COMPATIBILITY OF REFRIGERANTS AND LUBRICANTS WITH MOTOR MATERIALS UNDER RETROFIT CONDITIONS⁽¹⁾

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ABSTRACT

Compatibility tests were conducted on motor materials to determine whether exposure to the original refrigerant/mineral oil would affect compatibility of the motor materials with the alternative refrigerant/lubricant after retrofit. The motor materials were exposed at elevated temperature to the original refrigerant and mineral oil for 500 hours, followed by exposure to the alternative refrigerant and lubricant for 500 hours.

Motor materials exposed to the alternative refrigerant and lubricant (after an initial exposure to the original refrigerant and mineral oil) appeared to be compatible with the alternative refrigerant and lubricant. The only concern was delamination and blistering of the sheet insulation containing Nomex, especially after removal of absorbed refrigerant at high temperature. This was attributed to incompatibility of the adhesive and not to the Nomex itself. Embrittlement of the polyethylene terephthalate (PET) sheet and sleeving insulations was initially observed, but subsequent tests under extremely dry conditions showed that embrittlement of the PET materials was attributed to moisture present during the exposure.

INTRODUCTION

A major concern in retrofitting air-conditioning and refrigeration equipment is the compatibility of the hermetic motors that have been operated with a CFC refrigerant and mineral oil for years and after conversion will be operated with the alternative refrigerant and lubricant. That prior exposure may affect the compatibility with the retrofit refrigerant and lubricant. Compatibility tests on these old motor materials could be performed by two methods. The first method would require samples obtained from a motor that had operated in original refrigerant for years, and perform compatibility tests on those materials. This method would be subject to a number of variables, including materials identification, exposure conditions over the years, cross contamination and damage to materials on removal from an electric motor. The method actually used started with new motor materials which were then exposed at elevated temperatures to original refrigerant/mineral oil, followed

by exposure to alternative refrigerant/lubricant to simulate years of exposure in the field to both refrigerants.

Underwriters Laboratories (UL) recently issued UL Standards 2171⁽³⁾ covering retrofits. That standard requires tests after sequential exposures to the original refrigerant/lubricant followed by the alternative refrigerant/lubricant to verify the compatibility of the motors. This work was conducted in accordance with the requirements of UL Standard 2171. The tests were conducted on individual samples of the motor materials. Motorettes were also included to correlate with the results of tests on the individual motor materials. Compatibility tests of motor materials after sequential exposures to refrigerants and lubricants were not previously conducted.

Motor Materials

The motor materials tested were the same motor materials tested in the prior MCLR program⁽²⁾. These materials have been used in hermetic motors since about 1973. The motor materials tested are listed in the Compatibility Chart located in this article.

Refrigerants and Lubricants

Equipment operating today with CFC's R-11, R-12 and R-502 (a HCFC-22/CFC-115 blend) and HCFC 22 are most likely to be retrofitted with HCFC's or HFC's. Lubricants for this study were randomly selected by a drawing at ARTI from a larger list of commercially available polyolesters. Because of interest in R-245ca as a possible chlorine-free replacement for R-11 or R-123, and the fact that a chiller test with R-245ca was planned on another ARTI MCLR project, the compatibility of motor materials with R-245ca after retrofit from R-11 or R-123 was conducted. The original refrigerant and the alternative considered for retrofit were as follows:

Original Refrigerant	Alternative Refrigerant	Exposure Temperature
R-12/Mineral Oil	R-134a/Polyol Ester	127°C (260°F)
R-22/Mineral Oil	R-407C/Polyol Ester	127°C (260°F)
R-502/Mineral Oil	R-404A/Polyol Ester	127°C (260°F)
R-11/Mineral Oil	R-123/Mineral Oil	100°C (212°F)
R-11/Mineral Oil	R-245ca/Polyol Ester	100°C (212°F)
R-123/Mineral Oil	R-245ca/Polyol Ester	100°C (212°F)

Compatibility Exposures

The compatibility exposures were based on the procedures previously used by Trane to determine the compatibility of current motor materials and were modified to comply with UL Standard 2171. The motor material samples were dried for 24 hours at 127°C (260°F) and placed in two-liter, stainless steel

pressure vessels. Polyolester lubricants were dried to 50 ppm moisture or less before use. Mineral oils were dried to 30 ppm or less. The original lubricant (mineral oil) was added in sufficient quantity to cover the materials, taking into consideration the thermal expansion of the lubricant and the solubility of the refrigerant. For the higher pressure refrigerants, R-12, R-502, and R-22, refrigerant was added to provide a pressure of about 2109 kPa (300 psi) at 127°C (260°F). For the low pressure refrigerant, R-11, the amount of refrigerant added was about 50% by weight. The ratio of refrigerant to lubricant ranged from approximately 20/80 for the high pressure refrigerants to 50/50 for R-11, R-123 and R-245ca depending on the solubility and pressure of the particular refrigerant/lubricant combination.

Samples were exposed to the original refrigerant and mineral oil for 500 hours at 127°C (260°F) for R-12, R-502 and R-22 or at 100°C (212°F) for R-11 and R-123 followed by exposure to the alternative refrigerant and lubricant for an additional 168, 336 and 500 hours at the same temperatures. Exposures for R-11, R-123, and R-245ca were conducted at 100°C (212°F) to prevent thermal decomposition of the least stable refrigerant, R-11.

After exposure to the original refrigerant/mineral oil for 500 hours some of the samples were removed for evaluations. Results were used as a baseline for comparison with results on the samples after exposure to the retrofit refrigerant/lubricant. Other samples from the first exposure were divided into three pressure vessels and exposed to the retrofit refrigerant/lubricant for an additional 168, 336 and 500 hours. In addition, exposures to the original refrigerant/mineral oil was continued on some samples for an additional 500 hours (1000 hours total).

Motorette samples were exposed to each combination of original refrigerant/mineral oil for 500 hours and to the alternative refrigerant/lubricant for an additional 168, 336 and 500 hours.

Evaluations

Evaluations of the motor material samples and the motorettes were conducted prior to exposure and after the 500 and 1000 hour exposures to the original refrigerant/mineral oil, as well as after the 168, 336 and 500 hours of additional exposures to the alternative refrigerant/lubricant. In addition to evaluations immediately after exposure, the sheet insulation and varnished helical coils were evaluated after an additional 24 hour bake in air at 127°C (260°F) to determine the effect of refrigerant desorption.

RESULTS

The compatibility of each motor material with the six retrofit refrigerant-lubricant combinations is summarized in the following Compatibility Chart on the next page and discussed in the following section.

Motor Material Compatibility Chart

MOTOR MATERIAL	Refrigerant-Lubricant Exposure					
	R-12 to R-134a	R-22 to R-407C	R-502 to R-404A	R-11 to R-123	R-11 to R-245ca	R-123 to R-245ca
<u>Magnet Wires</u>						
-Modified polyester overcoated with polyamide imide	Yes	Yes	Yes	Yes	Yes	Yes
-Modified polyester overcoated with polyamide imide and epoxy saturated glass	Yes	Yes	Yes	Yes	Yes	Yes
-Polyester imide overcoated with polyamide imide	Yes	Yes	Yes	Yes	Yes	Yes
<u>Varnishes</u>						
U-475 EH	Yes	Yes	Yes	Yes	Yes	Yes
No. 923	Yes	Yes	Yes	Yes	Yes	Yes
Isopoxy 800	Yes	Yes	Yes	Yes	Yes	Yes
<u>Sheet Insulations</u>						
Nomex/Mylar/Nomex	Concern*	Concern*	Concern*	Concern*	Concern*	Concern*
Dacron/Mylar/Dacron	Yes	Yes	Yes	Yes	Yes	Yes
Mylar	Yes	Yes	Yes	Yes	Yes	Yes
Nomex	Yes	Concern*	Yes	Yes	Yes	Yes
Nomex Mica	Yes	Yes	Yes	Yes	Yes	Yes
Melinex	Yes	Yes	Yes	Yes	Yes	Yes
<u>Sleeving Insulations</u>						
Nomex	Yes	Yes	Yes	Yes	Yes	Yes
Mylar	Yes	Yes	Yes	Yes	Yes	Yes
Nomex/Mylar	Yes	Yes	Yes	Yes	Yes	Yes
<u>Tapes</u>						
Heat Cleaned Glass	Yes	Yes	Yes	Yes	Yes	Yes
Heat Shrinkable Polyester	Yes	Yes	Yes	Yes	Yes	Yes
<u>Lead Wire Insulation</u>						
Dacron/Mylar/Dacron	Yes	Yes	Yes	Yes	Yes	Yes
Dacron/Mylar/Teflon/Dacron	Yes	Yes	Yes	Yes	Yes	Yes
<u>Tie Cord</u>						
Polyester	Yes	Yes	Yes	Yes	Yes	Yes

Yes signifies that the material should be compatible. Concern signifies caution in the use of this material. No signifies that the material is incompatible.

*A concern about the compatibility of the Nomex/Mylar/Nomex and Nomex sheet insulation was raised when pockets of delamination appeared between the layers of sheet insulation. These pockets appeared after the retrofit exposure plus a 24 hour air bake at 260°F(127°C).

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Condition of Materials

The magnet wire insulations, varnishes, lead wire insulators, tapes and tie cords were not adversely affected by either exposure to the old refrigerant and mineral oil or to the alternative refrigerant and lubricant. All motorettes maintained electrical integrity. Sheet insulation was affected.

Sheet Insulations Exposed to R-22/R-407C, R-12/R-134a, and R-502/R-404A

Degradation of certain sheet insulation materials and sleeving was observed after the 500 and 1000 hour exposures to R-22, R-12, and R-502. Polyethylene terephthalate (PET) found in the Mylar and Melinex sheet insulations and sleeving became brittle after the 1000 hour exposure to the original refrigerant/mineral oil. Blisters and delamination were noted in the Nomex-Mylar-Nomex (NMN) sheet insulations. After the 1000 hour exposures the Mylar layer in the NMN and Dacron-Mylar-Dacron (DMD) was very brittle. In some cases the PET from the sleeving exposed to R-22 was embrittled to the extent that samples could not be removed from the pressure vessel without breaking.

A sample of Mylar MO that was embrittled after 1000 hours exposure to R-12/mineral oil was sent to Dr. Charles C. Walker of DuPont Circleville Research Laboratory for analysis. His analysis revealed that the material had an intrinsic viscosity of 0.24 which suggested that the embrittlement was caused by substantial chain cleavage through hydrolysis, rather than by thermal breakdown.

Exposure of the PET and Nomex sheet insulation to R-407C/ICI Emkarate RL32H, R-134a/Solest 68 and R-404A/Castrol Icematic SW32 (following the R-22, R-12, and R-502 exposures with mineral oil, respectively) suggested that degradation increased less after exposure to the alternatives. Comparison of these sheet insulations and sleeveings after 500 hour exposure in the alternative refrigerant/lubricant and after the 1000 total hour exposures in the old refrigerant/mineral oil again indicated that exposure to the alternative refrigerant/lubricant was less severe. Motorettes with Nomex sheet insulation retained electrical integrity and there was no indication of blisters or delamination in the motorette system. The insulation materials used in the motorette are covered with varnish.

Exposure of Sheet Insulation Under Dry Conditions

Exposures of the sheet insulation to R-12/R-134a and R-22/R-407C and lubricants was repeated under dry conditions where degradation of the sheet insulation due to moisture was not expected to occur. Extra care was taken to insure that all materials were dried. The mineral oil was dried to 9.7 ppm, and motor materials were dried overnight at 127°C and for an additional four hours at 145-160°C (293-320°F). Extra care was taken to avoid moisture during the evaluations and in between exposures. Sheet insulations, which became embrittled after the first exposures, remained flexible after exposures

under extra dry conditions. Embrittlement of the polyester sheet insulation can be attributed to moisture.

Blisters and pockets of delamination of the Nomex composite materials still occurred under the dry conditions. Complete delamination in the original refrigerant/mineral oil was not observed. Blisters occurred in both the Nomex and Nomex-Mylar-Nomex materials. Exposure to R-12/R-134a was not as severe as R-22/R-407C. The Nomex produced no blisters and the Nomex-Mylar Nomex exhibited only slight blisters after the 168, 336 and 500 hour exposure to R-134a, but not after the after the 500 and 1000 hour exposures to R-12 . Under dry conditions, blistering of the Nomex composite sheet material is more prevalent in the alternative refrigerant than the original R-22 or R-12 mineral oil.

The cause of the blistering is due to absorbed refrigerant in between the layers of Nomex-Mylar-Nomex attempting to escape as a vapor. The polyester adhesive absorbed refrigerant under pressure, and pressure was produced in between the Nomex layers as the refrigerant vaporized. Use of an alternative adhesive may have prevented the blister formation.

R-11/R-123 Retrofit Exposures

Tests showed that all motor materials were in good condition after exposure to R-11/mineral oil for 500 hours followed by exposure to R-123/mineral oil for 168, 336, and 500 hours at 100°C (212°F). Materials evaluated at the end of the 500 hour R-123/mineral oil were compared to the same materials exposed to R-11/mineral oil for an additional 500 hours or 1000 hours total. The Dacron-Mylar-Dacron (DMD) and Permacel tape darkened slightly in the R-123 but were darker after exposure to R-11/mineral oil. The Mylar sheet insulation and sleeving were still flexible and the Nomex 410 materials showed no signs of blistering or delamination. Motorettes maintained electrical integrity. However, separation of the 475 varnish from the metal surfaces of the motorettes was observed after exposure to R-123/mineral oil for 336 and 500 hours. Varnish remained intact on all electrical insulation materials. Additional tests of the same varnish on motorettes exposed to R-11/R-245ca and R-123/R-245ca showed that the varnish remained intact on motorette metal surfaces. The separation of the 475 varnish from metal surfaces may have been influenced by the condition of the metal surface or surface contamination before application of the varnish.

R-11/R-245ca and R-123/R-245ca Retrofit Tests

All motor material exposed to R-11/R-245ca and R-123/R-245ca remained in good condition. The Nomex-Mylar-Nomex (NMN) sheet insulation did not exhibit any blisters after the retrofit exposure, but blisters were produced in the NMN after the subsequent 24 hour exposure to air at 127°C (260°F).

Electrical and Mechanical Property Measurements.

Trends and conclusions are discussed in the following section. Additional information and the complete set of data is available in the final report.⁽⁴⁾ The three magnet wires are designated as **A** - Polyester base with amide imide overcoat; **B** - Esterimide base with amide imide overcoat; and **C** - Polyester base with amide imide overcoat and epoxy saturated glass serving

Varnish

Helical coil bond strength on coils coated with Isopoxy 800 varnish was not reduced after exposure to the three high pressure refrigerant/lubricant exposures under retrofit conditions. The bond strength of coils coated with 923 varnish was reduced about 20% for magnet wire B (ester imide with amide imide overcoat) and 50% for magnet wire A (polyester with amide imide overcoat) after exposure to all three high pressure refrigerants/lubricants retrofit combinations. Bond strength decrease was similar in the original refrigerant/mineral oil as in the alternative refrigerant/lubricant, suggesting that compatibility problems are not anticipated.

The bond strength of 475 varnish on magnet wire C (glass served) was not appreciably decreased by exposure to R-11 or R-123/mineral oil. Exposures for 168, 336 and 500 hours produced no significant trend, above experimental scatter, in any of the four refrigerant/lubricant retrofit exposures. Exposure to R-245ca/polyol ester after either R-11 or R-123/mineral oil caused an increase in the varnish bond strength suggesting that compatibility with the varnish should not be a concern.

Weight changes in the varnish varied from -9.6% for R-502 and Isopoxy 800 to +14.4% for R-123 with 475 varnish. Volume changes varied from -12.4% for R-502 and -12.5% for R-404A with Isopoxy 800 to +8.2% for R-123 and 475 Varnish. The Isopoxy 800 usually loses weight due to extraction and 475 varnish absorbs R-123. Absorption of refrigerant is usually less in refrigerant/lubricant mixtures than in pure refrigerant.

Magnet Wire

After the R-12/R-134a exposure, dielectric strength increased for the unvarnished magnet wires and for magnet wire A (polyester with amide imide overcoat). The dielectric strength of magnet wire B (ester imide with amide imide overcoat) decreased slightly for both 800 and 923 varnishes. The burnout time decreased for both unvarnished and varnished magnet wires with values as high as -66% in R-12. Burnout decrease was always greater for the R-12/mineral oil than for the R-134a/polyol ester. There were no trends observed over experimental deviation for the 168, 333 and 500 hour exposures.

For R-502/R-404A exposures, the dielectric strength usually increased except for a slight decrease for magnet wire B with the 923 varnish. Burnout times

decreased for all exposures ranging from -5.4% to -44.3%. Burnouts usually decreased about -25% and the decrease was greater for the R-502/mineral oil than the R-404A/polyol ester lubricant. No trends were indicated as a function of the length of exposure.

For R-22/R407C dielectric strength increased after exposure except for a slight decrease for magnet wire B with the 923 varnish. Burnout times decreased about -25% and the burnout time decreases were usually greater in the R-22 mineral oil than the R-407C. No trends over time were observed.

Exposure to R-11/R-123 decreased the burnout time of magnet wire C (glass served) only slightly and actually increased the dielectric strength. For the R-11/R-245ca and the R-123/R-245ca retrofit exposures, the dielectric strength of the magnet wire increased about 10-15% and the burnout time decreased only about 1%.

Lead Wire

The dielectric strength of the Dacron-Mylar-Teflon-Dacron (DMTD) lead wire insulation increased after exposure under retrofit conditions while that of the Dacron-Mylar-Dacron (DMD) lead insulation was decreased, but to a lesser extent than observed after the 1000 hour exposure to the original refrigerant/mineral oil.

Sleeving

The sleeving material retained dielectric strength, but the PET insulation became brittle especially after the R-12 and R-22 mineral oil exposures. The brittleness was due to hydrolysis caused by small amounts of water present during the exposures, and was not observed after repeating the exposure under dry conditions. A crack in the brittle insulation could allow the spark to pass through during the dielectric test, but this was not observed. The Nomex-Mylar sleeving retained dielectric strength in all cases and embrittlement of the Mylar layer left the Nomex intact.

Sheet Insulation

The sheet insulation materials were most affected by exposures to the refrigerant/lubricants under retrofit conditions. Embrittlement of the PET material and delamination of the DMD or NMN had an effect on the tensile strength and percent elongation. The dielectric strength was not affected. In most of the dielectric tests, the spark would travel around the 2 x 3 inch samples rather than through the material. Dielectric strengths were recorded as greater than the recorded voltage (>_kV), rather than percent change.

Exposure of the sheet insulations to R-502/R-404A resulted in embrittlement of the PET materials and delamination of the NMN composite. Embrittlement was most pronounced after the 1000 hour exposure to R-502/mineral oil, but also resulted in a decrease in the percent elongation after the 500 hour exposure to

R-404A/polyol ester lubricant. Tensile strength of the PET decreased by about 20% after the R-404A exposure. Dielectric strength of all sheet insulation was not decreased and in most cases actually increased. In some cases there appeared to be a trend of decreasing percent elongation with exposure time, but experimental deviation predominated in at least half of the data sets.

Exposure of sheet insulation to R-22/R-407C resulted in embrittlement of the PET materials and delamination of the NMN. This had an effect on the tensile strength and percent elongation. Exposure to R-22/mineral oil for 1000 hours caused embrittlement of the PET to the extent that tensile strength and percent elongation of the PET material could not be determined. Results at the other conditions showed decreased tensile strength and percent elongation with increased time of exposure. For example the tensile strength of Mylar decreased -28.2%, -31.3% and -32.5% from 168, 336 and 500 hours exposure to R-407C, and percent elongation decreased -38.2%, -71.9% and -84.3%, respectively. The DMD form of PET showed similar behavior. With other sheet insulation materials the effect of time on tensile strength and elongation was inconclusive. Dielectric strength was unaffected.

Exposure of sheet insulation to R-12/R-134a showed similar results to that of R-22/R-407C. The PET tensile strength and percent elongation decreased with time of exposure and was most severe after 1000 hours in R-12/mineral oil. The dielectric strength usually increased after exposure to refrigerant lubricant.

The exposure of sheet insulation to R-22/R-407C and R-12/R-134a was repeated to determine if extra care in drying would prevent embrittlement of the PET materials and blistering of the NMN. Care was taken to dry materials both before and in between the exposures. Results showed that embrittlement of the PET materials was prevented, but blistering of the Nomex-Mylar-Nomex still occurred.

In the R-11 to R-123 retrofit scenario, the lubricant remained the same, namely mineral oil. A small amount of moisture in mineral oil had a greater effect on hydrolysis of PET materials than larger amounts of moisture in polyol ester lubricant due to solvolysis of the water by the ester lubricant. The PET sheet insulation appeared satisfactory after the 1000 hour exposure to R-11 or R-11/R-123 but the percent elongation was severely reduced, especially after the 24 hour bake. Tensile strength was reduced by only 25% for the same materials. There was no evidence of delamination and dielectric strength was retained. There was a trend toward increased embrittlement, and decreased tensile strength as the exposure to R-123 increased from 168 to 326 to 500 hours.

Exposure to R-245ca polyol ester after exposure to either R-11 or R-123 mineral oil resulted in blisters in the NMN after the 127°C bake, but little embrittlement of the PET sheet insulation. Percent elongation actually increased

slightly from the 118% in R-123 to 134% (same as the unexposed value) in R-245ca. The dielectric remained the same.

Tapes and Tie Cords

The heat shrinkable braided polyester tape showed about -20% decrease in tensile strength and +3 to -57% decrease in elongation after exposure to the alternative refrigerant/polyol ester. There was a greater decrease after exposure to the old refrigerant mineral oil for 1000 hours: -39.4% for R-22, -78.7% for R-12 and -82.7% for R-502. The braided polyester tape with acrylic binder and polyester tie cords showed less decrease in tensile strength and percent elongation than the heat shrinkable braided polyester tape after exposure. In most cases, the percent elongation actually increased after the exposures.

Motorettes

All motorettes passed the voltage withstand test (600 volts for one minute applied between windings, windings & ground, and turn to turn) after exposure to the original refrigerant/mineral oil followed by the alternative refrigerant/lubricant.

CONCLUSION

Most of the motor materials, appeared to be compatible with the alternative refrigerants and lubricants after retrofit from the original refrigerant and mineral oil. The major concern was delamination and blistering of the Nomex composite sheet insulation. The embrittlement observed in the PET insulation materials was thought to be due to hydrolysis from moisture present in the insulation and in the lubricant during the compatibility exposure. Tests were repeated with very dry PET insulation and lubricants. Embrittlement was not observed. The electrical insulation materials were either unaffected or affected by the old refrigerant/mineral oil to a similar or greater extent than by the alternative refrigerant and lubricant. These motor materials have an excellent history of reliability in R-22, R-12, R-502, and R-11, and should offer equal or superior reliability with the alternative refrigerants and lubricants.

REFERENCES

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