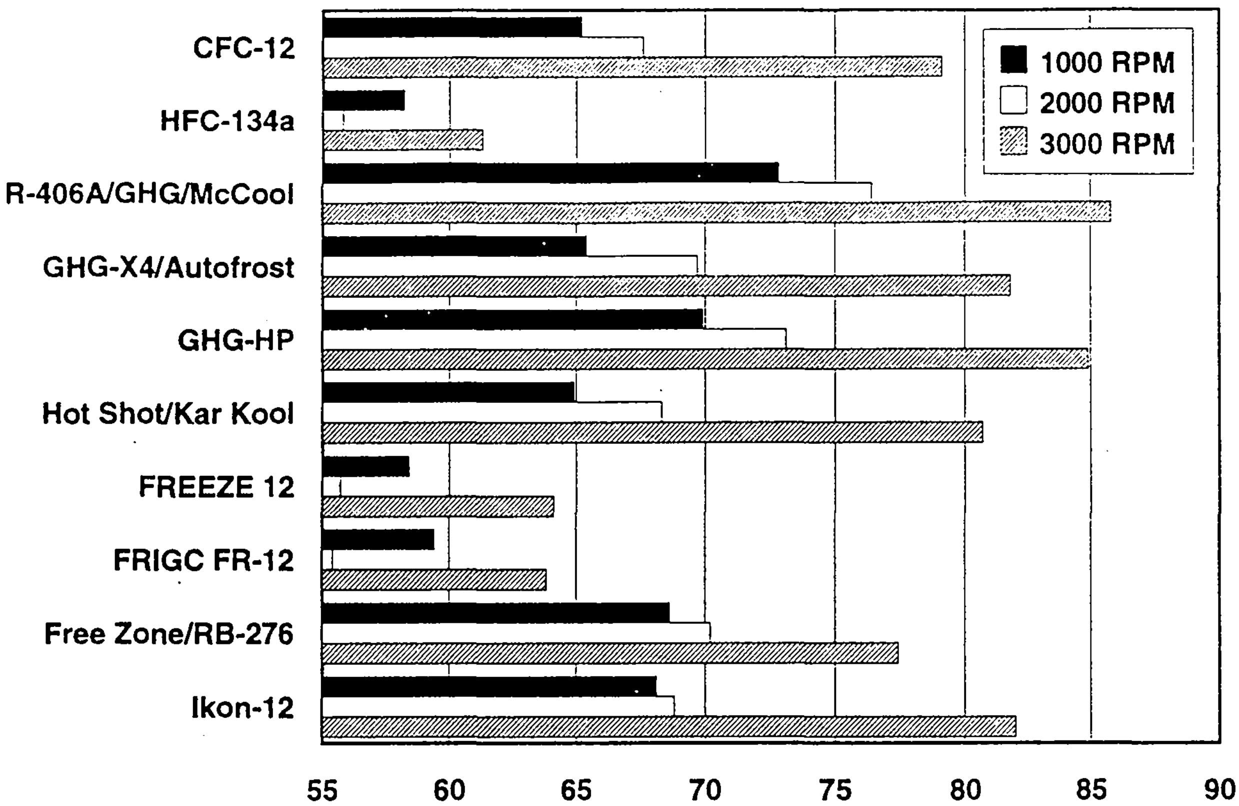

Figure 5. Compressor Discharge Temperature (Degrees Celsius)

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16. ABSTRACT The paper gives results of testing of alternatives for chlorofluorocarbon (CFC)-12 refrigerant in automotive air conditioning. Ten refrigerants, including CFC-12, hydrofluorocarbon (HFC)-134a, and eight refrigerant blends, were tested in an instrumented automotive air-conditioning system designed for CFC-12. The refrigerants were compared at three test conditions for refrigeration capacity, coefficient of performance, compressor discharge pressure and temperature, and evaporator outlet pressure. Due to limitations of the testing, test results should not be used as conclusive evidence of the performance of the refrigerants. However, the results were obtained by testing all the refrigerants in the same system under the same conditions, and the results provide an indication of the comparative performance of the refrigerants. Further laboratory and field testing would be required to adequately evaluate performance and other important refrigerant characteristics including materials compatibility, chemical stability, fractionation, and long-term durability. Refrigeration capacities for CFC-12 substitutes ranged from 9% lower to 9% higher than those for CFC-12.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Pollution Control	13B
Substitutes	Stationary Sources	14G
Refrigerants	Automotive Air Conditioning	13A
Halohydrocarbons		07C
Air Conditioning		
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