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COMPATIBILITY OF ALTERNATIVE REFRIGERANTS WITH VARNISHED MAGNET WIRE

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Abstract - The compatibility of 24 motor materials with 11 pure refrigerants and 17 refrigerant-lubricant combinations was determined under a \$382,000 contract funded by the Department of Energy (DOE) and administered by the Air-Conditioning and Refrigeration Technology Institute (ARTI). This article is a summary of the effect of refrigerants on varnished magnet wire.

The greatest effect on the motor materials was caused by absorption followed by desorption of refrigerants at higher temperatures. The high internal pressure of the absorbed refrigerants and the tendency of these refrigerants to evolve from the materials resulted in blisters, cracks and internal bubbles in the varnish and magnet wire insulation. The degradation of the insulation resulted in changes in the bond, dielectric and burnout strength of the varnished magnet wire. Desorption of HCFC-22, and to a lesser extent HFC-32, HFC-134 and HFC-152a, had the greatest effect on insulation integrity.

Of the refrigerants tested, exposure to HCFC-22 produced the most deleterious effects on the magnet wire insulation and varnishes. Since many of the materials tested have excellent reliability with HCFC-22 in current applications, these materials are expected to be reliable when used with the new refrigerants.

INTRODUCTION

Because of ozone depletion attributed to the chlorofluorocarbons (CFC's), a program to develop alternative refrigerants is currently underway. An environmentally acceptable refrigerant includes hydrogen (HCFC) to decrease atmospheric life and/or excludes chlorine (HFC) to eliminate ozone depletion. A primary requirement of a new refrigerant is compatibility with the hermetic motor materials.

The compatibility of polymeric insulation material with refrigerants depends on two primary modes of interaction: absorption of refrigerant and extraction by refrigerant.

Absorption of the refrigerant can affect the insulation material by changing its dielectric strength or physical integrity. Absorption can cause excessive swelling, softening or decreased strength. In addition to the direct effect of the absorbed refrigerant, a more deleterious effect may occur due to rapid desorption of the refrigerant. Absorption and desorption can result in high internal pressures causing blisters, crazing, surface craters or bubbles within the insulating material. A pronounced decrease in the dielectric and physical strength of the material is often observed.

Extraction of material by the refrigerant results in a range of effects varying from complete dissolution to only a slight change in properties as a result of dissolving only unpolymerized material. The usual effect of the extraction on insulation materials is embrittlement caused by extraction of low molecular weight polymers (oligomers) or plasticizers. Extraction or chemical dissolution of a material can also cause serious problems within hermetic systems by causing components to stick or by clogging passages such as capillary tubes.

The data presented in this paper show the effects of absorption, desorption and extraction on the physical properties of the insulating materials. Results immediately after the 500 hour exposures illustrate the effects of absorbed refrigerant on insulation properties such as bond strength, burnout resistance, and dielectric strength. The results after the 150°C (302°F) bake in air, following the refrigerant or refrigerant-lubricant exposure, indicate the effects of desorption on the same properties.

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Comparison of the compatibility data for refrigerant-lubricant combinations with that of pure refrigerants showed that, in general, pure refrigerants exhibited a greater effect on varnished magnet wire. This effect occurred even though exposures to pure refrigerants were at a lower temperature.

The information presented in this report can best be interpreted by comparisons to a refrigerant with a history of reliability. Since pure HCFC-22 showed the most deleterious effect on materials and has a well documented reliability history, results were compared to HCFC-22.

REFRIGERANTS AND MATERIALS EVALUATED

This paper covers compatibility tests of three commercial magnet wires combined with six motor varnishes exposed to 11 pure refrigerants. Exposures were conducted in stainless steel pressure vessels. Magnet wire and varnish samples were covered with liquid refrigerant at an exposure temperature below critical temperature. Materials were evaluated in triplicate immediately after a 500 hour exposure and after a 500 hour exposure followed by an additional 24 hour bake at 150°C(302°F) in air to remove absorbed refrigerant. The effect of heat alone was determined by exposures in nitrogen gas.

The refrigerants, magnet wires, varnishes, and tests performed on the motor are listed below:

REFRIGERANTS

The motor materials were exposed to the 11 pure refrigerants for 500 hours at the temperatures indicated below. HFC-245ca, [1] a research chemical with properties similar to CFC-11 and HCFC-123, was added to the test program. The HCFC's included 22, 123, 124, and 142b. The HFC's included 32, 125, 134, 134a, 143a, 152a, and 245ca. Exposure temperature was 90°C/194°F for all refrigerants except HFC-32, -125, -143a (60°C/140°F) and HFC-245ca (121°C/250°F).

MAGNET WIRE AND VARNISHES

Magnet Wire

- A. Modified polyester overcoated with polyamide imide per Section MW 73 of NEMA Standard MW 1000
- B. Modified polyester overcoated with polyamide imide and epoxy saturated glass per Section MW 73 and MW 46 of NEMA Standard MW 1000
- C. Polyester imide over coated with polyamide imide

Varnishes

- U475EH, solvent epoxy
- Y390PG, solvent epoxy-phenolic
- ER610, 93% solids epoxy
- Y833, 100% solids VPI epoxy
- 923, solvent epoxy
- Isopoxy 800, water-borne epoxy

EVALUATIONS PERFORMED

Evaluations, in addition to visual examinations, were performed on the motor materials both before and after the exposures. Measurements, including bond, dielectric, and burnout strengths, were conducted according to standard methods[2].

RESULTS

The compatibility measurements after the 500 hour exposure to 11 pure refrigerants or 17 refrigerant-lubricant combinations are presented as 620 pages of data tables in Volumes II and III of the final report [3]. Pictures documenting observed changes comprise Volume IV. The 620 pages of data are summarized in 84 tables of average percent change from unexposed values. The percent change tables, procedures, motor material specifications, discussions, compatibility charts, etc., are located in Volume I of the report.

Percent change tables in this article will be restricted to the effect of pure refrigerants on the varnishes and Magnet wire A only. Discussion will include all three varnished magnet wires.

DISCUSSION

Varnishes

Before discussing the effects of refrigerants on the bond, dielectric and burnout strengths of varnished magnet wires, it is best to examine the effects on pure varnish cast in the form of thin disks.

Varnish Disks
% Change in Weight
Results after 500-hour exposure

Exposure to	Varnish Type					
	U-475	Y-390	ER-610	Y-833	No. 923	ISO-800
N ₂ @ 60°C	0.3%	0.3%	0.4%	0.2%	0.3%	0.2%
N ₂ @ 90°C	0.0%	0.3%	0.3%	0.0%	-0.1%	-0.3%
HCFC-22	16.9%	12.5%	18.7%	15.4%	14.4%	7.4%
HCFC-123	27.6%	24.6%	25.5%	44.0%	26.2%	13.9%
HCFC-124	4.8%	2.4%	7.4%	13.2%	1.8%	0.9%
HCFC-142b	6.1%	6.5%	10.0%	6.3%	6.2%	0.0%
HFC-152a	6.4%	4.9%	9.1%	8.1%	5.2%	0.1%
HFC-134a	1.7%	1.2%	2.8%	4.7%	1.5%	0.9%
HFC-134	7.5%	4.5%	9.1%	7.6%	7.3%	-1.1%
HFC-125	1.6%	2.4%	2.4%	2.0%	2.6%	1.0%
HFC-32	8.1%	6.8%	9.2%	9.5%	6.1%	4.8%
HFC-143a	1.2%	8.5%	4.2%	5.1%	1.7%	0.1%
HFC-245ca	7.2%	4.6%	9.6%	8.4%	3.2%	2.3%

Table 1

HCFC-123 was absorbed to the greatest extent (13.9% to 44.0%) by all varnishes followed by HCFC-22 (7.4% to 18.7%). Other refrigerants such as HCFC-124 (0.9-13.2%) and HCFC-142b (0-10.0%) were also absorbed in fairly large amounts by the varnishes. This trend suggested that HCFC's with some chlorine were generally absorbed to greater amounts than HFC's. However, HFC-32 (4.8-9.5%), HFC-134 (1.1-9.1%) and HFC-152a (0.1-9.1%) are absorbed to an extent similar to HCFC-124 and HCFC-142b, suggesting that other factors are involved besides the presence or absence of chlorine. For example, the refrigerants absorbed to the greatest extent and exhibiting the greatest effect on varnish disks and varnished magnet wire (HCFC-22, HFC-32, HFC-134 and HFC-152a) contained the -CHF₂ group.

The high absorption values for HCFC-123 lead to the expectation that HCFC-123 should cause the greatest compatibility concerns with varnishes. However, only the 833 varnish with 44% absorption, was found to be incompatible with HCFC-123 by this study and by previous studies [4]. Absorption of HCFC-123 as high as

27.6% by weight appeared to have little effect on the other varnishes.

Varnishes exposed to HCFC-22, and to a lesser extent HFC-32, HFC-134 and HFC-152a, exhibited internal bubbles and external blisters after the 150°C (302°F) bake, but HCFC-123 and the other refrigerants did not exhibit this effect. This may be due to lower internal refrigerant pressure or to a slower rate of desorption for those refrigerants not affecting the varnishes.

Magnet Wire

The effects of refrigerants and refrigerant-lubricants on the relatively thick varnish disks (0.05 inch) are only indications of potential problems that may occur with varnished magnet wires in actual motors. The varnish thickness on magnet wire in actual motors is only about 0.002 inch. As a further step to evaluate the effects, studies were conducted on actual varnished magnet wires. The three magnet wire types were tested unvarnished and varnished with six different varnishes.

Bond Strength

The greatest effect of the refrigerant absorption/desorption phenomena was exhibited by changes in the helical coil bond strength.

Varnish Coated on Magnet Wire A
BOND STRENGTH
Results after 500-hour exposure plus a 24-hour air bake @ 150°C

Exposure to	Varnish Type					
	U-475	Y-390	ER-610	Y-833	No. 923	ISO-800
Unexposed (100%)	73.7	43.8	51.8	9.9	4.3	45.0
Exposure to	% Change from Unexposed					
	U-475	Y-390	ER-610	Y-833	No. 923	ISO-800
N ₂ @ 60°C	-5.8%	23.8%	6.9%	56.2%	12.4%	23.5%
N ₂ @ 90°C	-15.9%	26.0%	37.8%	35.3%	7.9%	1.4%
HCFC-22	94.6%	-79.6%	90.4%	14.7%	63.9%	37.6%
HCFC-123	-1.0%	12.8%	59.9%	49.7%	6.0%	15.1%
HCFC-124	0.3%	22.7%	27.3%	13.4%	6.2%	6.5%
HCFC-142b	-9.7%	30.5%	22.3%	36.1%	25.5%	15.4%
HFC-152a	91.2%	-83.1%	84.8%	15.2%	-19.4%	39.7%
HFC-134a	19.0%	11.1%	7.6%	4.6%	7.5%	5.7%
HFC-134	31.1%	45.5%	-23.3%	20.1%	2.1%	0.2%
HFC-125	10.7%	42.0%	13.5%	29.1%	11.5%	2.1%
HFC-32	-66.2%	-80.1%	92.4%	26.9%	56.0%	19.0%
HFC-143a	4.7%	22.3%	12.5%	13.4%	20.1%	13.3%
HFC-245ca	-40.8%	15.4%	-27.8%	17.7%	3.8%	10.1%

Table 2

Refrigerant HCFC-22 had the greatest effects(-20% to -49%) on the bond strengths of magnet wire A (polyester with amide imide overcoat) with the six varnishes as measured immediately after the exposure. After bakeout of HCFC-22 the bond strength was reduced -38 to -95%. Exposure to HFC-32 (-19 to -86%) and HFC-152a (-19 to -91%) also produced greatly decreased bond strengths after bakeout. Significant decreases in bond strengths were also observed for magnet wire B (glass served) with the six varnishes after exposures to HFC-22 (-20 to -59%), HFC-32 (-6 to -75%), HFC-152a (-7 to -59%) and HCFC-123 (+1 to -80%). For magnet wire C (ester-imide/amide-imide) similar losses of bond strength were measured for HCFC-22 (-45 to -84%) and HFC-32 (+13 to -95%) but not for HFC-152a, HCFC-123 or other refrigerants.

In general, the helical coil bond strength of the varnished magnet wires was decreased by the effects of absorption and desorption of refrigerants. The refrigerant having the greatest effect was HCFC-22. Bond strength for the 833 varnish was less than the other varnishes, but should not be compared to the other varnishes because the 833 is used primarily for its electrical insulation properties rather than its bond strength.

Burnout Strength

Burnout strength was also measured on the varnished and unvarnished magnet wires before and after exposures to refrigerants and refrigerants-lubricants. The burnout test simulates the effects of high current loads on motor stators that may occur during start up or other transient conditions. The burnout test applies a 120 volt AC current over time through twisted pairs, causing resistance heating of the wire and records the time at which the insulation fails.

The amount of refrigerant absorbed and the effect of the 150°C(302°F) bake had less effect on burnout strength than on the other properties of the magnet wire. This results because the burnout test heated the wire similar to the bake out, except to higher temperatures and faster. In many instances, the effect on the burnout strengths of the wires was greater when the absorbed refrigerant was not completely expelled prior to the test.

Varnish Coated on Magnet Wire A
BURNOUT STRENGTH(seconds)
Results after 500-hour exposure plus a 24-hour air bake @ 150°C

	Varnish Type					
	Unexposed	HCFC-22	HFC-32	HCFC-123	HFC-152a	Other
Unexposed	536	430	510	440	528	406
% Change from Unexposed						
Unexposed to	Unexposed	HCFC-22	HFC-32	HCFC-123	HFC-152a	Other
H ₂ O @ 60°C	-4.3%	21.0%	6.8%	-5.2%	-4.7%	-1.2%
H ₂ O @ 90°C	-3.0%	12.6%	9.2%	12.2%	9.7%	-1.7%
HCFC-22	8.9%	24.0%	16.2%	29.2%	15.1%	-43.1%
HCFC-123	28.2%	35.1%	15.6%	9.7%	24.1%	51.5%
HCFC-124	19.7%	38.7%	11.6%	2.9%	7.2%	32.0%
HCFC-142b	-12.7%	41.6%	24.5%	16.5%	12.0%	45.8%
HFC-142b	-11.2%	22.3%	30.9%	1.1%	12.1%	12.2%
HFC-134a	-1.5%	52.5%	18.4%	-6.9%	6.5%	6.7%
HFC-125	-19.5%	18.2%	0.2%	17.2%	15.9%	2.4%
HCFC-32	2.4%	16.0%	4.4%	6.3%	-10.6%	20.8%
HFC-32	2.5%	-36.3%	9.2%	22.4%	-10.3%	16.5%
HCFC-143a	-0.6%	1.4%	-4.4%	13.0%	14.1%	-15.6%
HFC-245fa	13.5%	16.2%	19.0%	22.0%	9.0%	11.1%

Table 3

The most important information revealed from the burnout test is the superior performance of magnet wire B (glass served) compared with the other types of magnet wires. The unexposed magnet wire B shows a burnout time of 736 to 755 seconds compared to 430 to 600 seconds for magnet wire A(ester with amide-imide overcoat) and 469 to 632 seconds for magnet wire C(ester-imide with amide-imide overcoat). These times translate into significant differences in temperature resistance of the three types of wire insulation. Secondly, exposures to refrigerants had very little effect on the burnout time of magnet wire B compared to the other wire types.

Dielectric Strength

The test for dielectric strength of magnet wire used the same type of twisted pairs that were used for the burnout test. Rather than increasing the current with time, the voltage between the two wires was increased until there was dielectric breakdown of the insulation and a spark jumped between the two wires. This dielectric breakdown voltage was automatically recorded.

For magnet wire A(ester with amide-imide overcoat), the greatest decrease in dielectric breakdown voltage results after desorption of refrigerant. As observed previously from the degradation of varnish disks, the greatest effects resulted from exposures to HCFC-22 (+8.8 to

-69.9%), HFC-32 (-2.2 to -59.0%) and R-152a (-1.0 to -50.1%). Results for magnet wire C (ester-imide with amide-imide overcoat) were very similar to those for magnet wire A. The dielectric strength of magnet wire B (polyester-glass served) was less affected by refrigerant exposure than the other magnet wire types. Surprisingly the dielectric strength of unexposed magnet wire B was less than the dielectric strength of other magnet wires.

Varnish Coated on Magnet Wire A DIELECTRIC STRENGTH Results after 500-hour exposure plus a 24-hour air bake @ 150 C							
Varnish Type							
	Uncoated	U-475	Y-390	FR-610	Y-833	No. 923	CG-800
Unexposed	15.8 kV	16.2 kV	18.8 kV	15.6 kV	12.0 kV	16.8 kV	19.1 kV
% Change from Unexposed							
Exposure to	Uncoated	U-475	Y-390	FR-610	Y-833	No. 923	CG-800
N ₂ @ 60 C	9.4%	-11.0%	-12.4%	-19.4%	-9.3%	-30.2%	-11.8%
N ₂ @ 90 C	-14.2%	8.5%	-11.2%	10.2%	-5.7%	-15.4%	-7.6%
HCFC-22	8.8%	-18.4%	-44.8%	-42.0%	-2.9%	-16.1%	-69.9%
HCFC-123	-15.0%	-3.0%	-19.9%	-2.1%	9.1%	-3.0%	-26.9%
HCFC-124	-2.8%	-5.5%	-7.6%	-21.5%	-12.2%	19.3%	13.8%
HCFC-142b	-9.8%	0.0%	-8.0%	-9.2%	-11.7%	-9.5%	2.9%
HFC-142b	-1.0%	-8.4%	-40.5%	-26.1%	-6.4%	-50.1%	-24.6%
HFC-134a	-20.4%	-18.1%	-17.1%	14.2%	-18.3%	8.4%	-20.5%
HFC-134	-22.7%	-25.9%	-38.2%	21.9%	-18.8%	-30.8%	-7.9%
HFC-125	13.2%	-7.3%	-21.4%	18.3%	-3.4%	7.5%	-2.3%
HFC-32	-2.2%	-21.0%	-54.0%	54.7%	7.0%	-59.0%	-28.9%
HFC-143a	-0.1%	23.2%	6.6%	-4.7%	-0.1%	19.3%	-19.2%
HFC-245ca	-18.2%	16.2%	-19.0%	-22.0%	-9.9%	-11.1%	-9.1%

Table 4.

SUMMARY

Absorption of HCFC-123 by most motor materials was higher than for other refrigerants. However, absorption of HCFC-22, HFC-32, HFC-134 and HFC-152a followed by desorption at higher temperatures, resulted in greater damage to the insulation material than was observed with HCFC-123. This result suggests that high internal pressures and rate of refrigerant desorption is as important as the amount of refrigerant absorbed. Desorption of refrigerant caused blisters, cracks, internal bubbles and delamination. The measured effects on properties of some materials was a decrease of bond strength (as high as 95%), a decrease of dielectric strength (as high as 70%), and a decrease of the physical integrity of the material. Compared to the bond and dielectric strengths, burnout was less influenced by desorption prior to the test. The burnout test caused desorption of refrigerant during the test. Magnet wire with polyester-glass serving had the best burnout resistance and was influenced

much less by the exposure to absorbed refrigerant.

Of the 11 refrigerants tested, HCFC-22 produced the greatest effects on motor materials. Since HCFC-22 has an excellent reliability history with many of these materials, the alternative refrigerants are also expected to be compatible with most materials.

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