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Effects of Temperature on Desiccant Catalysis of Refrigerant and Lubricant Decompositions

Final Report

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I. ABSTRACT

Accelerated aging at high temperatures (149°C) for short aging times (28 days), as used in the study under MCLR Project 655-51100, is effective in screening the compatibility of different materials in refrigeration systems. However, in actual applications temperatures are usually lower and operating times much longer. Therefore plots to allow for interpolation or extrapolation of experimental data to actual operating conditions are needed. In the current study under MCLR Project 670-54200, aging of refrigerant/lubricant/desiccant/metal systems was conducted at five different temperatures, and for each temperature at four different aging times. The data collected from this study provided plots relating refrigerant or lubricant decomposition to aging time, aging temperature, and type of desiccant, which can be used for interpolation or extrapolation.

II. SCOPE

In this project, four desiccants and three refrigerant/lubricant combinations of significant commercial interest, as listed below, were studied.

Desiccant/Refrigerant/Lubricant Combinations Under Study	
Desiccant	Refrigerant/Lubricant
4 A Molecular Sieve	R-22/Mineral Oil
	R-32/Mixed Acid Polyolester
	R-134a/Mixed Acid Polyolester
Activated Alumina from Scale	R-22/Mineral Oil
	R-32/Mixed Acid Polyolester
	R-134a/Mixed Acid Polyolester
3 A Molecular Sieve	R-22/Mineral Oil
	R-32/Mixed Acid Polyolester
	R-134a/Mixed Acid Polyolester
Activated Alumina from Trihydrate	R-22/Mineral Oil
	R-32/Mixed Acid Polyolester
	R-134a/Mixed Acid Polyolester

The refrigerants (R-22, R-32 and R-134a), lubricants (Suniso 3GS for Mineral Oil and Castrol

SW32 for Mixed Acid Polyolester) and three of the desiccants (4 A Molecular Sieve, 3 A Molecular Sieve, Activated Alumina from Trihydrate) were taken from the same stocks as used for MCLR Project 655-51100. The properties of these materials as received were described in a previous report.[1]

All desiccant/refrigerant/lubricant combinations, along with steel/aluminum/copper coupons, were aged at five temperatures: 120°C, 100°C, 80°C, 60°C, and 40°C. All aging tests were conducted in sealed glass tubes in accordance with ASHRAE/ANSI Standard 97-1989. Aging progress was determined by analysis of the tube contents at four time intervals for each aging temperature.

Tests with 3A Molecular Sieve at 100°C were repeated to provide three sets of results under identical conditions. These repeated results were used to determine the overall experimental variability.

III. METHODOLOGY

1. SAMPLE PREPARATION

The test tubes were cleaned by rinsing first with deionized water, followed by two rinses with methanol and one rinse with toluene. They were then dried at 175°C and kept dry in desiccators prior to use.

Lubricants were tested for moisture and dried by evacuation to below 50 ppm prior to use. Refrigerants were tested for moisture content prior to use. Those high in moisture were rejected and replaced. No attempts were made to dry the refrigerants on-site.

The metal catalyst coupons were prepared by punching 3.3x19.3 mm coupons from thin sheets. The coupons were held together by aluminum wire such that the steel and copper were separated by the aluminum. These prepared coupons were thoroughly cleaned and kept dry prior to use.

The desiccant samples were activated at 260°C for four hours prior to sealing in the tubes. These samples were weighed to within one bead of 0.5 gram.

2. TUBE PREPARATION AND AGING

The desiccant and metal coupons were first placed in the tube which was then necked down to a size through which a standard cannula could fit. Next 1.0 gram of lubricant, containing 1000 ppm moisture based on lubricant weight, was added accurately with a syringe and cannula. For the mineral oil water was added directly as droplets into the lubricant with constant stirring while for the mixed esters water was added to the lubricant by allowing it to absorb moisture from atmospheric air. Periodic analysis of the lubricant by Karl Fischer coulometry determined the amount of moisture added. The tube was evacuated to 30 microns followed by accurate charging with 0.7 gram of refrigerant through condensation from a calibrated gas handling system. Finally, the tube neck was sealed and annealed. The sealed tubes were placed in drilled holes in large aluminum blocks which were heated in air circulating ovens.

Forty tubes were made for each desiccant/refrigerant/lubricant combination. Five sets of eight tubes each were aged at five different aging temperatures. At four regular aging periods, two tubes from each group of eight were removed for analysis.

3. ANALYSIS

A. Visual Inspection

Visual inspections were made on each tube after removal from the oven and cooling to reduce internal pressure. The lubricant in each tube was compared to standard liquid color references, which give a numerical value for the amount of color change from water white to jet black. Similarly, changes in the presence of solid particulate, color of the desiccant, extent of steel and copper corrosion, and formation of copper plating were noted and scaled numerically.

B. Lubricant Total Acid Number

After aging and visual inspection, one tube was placed in liquid Nitrogen to freeze the tube contents and the top of the tube was broken. A nylon screen was inserted into the tube to retain the desiccant and metal coupons while the tube was inverted and allowed to thaw in a pre-weighed cup. The total acid number (TAN) was determined for the lubricant from the tube in accordance with a modified ASTM D664. The method was modified to accommodate the small one milliliter sample size by reducing the alcoholic KOH titrant concentration from 0.1 Normal to 0.01 Normal. This yielded sufficient sensitivity to determine acid numbers down to 0.1 mg KOH/g.

C. Halide Ions and Acid Anions

Anion concentrations were determined for the tube liquid phase and for the desiccant by ion chromatography (IC). After aging and visual inspection, one tube was placed in liquid Nitrogen to freeze the tube contents and the top of the tube was broken. A nylon screen was inserted into the tube to retain the desiccant and metal coupons while the tube was inverted and allowed to thaw in a pre-weighed cup containing 15 grams of deionized water. The water/lubricant mixture was stirred continuously for 24 hours to allow for extraction of halide ions and acid anions from the lubricant. The water extract was then analyzed by ion chromatography. The concentrations of fluoride ions, chloride ions, organic anions (such as formate, acetate, butyrate, pentanoate, hexanoate) and inorganic anions (such as nitrate, sulfate) were obtained by calibrating the ion chromatograph with standard solutions so that the peak area was proportional to the anion concentration. The desiccants were also extracted with 15 grams of deionized water. After 48 hours, the water extract was analyzed by ion chromatography.

Subsequent to the completion of the study under MCLR Project 655-51100, it was discovered that organic acids were produced when desiccants saturated with lubricant were extracted with excess water for analysis by ion chromatography [2]. A number of preparation and analysis modifications were proposed and tested to avoid the inclusion of these organic acids in the analysis of desiccants from aged sealed tubes. These modifications included repeated washings of the desiccants to remove the absorbed lubricant or extracting the organic acids formed during aging from the desiccants for analysis. The different solvents used for washing or extraction included Methanol, Hexane, Acetone, Toluene, Methylene Chloride and refrigerant R-11. However, these analysis modifications did not completely eliminate the organic acids that were inherent to the analytical process. Therefore, it was decided that baseline data would be obtained for each lubricant-desiccant combination. This data would represent the amount of organic acids formed from the lubricant retained in unaged desiccants and would be reported along with the organic acid concentrations obtained from the desiccants after aging.

IV. TEST RESULTS

Experimental data is tabulated in appendices at the end of this report. Appendix A includes the baseline data for each lubricant-desiccant combination. Appendix B includes the analytical data for the 120°C aging temperature, Appendix C for 100°C, Appendix D for 80°C, Appendix E for 60°C, and Appendix F for 40°C. Table 1 in each appendix from B to F summarizes the visual observations, total acid number, halide and low molecular weight organic acid ion concentrations of the aged sealed tubes. Table 2 shows the concentrations of the different organic acid ions detected by ion chromatography.

Analyses of the experimental data involve the development of correlations showing the effects of time, temperature and type of desiccants on refrigerant and lubricant decompositions. Regression analyses are used to find the best fit to the experimental data, and the coefficient of determination is used to represent how well the regression curves fit the data. The coefficient of determination is defined as:

$$r^2 = \frac{\text{Explained Variation}}{\text{Total Variation}} = \frac{\Sigma\left(y_{est} - \bar{y}\right)^2}{\Sigma\left(y - \bar{y}\right)^2}$$

and can be interpreted as the fraction of the total variation which is explained by the regression curve.[3] In practice, the coefficient of determination lies between zero and one, and the closer it is to one the better the regression curve fits the experimental data.

1. R-22/MINERAL OIL SYSTEMS

Figures 1.1 to 1.4 and Tables 1.1 and 1.2 summarize the stability results of the R-22/mineral oil system in the presence of the different desiccants. Figure 1.1 shows the refrigerant R-22 decomposition as a function of aging time with the aging temperature as the main parameter. The percent refrigerant decomposition was calculated from the chloride ion concentrations determined by ion chromatography. The best fit regression curves for this data are represented by the equation:

$$\mathbf{Y = Bt^A}$$

where **Y** is the percent R-22 decomposed and **t** is the aging time. The empirical coefficients **A** and **B** for each curve are listed in Table 1.1, along with the coefficient of determination $\mathbf{r^2}$.

Figure 1.2 shows the total organic acid concentrations detected by ion chromatography in the R-22/mineral oil/desiccant system after aging, as a function of aging time with the aging temperature as the main parameter. The best fit regression curves for this data are represented by a second order polynomial of the form:

$$X = Et^2 + Ft + G$$

where **X** is the sum of the organic acid concentrations in the liquid phase and in the desiccant and **t** is the aging time. The empirical coefficients **E**, **F** and **G** for each curve are listed in Table 1.2, along with the coefficient of determination $\mathbf{r^2}$. The difference in the values of **G** (or the y-intercept in the figures) for the different types of desiccant reflects the difference in baseline data. Figures 1.3 and 1.4 show the same data replotted with the type of desiccant as the main parameter.

The following general conclusions were drawn for the R-22/mineral oil systems:

- The refrigerant R-22 decomposition was slow and gradual at temperatures less than or equal to 80°C with 4 A molecular sieves, and at temperatures less than or equal to 60°C with 3A molecular sieves. At higher temperatures, the R-22 decomposition reaction was fast within the first 50 days of aging, but slowed down with longer aging time.
- With alumina from scale or from trihydrate, the R-22 decomposition is less than with the molecular sieves. It is less than 2.5% after aging at 120°C for 400 days.
- The total organic acid concentrations, indicative of the mineral oil decomposition, were comparable for all the four types of desiccant tested and increased with increasing aging temperatures.
- In the R-22/mineral oil systems, all the organic acids (mainly formic acids) are retained by the desiccants. There was practically no organic acid detected in the liquid phase.

2. R-32/MIXED ESTER SYSTEMS

Figures 2.1 to 2.6 and Tables 2.1 to 2.3 summarize the stability results of the R-32/mixed ester system in the presence of the different desiccants. Figure 2.1 shows the refrigerant R-32 decomposition as a function of aging time with the aging temperature as the main parameter. The percent refrigerant decomposition was calculated from the fluoride ion concentrations determined by ion chromatography. The best fit regression curves for this data are represented by the equation:

$$Y = Dt^{C}$$

where **Y** is the percent R-32 decomposed and **t** is the aging time. The empirical coefficients **C** and **D** for each curve are listed in Table 2.1, along with the coefficient of determination $\mathbf{r^2}$.

Figure 2.2 shows the total organic acid concentrations detected by ion chromatography in the R-32/mixed ester/desiccant system after aging. The best fit regression curves for this data are represented by a second order polynomial of the form:

$$X = Ht^2 + It + J$$

where **X** is the sum of the organic acid concentrations in the liquid phase and in the desiccant and **t** is the aging time. The empirical coefficients **H**, **I** and **J** for each curve are listed in Table 2.2, along with the coefficient of determination $\mathbf{r^2}$.

In Figure 2.3 the organic acids detected in the liquid phase are shown to correlate linearly with the aging time, according to the equation:

$$Z = Nt$$

where **Z** is the total organic acid concentration in the liquid phase, **t** is the aging time and **N** is the empirical coefficient listed in Table 2.3. Figures 2.4 to 2.6 show the same data replotted with the type of desiccant as the main parameter.

The following general conclusions were drawn for the R-32/mixed ester systems:

- The refrigerant R-32 decomposition was small with 4A or 3A molecular sieves, reaching less than 1.2% after aging at 120°C for 400 days.
- With alumina from scale or from trihydrate, the R-32 decomposition was very small or nil at temperatures less than or equal to 80°C. At temperatures higher than 100°C, the percent R-32 decomposed increased sharply with time.
- The total organic acid concentrations (mainly formic and pentanoic acids) in the liquid phase and in the desiccants was small at temperatures less than or equal to 80°C for all the four desiccants. These concentrations are higher at 100°C and increased sharply with time at 120°C for the alumina from scale or trihydrate.
- Similarly, the organic acid concentrations in the liquid phase of the aged sealed tubes were small at aging temperatures less than or equal to 80°C. These concentrations are higher at 100°C and increased sharply with time at 120°C for the alumina from scale or trihydrate.

3. R-134a/MIXED ESTER SYSTEMS

Figures 3.1 to 3.4 and Tables 3.1 and 3.2 summarize the stability results of the R-134a/mixed ester system in the presence of the different desiccants. There was practically no R-134a decomposition with the four desiccants tested, up to 120°C aging temperature and 365 day aging time. Figure 3.1 shows the total organic acid concentrations detected by ion chromatography in the R-134a/mineral oil/desiccant system after aging, as a function of aging time with the aging temperature as the main parameter. The best fit regression curves for this data are represented by a second order polynomial of the form:

$$X = Kt^2 + Lt + M$$

where **X** is the sum of the organic acid concentrations in the liquid phase and in the desiccant and **t** is the aging time. The empirical coefficients **K**, **L** and **M** for each curve are listed in Table 3.1, along with the coefficient of determination $\mathbf{r^2}$. In Figure 3.2 the organic acids detected in the liquid phase are shown to correlate linearly with the aging time, according to the equation:

$$Z = Pt$$

where **Z** is the total organic acid concentration in the liquid phase, **t** is the aging time and **P** is the empirical coefficient listed in Table 3.2. Figures 3.3 and 3.4 show the same data replotted with the type of desiccant as the main parameter.

The following general conclusions were drawn for the R-134a/mixed ester systems:

- There was practically no R-134a decomposition with the four desiccants tested, up to 120°C aging temperature and 365 day aging time.
- With the alumina from scale, the total organic acid concentrations (mainly formic and pentanoic acids) in the liquid phase and in the desiccants were small at temperatures less than or equal to 100°C, but increased sharply with time at 120°C. With the other three desiccants the total organic acid concentrations were small.
- The organic acid concentrations in the liquid phase of the aged sealed tubes followed the same pattern as the total organic acid concentrations. With the alumina from scale, these concentrations were small at temperatures less than or equal to 100°C, but increased sharply with time at 120°C. With the other three desiccants the organic acid concentrations in the liquid phase were small.

4. INTERPOLATION AND EXTRAPOLATION OF DATA

Although there is no correlation between data from sealed tube tests and actual performance of refrigeration systems, sealed tube tests have been used widely in the refrigeration industry to screen for material compatibility and stability of systems. The data collected in this study can be used to compare the stability of different refrigerant/lubricant/desiccant combinations at any reaction temperature. To illustrate this application of the data, a criterion which is arbitrary and varies greatly depending on the application of the refrigeration system was selected to indicate system instability. This chosen criterion was the concentration of organic acids in the liquid phase of 2,000 ppm, corresponding to a total acid number of 1.5 based on pentanoic acids. From Figures 2.3 and 3.2, and Tables 2.3 and 3.2, the aging time corresponding to a concentration of organic acids in the liquid phase of 2000 ppm was determined for each of the operating temperatures and refrigerant/lubricant/desiccant systems. These times are shown in Table 4.1 and plotted versus temperature in Figures 4.1 and 4.2. The best fit linear regressions can be interpolated or extrapolated to determine the time to reach instability criterion at any operating temperature.

Based on the instability criterion of 2,000 ppm organic acids in the lubricant, it was observed that the use of scale alumina as desiccants in systems of R-32/mixed esters and R-134a/ mixed esters resulted in shorter lifetime than the use of molecular sieves. With trihydrate alumina, the slope of the time versus temperature line was greater than with the other desiccants, which meant that the refrigerant lubricant systems had a longer aging time with trihydrate alumina at the lower temperatures, but a shorter time at the higher temperatures.

5. EXPERIMENTAL VARIABILITY

Tests with 3A Molecular Sieve at 100°C were repeated to provide three sets of results under identical conditions. These repeated results, indicative of the overall experimental variability, are shown in Tables 5.1 to 5.3. Runs 1 and 2 were repeated tests of Run 3 which was part of the original test matrix. The data from Run 3 was reported in Appendix C and analyzed in sections 1 through 4. The experimentally measured data for Run 3 did not include the aging time of 154 days. However, using the regression analyses developed in sections 1 through 4, projected data corresponding to this aging time could be calculated. As shown in Table 5.4, these projected data were in the same order of magnitude as the measured data from Runs 1 and 2.

V. CONCLUSIONS

The following general conclusions were drawn from this study:

1. Although there is no correlation between data from sealed tube tests and actual performance of refrigeration systems, sealed tube tests have been used widely in the refrigeration industry to screen for material compatibility and stability of systems. The data collected in this study can be used to compare the stability of different refrigerant/ lubricant/desiccant combinations at any reaction temperature. However, a criterion for system instability or incompatibility must be chosen. Possible end points include visual changes, total acid number (TAN), Total Organic Acids and/or halide ion concentrations.
2. There was no R-134a refrigerant decomposition, while the best fit regression curves for R-22 and R-32 decompositions versus time have the form $Y=Bt^A$.
3. The best fit regression curves for the total organic acids (in the liquid phase and in the desiccants) versus time are second degree polynomials of the form $X = Et^2 + Ft + G$.

4. The best fit regression curves for the organic acids in the liquid phase versus time are straight lines (Z = Nt) for R-32/mixed esters and R-134a/mixed esters systems, while for R-22/mineral oil, there was practically no organic acid detected in the liquid phase. All the organic acids, mainly formic acids, are retained by the desiccants.
5. In general, the most important variable is temperature. Below 80°C, both refrigerant and lubricant decompositions are small, at the most 2% per year for R-22 or R-32 refrigerant decompositions.
6. R-32/desiccant combinations are more reactive and thus have shorter aging times than R-134a/desiccant combinations.

COMPLIANCE WITH AGREEMENT

The tasks specified in the Work Statement for this project have been completed. Four desiccants and three refrigerant/lubricant combinations were studied. Each desiccant/refrigerant/lubricant combination, along with steel/aluminum/copper coupons and 1000 ppm water, was aged at five temperatures. Aging tests were conducted in sealed glass tubes in accordance with ASHRAE/ANSI Standard 97-1989. Aging progress was determined by analysis of the tube contents at four time intervals for each aging temperature. Tests on one material combination at one intermediate temperature were repeated to provide three sets of results under identical conditions. These repeated results were used to determine the overall experimental variability. More than 500 sealed tubes were prepared, aged and analyzed. Correlations showing the effects of time, temperature and type of desiccants on refrigerant and lubricant decompositions were developed and presented in graphical as well as tabular forms. Regression analyses were used to find the best fits to the experimental data. Illustrations of the interpolation or extrapolation of the experimental data were described and plots of lifetime versus temperatures were prepared.

PRINCIPAL INVESTIGATOR EFFORT

Dr. N. D. Rohatgi, the principal investigator, applied 35% of her time during the course of this investigation, directing research technicians, organizing and analyzing the experimental data, developing the correlations, and preparing the technical presentations and reports.

REFERENCES

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2. Field, Jay E., "Decomposition of Lubricants During Analysis", ASHRAE San Antonio Annual Meeting, Seminar 32, System Chemistry of Refrigeration Lubricants, June 22-26, 1996.
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Table 1.1: Regression Analysis of R-22 Decomposition Data **$Y = Bt^A$**				
Refrigerant/Lubricant/Desiccant	Temperature °C	**A**	**B**	Coefficient of Determination **r^2**
R-22/Mineral Oil/4A Sieve	120	0.149	2.014	0.97
	100	0.270	0.861	0.98
	80	0.922	0.011	0.96
	60	1.351	2.954E-4	0.88
	40	1.983	1.005E-6	0.92
R-22/Mineral Oil/3A Sieve	120	0.155	2.137	0.93
	100	0.270	0.961	0.98
	80	0.390	0.285	1.00
	60	0.979	6.526E-3	0.98
	40	3.004	4.812E-9	0.92
R-22/Mineral Oil/Scale Alumina	120	0.177	0.810	0.74
	100	0.301	0.422	1.00[a]
	80	0.087	0.879	0.90
	60	0.103	0.588	0.78
	40	0.221	0.214	0.91
R-22/Mineral Oil/Trihydrate Alumina	120	0.122	1.108	0.62
	100	0.166	0.798	0.87
	80	0.129	0.773	0.87
	60	0.231	0.362	0.91
	40	0.237	0.282	0.83[a]

[a] Only three data points were used in regression to obtain a better fit

Table 1.2: Regression Analysis of Decomposition Data of Mineral Oil in R-22 **$X = Et^2 + Ft + G$**					
Refrigerant/Lubricant/Desiccant	Temperature °C	**E**	**F**	**G**	Coefficient of Determination **r^2**
R-22/Mineral Oil/4A Sieve	120	-0.133	50.7	530	0.95
	100	-0.078	38.4	154	0.99
	80	-0.064	29.3	72.3	0.99
	60	-0.023	15.0	242	0.92
	40	0.004	4.47	386	0.69
R-22/Mineral Oil/3A Sieve	120	-0.155	51.1	1320	0.80
	100	-0.100	43.7	952	0.93
	80	-0.051	28.7	586	0.98
	60	-0.007	11.2	480	1.00
	40	0.002	0.941	356	0.83
R-22/Mineral Oil/Scale Alumina	120	-0.092	34.2	1412	0.82
	100	-0.054	27.1	1200	0.89
	80	-0.053	22.5	1096	0.80
	60	-0.036	14.2	913	0.83
	40	-0.015	7.19	808	0.86
R-22/Mineral Oil/Trihydrate Alumina	120	-0.082	29.2	2014	0.94
	100	-0.012	11.1	2122	0.90
	80	-0.003	3.42	1933	0.90
	60	No Decomposition			
	40	No Decomposition			

Table 2.1: Regression Analysis of R-32 Decomposition Data **$Y = Dt^c$**				
Refrigerant/Lubricant/Desiccant	Temperature °C	**C**	**D**	Coefficient of Determination **r^2**
R-32/Mixed Esters/4A Sieve	120	0.504	0.056	0.82
	100	0.304	0.118	0.94
	80	1.116	9.208E-4	0.99
	60	2.035	2.210E-6	0.96
	40	2.225	1.943E-7	0.96
R-32/Mixed Esters/3A Sieve	120	0.328	0.154	1.00
	100	0.189	0.212	0.60
	80	0.264	0.126	0.95
	60	0.341	0.056	0.87
	40	0.939	7.121E-4	0.98
R-32/Mixed Esters/Scale Alumina	120	3.335	2.809E-7	0.93
	100	5.118	1.446E-12	1.00[b]
	80	2.125	2.523E-7	0.91
	60	1.207	1.207E-5	0.99[b]
	40	No Decomposition		
R-32/Mixed Esters/Trihydrate Alumina	120	3.453	1.478E-7	0.99
	100	1.932	3.538E-6	0.91
	80	No Decomposition		
	60	No Decomposition		
	40	No Decomposition		

[b] Only three data points were used in regression to obtain a better fit

Table 2.2: Regression Analysis of Decomposition Data of Mixed Esters in R-32 **$X = Ht^2 + It + J$**					
Refrigerant/Lubricant/Desiccant	Temperature °C	**H**	**I**	**J**	Coefficient of Determination **r^2**
R-32/Mixed Esters/4A Sieve	120	-0.857	156	2531	0.85
	100	0.095	6.99	3132	0.91
	80	-0.056	28.8	2588	0.69
	60	-0.043	29.9	1628	0.83
	40	-0.031	16.3	2058	0.84
R-32/Mixed Esters/3A Sieve	120	-0.082	115	131	0.99
	100	0.051	2.09	1518	0.90
	80	-0.063	23.1	1052	0.94
	60	-0.058	21.4	1013	0.93
	40	-0.005	3.71	852	0.95
R-32/Mixed Esters/Scale Alumina	120	-1.692	421	11908	0.78
	100	-0.888	248	9480	0.74
	80	-0.100	42.8	8806	0.95
	60	-0.091	41.9	8805	0.96
	40	-0.020	19.8	8794	0.97[c]
R-32/Mixed Esters/Trihydrate Alumina	120	-0.285	258	10081	0.97
	100	-0.004	51.7	9459	0.97
	80	0.015	2.84	9749	0.62[c]
	60	-0.031	13.4	9205	0.97[c]
	40	0.003	3.32	9268	0.88

[c] Only three data points were used in regression to obtain a better fit

Table 2.3: Regression Analysis of Data on Organic Acids in Liquid Phase (R-32/Mixed Esters) **Z = N*t**			
Refrigerant/Lubricant/Desiccant	Temperature °C	**N**	Coefficient of Determination R^2
R-32/Mixed Esters/4A Sieve	120	43.1	1.00
	100	11.9	0.92
	80	2.17	0.70
	60	2.28	0.99
	40	0.257	0.90
R-32/Mixed Esters/3A Sieve	120	48.0	0.99
	100	4.63	0.87
	80	1.96	0.79
	60	1.32	0.85
	40	0.300	0.94
R-32/Mixed Esters/Scale Alumina	120	267	0.95
	100	37.4	0.96[d]
	80	9.93	0.95
	60	3.80	0.96
	40	1.03	0.89
R-32/Mixed Esters/Trihydrate Alumina	120	100	0.98
	100	26.5	0.95
	80	5.43	0.98
	60	2.24	0.99
	40	0.205	0.84

[d] Only three data points were used in regression to obtain a better fit

Table 3.1 : Regression Analysis of Decomposition Data of Mixed Esters in R-134a **$X = Kt^2 + Lt + M$**					
Refrigerant/Lubricant/Desiccant	Temperature °C	**K**	**L**	**M**	Coefficient of Determination **r^2**
R-134a/Mixed Esters/4A Sieve	120	-0.126	42.4	3106	0.61
	100	-0.083	35.2	3032	0.61
	80	-0.078	38.5	2497	0.82
	60	-0.038	21.5	2054	0.94
	40	-0.015	9.95	2097	0.71
R-134a/Mixed Esters/3A Sieve	120	-0.047	23.6	1629	0.72
	100	-0.047	20.6	1399	0.77
	80	-0.041	20.0	947	0.97
	60	-0.009	7.44	903	0.98
	40	-0.003	2.28	903	0.98
R-134a/Mixed Esters/Scale Alumina	120	1.403	126	9470	0.82
	100	-0.907	220	8409	0.68
	80	-0.169	52.8	8323	0.87
	60	-0.057	26.8	9003	0.88
	40	-0.085	40.5	8775	0.77
R-134a/Mixed Esters/Trihydrate Alumina	120	-0.665	109	9184	0.92
	100	-0.062	32.5	8768	0.78
	80	-0.062	28.2	8804	0.72
	60	-0.153	64.7	8414	0.89
	40	-0.078	33.6	9375	0.76

Table 3.2 : Regression Analysis of Data on Organic Acids in Liquid Phase (R-134a/Mixed Esters) **Z = Pt**			
Refrigerant/Lubricant/Desiccant	Temperature °C	**P**	Coefficient of Determination **r^2**
R-134a/Mixed Esters/4A Sieve	120	3.79	0.98
	100	1.46	0.98
	80	0.232	0.88
	60	0.391	0.77
	40	No Organic Acids in Liquid Phase	
R-134a/Mixed Esters/3A Sieve	120	6.39	0.93
	100	2.88	0.89
	80	1.25	0.88
	60	0.69	0.98
	40	No Organic Acids in Liquid Phase	
R-134a/Mixed Esters/Scale Alumina	120	217	0.83
	100	16.0	0.61[e]
	80	3.96	0.76
	60	2.56	0.89
	40	0.250	0.76[e]
R-134a/Mixed Esters/Trihydrate Alumina	120	25.2	0.95
	100	6.71	0.86
	80	2.55	0.96
	60	1.10	0.91
	40	0.175	0.77[e]

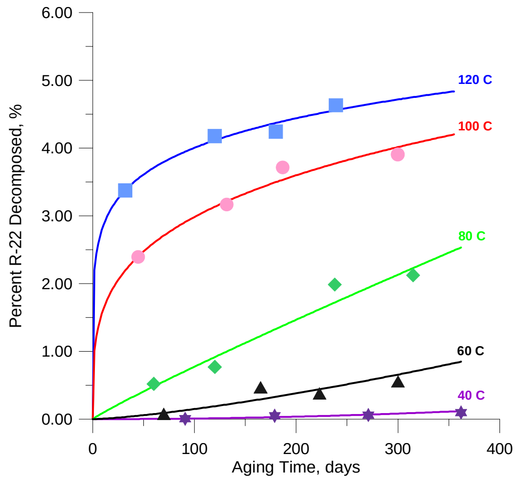
Table 4.1: Time to Reach a Concentration of Organic Acids in the Liquid Phase of 2000 ppm					
R-32			R-134a		
Lubricant/desiccant	Temperature °C	Time days	Lubricant/desiccant	Temperature °C	Time days
Mixed Esters/4A Sieve	120	46	Mixed Esters/4A Sieve	120	528
	100	168		100	1,370
	80	922		80	8,621
	60	877		60	5,115
	40	7,782		40	---
Mixed Esters/3A Sieve	120	42	Mixed Esters/3A Sieve	120	313
	100	432		100	694
	80	1,020		80	1,600
	60	1,515		60	2,899
	40	6,667		40	---
Mixed Esters/Scale alumina	120	7	Mixed Esters/Scale alumina	120	9
	100	53		100	125
	80	201		80	505
	60	526		60	781
	40	1,942		40	8000
Mixed Esters/Trihydrate alumina	120	20	Mixed Esters/Trihydrate alumina	120	79
	100	75		100	298
	80	368		80	784
	60	893		60	1,818
	40	9,756		40	11,429

Table 5.1: Repeatability Data (R-22/Mineral Oil/3A Molecular Sieve at 100°C)						
Property	Time	Run 1	Run2	Run3	Average	Standard Deviation
Chloride in Liquid (ppm)	45	1	2	2	2	0
	132	2	1	0	1	1
	154	3	2	---	3	1
Fluoride in Liquid (ppm)	45	1	1	1	1	0
	132	1	0	0	0	0
	154	1	1	---	1	0
Chloride in desiccant (ppm)	45	7,749	7,915	7,662	7,775	105
	132	10,061	11,065	10,506	10,544	411
	154	11,145	12,575	---	11,860	715
Fluoride in desiccant (ppm)	45	1,101	1,555	1,127	1,261	208
	132	837	1,030	1,102	990	112
	154	1,000	1,019	---	1,010	10
Total Acid Number (mg KOH/g)	45	0	0	0.01	0	0
	132	0.01	0.01	0.03	0.02	0
	154	0	0	---	0	0
Total Organic Acids in Liquid (ppm)	45	6	0	0	2	3
	132	0	0	5	2	2
	154	0	0	---	0	0
Total Organic Acids in Desiccant (ppm)	45	4,225	3,545	3,622	3,797	304
	132	4,249	5,220	4,620	4,696	400
	154	4,826	5,964	---	5,395	569

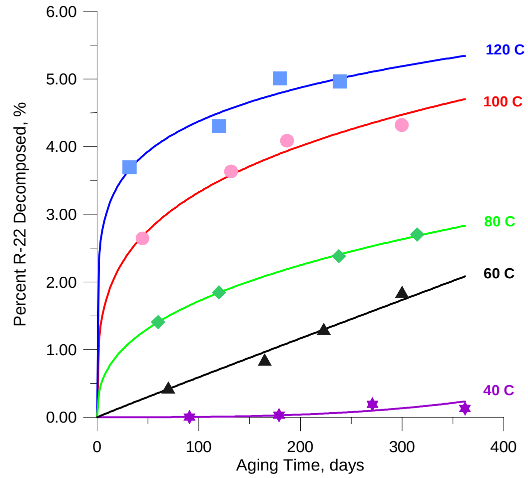
Table 5.2: Repeatability Data (R-32/Mixed Esters/3A Molecular Sieve at 100°C)						
Property	Time	Run1	Run2	Run3	Average	Standard Deviation
Chloride in Liquid (ppm)	45	1	1	3	2	1
	132	1	1	1	1	0
	154	2	2	---	2	0
Fluoride in Liquid (ppm)	45	1	1	17	6	8
	132	1	1	2	1	0
	154	2	2	---	2	0
Chloride in desiccant (ppm)	45	12	17	22	17	4
	132	27	20	29	25	4
	154	0	0	---	0	0
Fluoride in desiccant (ppm)	45	1,228	1,166	1,159	1,184	31
	132	1,399	1,171	1,380	1,317	103
	154	2,014	1,553	---	1,784	231
Total Acid Number mg KOH/g	45	0.25	0.27	0.28	0.27	0
	132	0.28	0.28	0.28	0.28	0
	154	0.20	0.21	---	0.21	0
Total Organic Acids in Liquid (ppm)	45	624	808	687	706	76
	132	763	849	608	740	100
	154	813	674	---	744	70
Total Organic Acids in Desiccant (ppm)	45	1,888	1,724	1,920	1,844	86
	132	1,267	870	2,398	1,512	647
	154	1201	1296	---	1,249	48

Table 5.3: Repeatability Data (R-134a/Mixed Esters/3A Molecular Sieve at 100°C)						
Property	Time	Run 1	Run2	Run3	Average	Standard Deviation
Chloride in Liquid (ppm)	45	2	1	1	1	0
	132	0	0	0	0	0
	154	0	2	---	1	1
Fluoride in Liquid (ppm)	45	0	0	1	0	0
	132	0	0	0	0	0
	154	0	0	---	0	0
Chloride in desiccant (ppm)	45	8	7	5	7	1
	132	9	13	7	10	3
	154	10	10	---	10	0
Fluoride in desiccant (ppm)	45	11	21	16	16	4
	132	10	8	9	9	1
	154	11	10	---	11	0
Total Acid Number mg KOH/g	45	0.13	0.14	0.20	0.16	0.03
	132	0.21	0.25	0.23	0.23	0.02
	154	0.21	0.22	---	0.22	0.01
Total Organic Acids in Liquid (ppm)	45	391	359	400	383	18
	132	589	539	603	577	27
	154	610	774	---	692	82
Total Organic Acids in Desiccant (ppm)	45	2,076	2,458	2,665	2,400	244
	132	2,569	2,931	2,558	2,686	173
	154	2,519	2,580	---	2,550	31

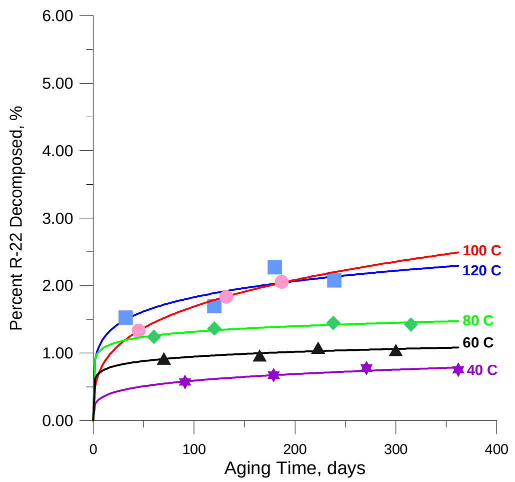
Table 5.4: Comparison of Measured and Predicted Values (3 A Molecular Sieve at 100^{o} C and 154 days)			
Refrigerant/lubricant	Property	Average value from repeatability tests	Calculated value from regression curve
R-22/mineral oil	Percent R-22 decomposed	4.10 ± 0.25	3.74
	Total organic acid concentrations	5,395 ± 569	5,310
R-32/mixed esters	Percent R-32 decomposed	0.69 ± 0.09	0.55
	Total organic acid concentrations	1,992 ± 22	3,049
	Organic acid concentrations in liquid phase	744 ± 70	713
R-134a/mixed esters	Total organic acid concentrations	3,242 ± 113	3,457
	Organic acid concentrations in liquid phase	692 ± 82	444



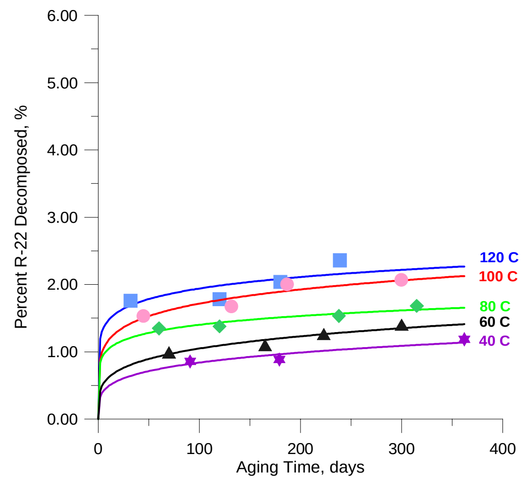
R-22 Decomposition (R-22/Mineral Oil/4A Molecular Sieve)



R-22 Decomposition (R-22/Mineral Oil/3A Molecular Sieve)

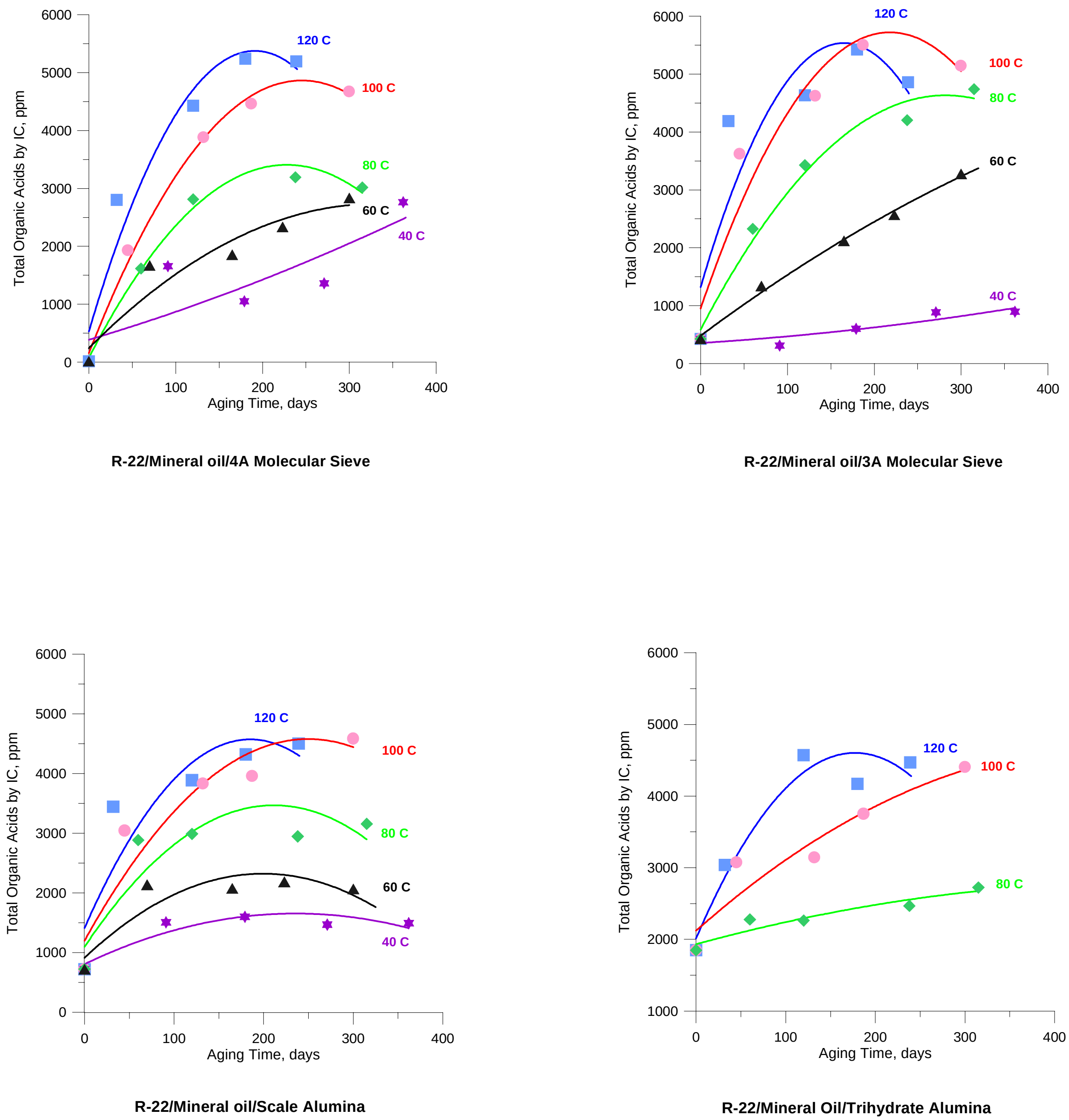


R-22 Decomposition (R-22/Mineral Oil/Alumina from Scale)



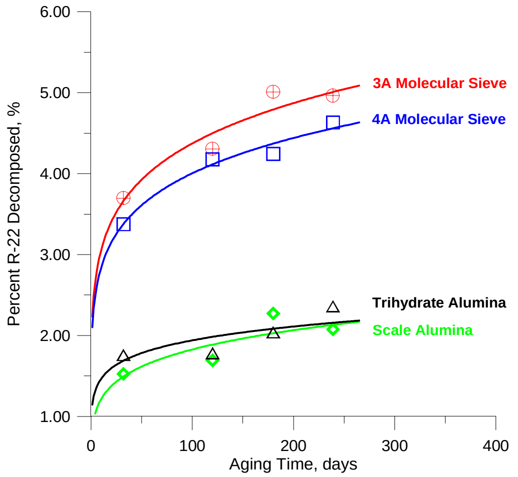
R-22 Decomposition (R-22/Mineral Oil/Alumina from Trihydrate)

Figure 1.1: Effect of Aging Temperature on R-22 Decomposition

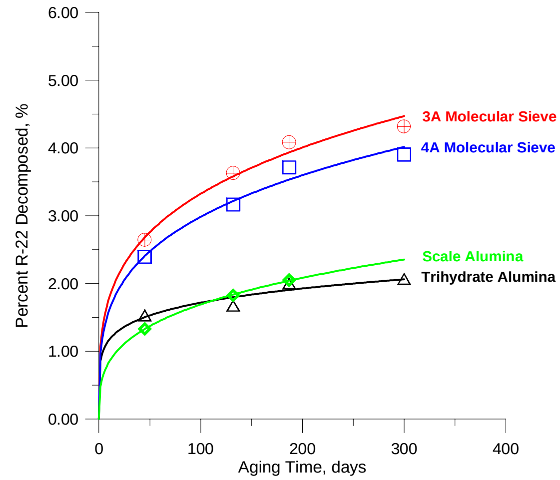


No decomposition at 60° C and 40° C

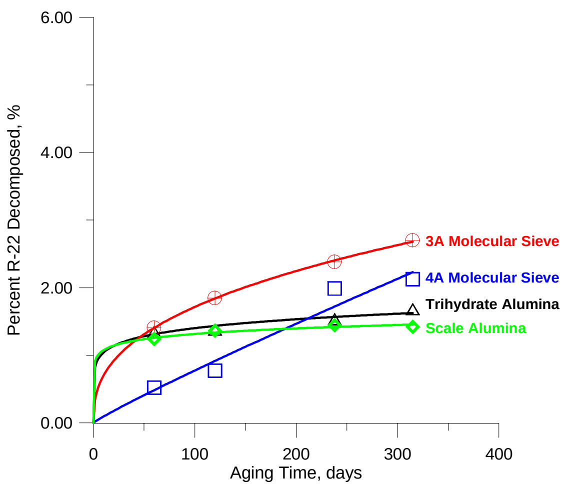
Figure 1.2: Effect of Temperature on Total Organic Acids (in Liquid and in Desiccant) R-22/Mineral Oil



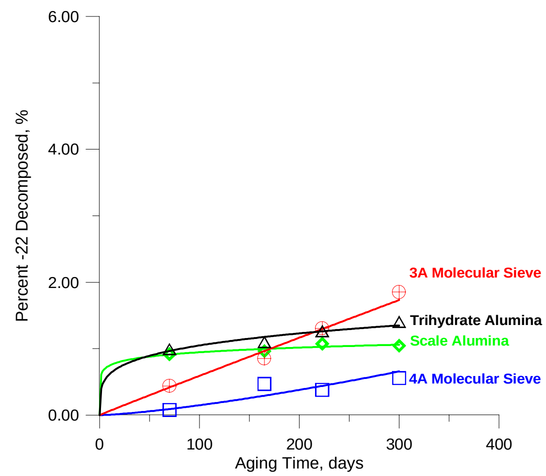
R-22 Decomposition at 120 C



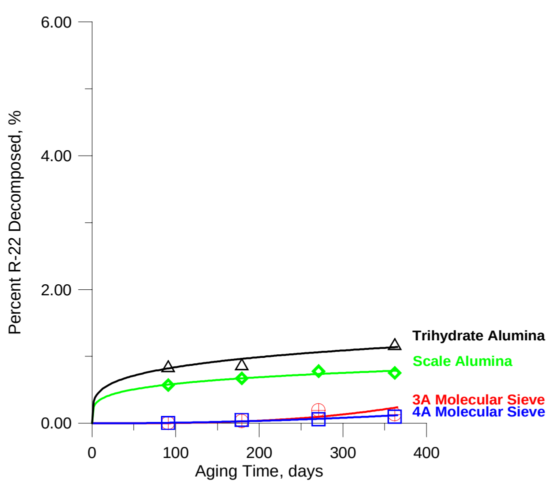
R-22 Decomposition at 100 C



R-22 Decomposition at 80 C

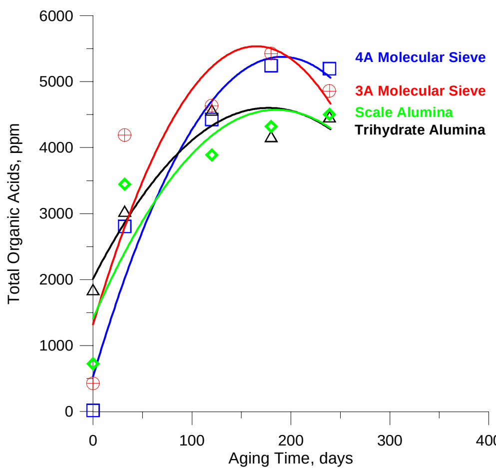


R-22 Decomposition at 60 C

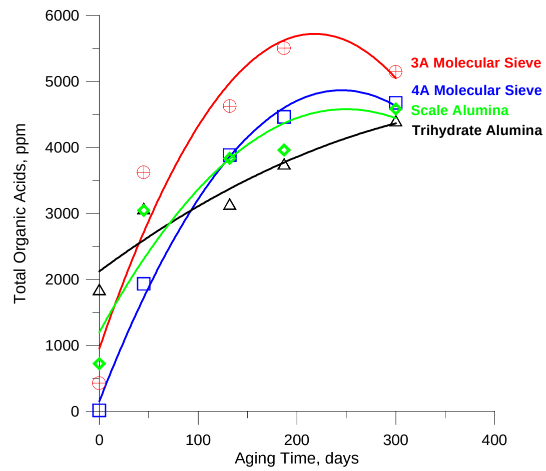


R-22 Decomposition at 40 C

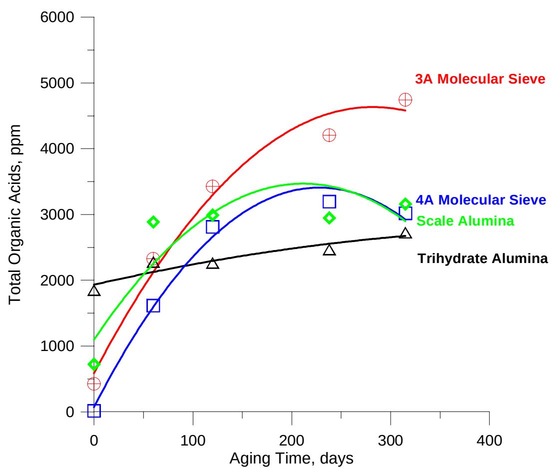
Figure 1.3: Effect of Type of Desiccant on R-22 Decomposition



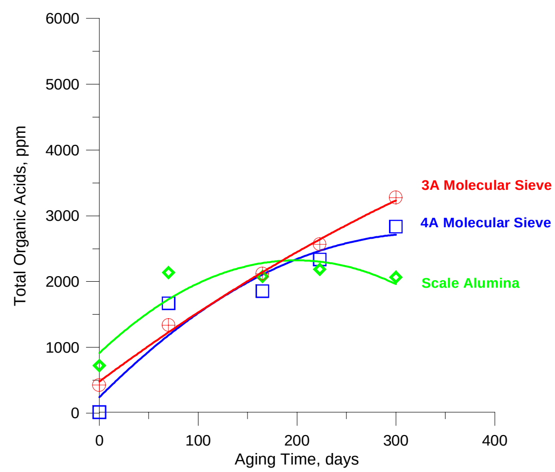
R-22/Mineral Oil at 120 C



R-22/Mineral Oil at 100 C

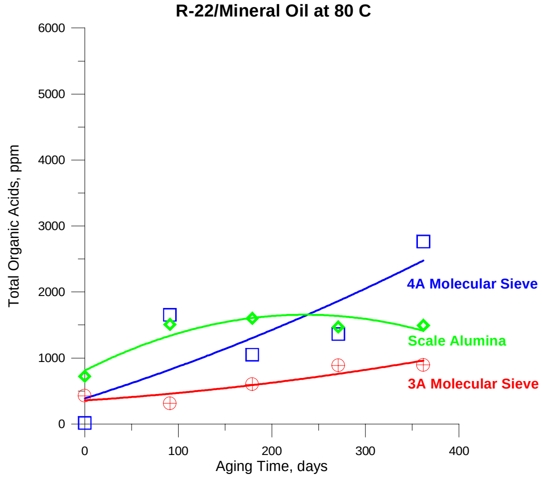


R-22/Mineral Oil at 80 C



R-22/Mineral Oil at 60 C

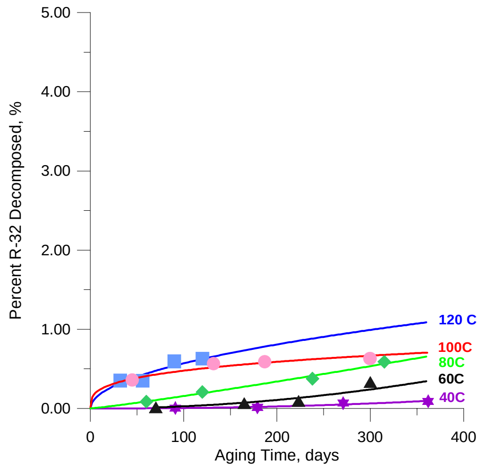
No decomposition with Trihydrate Alumina



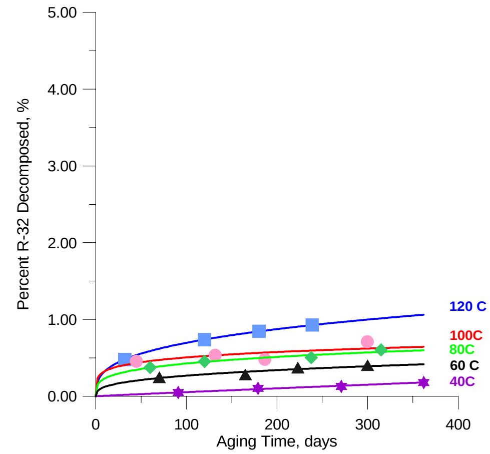
R-22/Mineral Oil at 40 C

No decomposition with Trihydrate Alumina

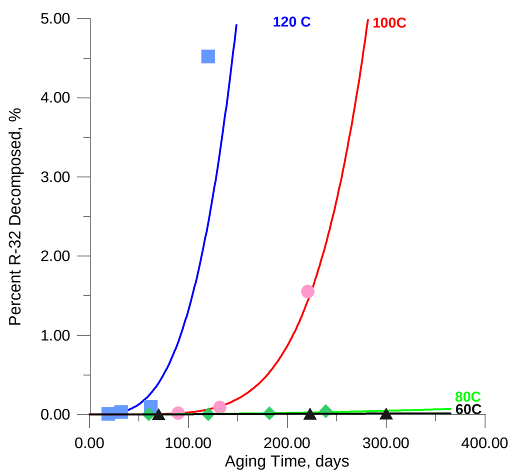
Figure 1.4: Effect of Type of Desiccant on Total Organic Acids (in Liquid and in Desiccant) R-22/Mineral Oil



R-32 Decomposition (R-32/Mixed Esters/4A Molecular Sieve)

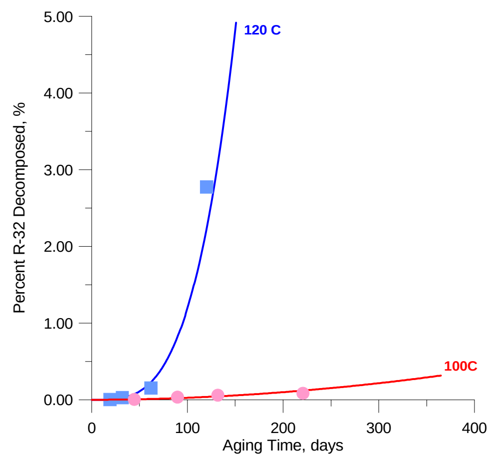


R-32 Decomposition (R-32/Mixed Esters/3A Molecular Sieve)



R-32 Decomposition (R-32/Mixed Esters/Alumina from Scale)

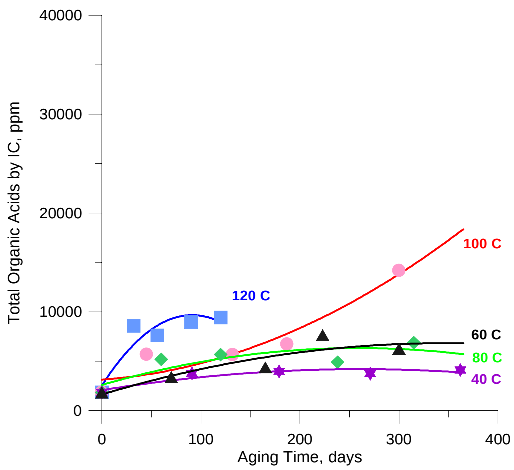
No decomposition at 40°C



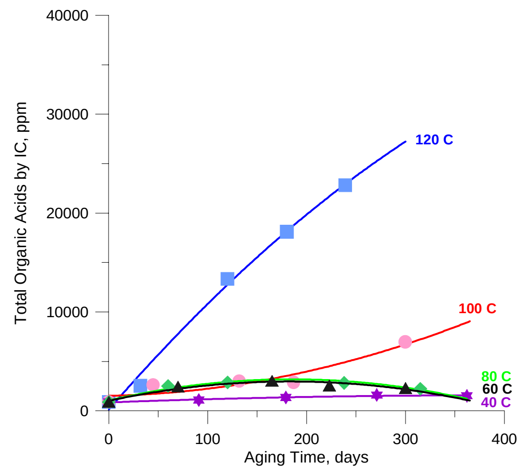
R-32 Decomposition (R-32/Mixed Esters/Alumina from Trihydrate)

No decomposition at 80°C, 60°C and 40°C

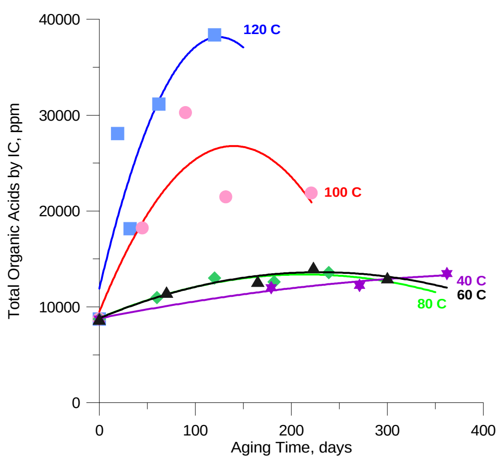
Figure 2.1: Effect of Temperature on R-32 Decomposition



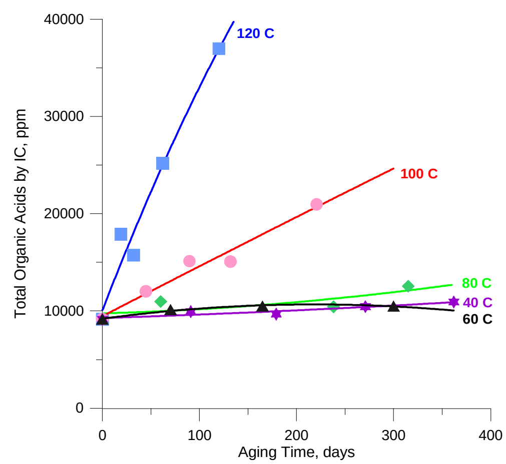
R-32/Mixed Esters/4A Molecular Sieve



R-32/Mixed Esters/3A Molecular Sieve

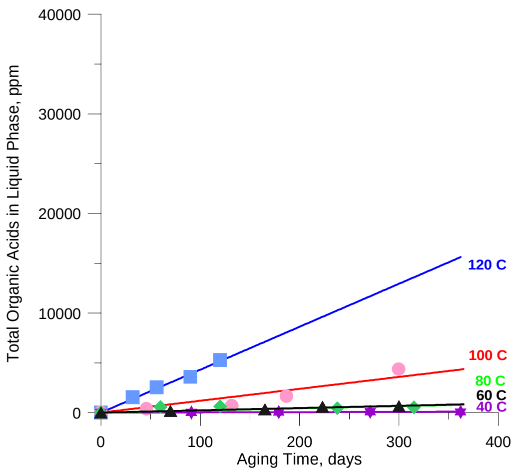


R-32/Mixed Esters/Scale Alumina

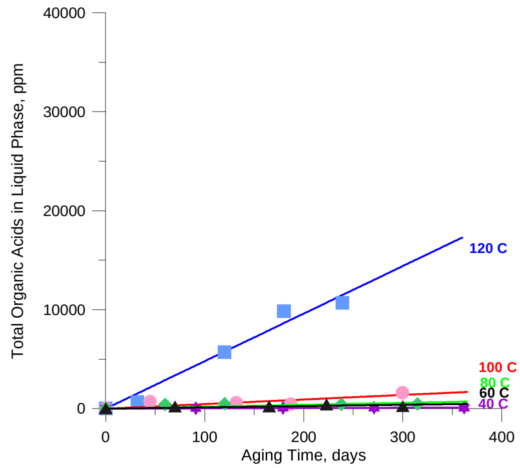


R-32/Mixed Esters/Trihydrate Alumina

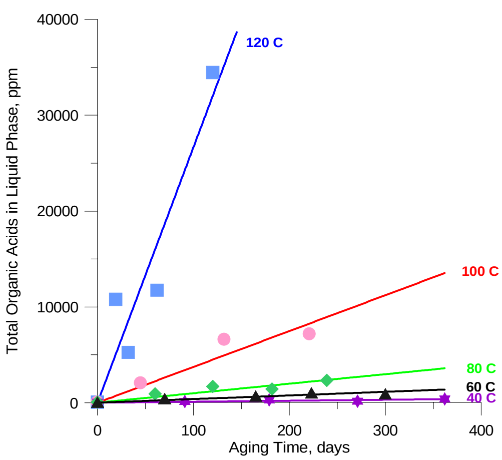
<u>Figure 2.2: Effect of Temperature on Total Organic Acids (in Liquid and in Desiccant)</u>
<u>R-32/Mixed Esters</u>



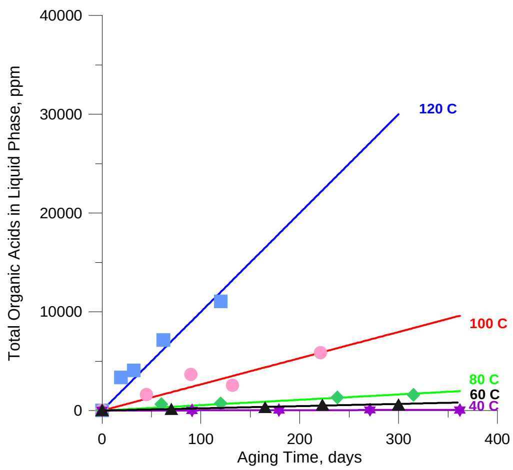
R-32/Mixed Esters/4A Molecular Sieve



R-32/Mixed Esters/3A Molecular Sieve

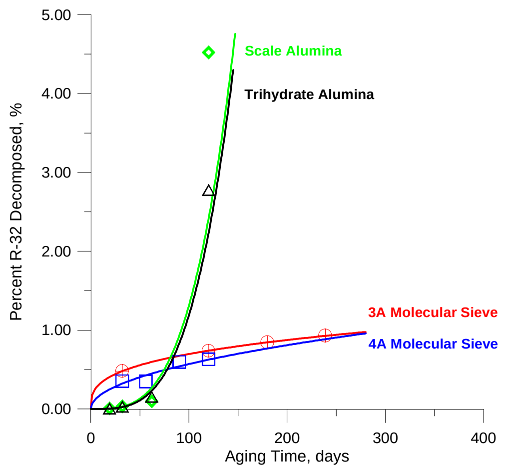


R-32/Mixed Esters/Scale Alumina

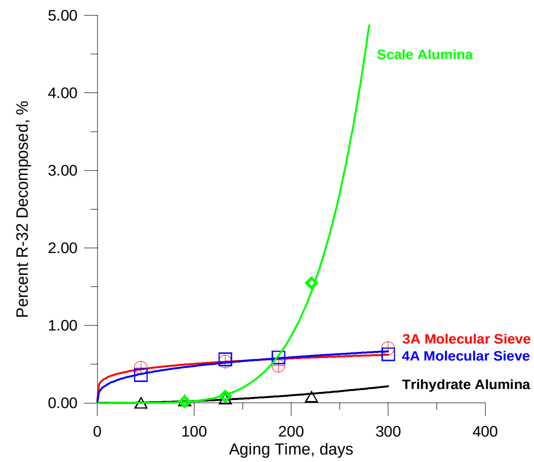


R-32/Mixed Esters/Trihydrate Alumina

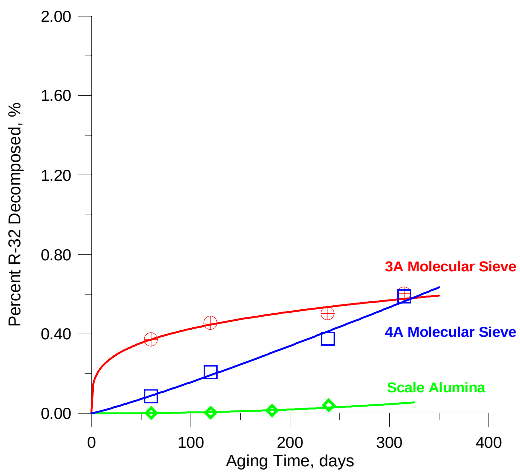
Figure 2.3: Effect of Temperature on Total Organic Acids in Liquid Phase
R-32/Mixed Esters



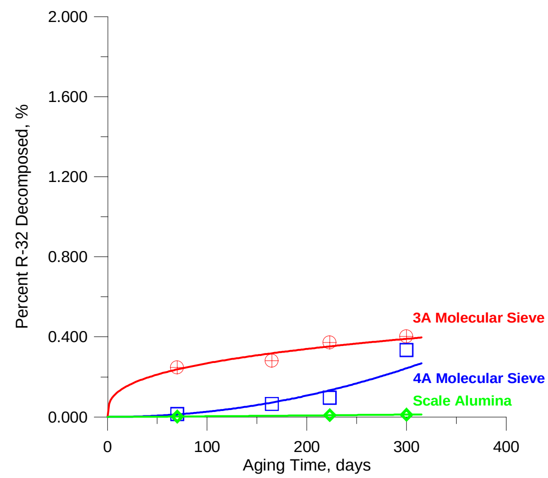
R-32 Decomposition at 120 C



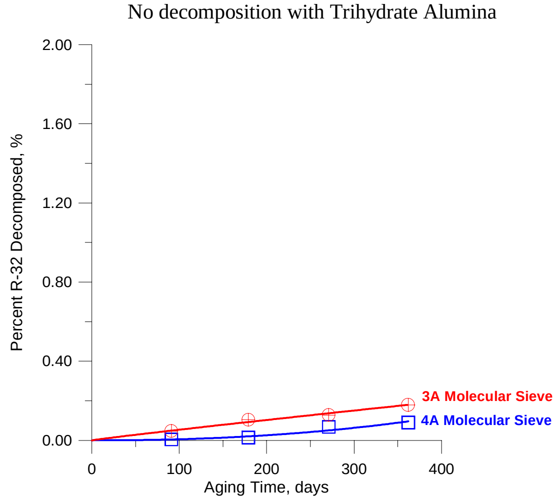
R-32 Decomposition at 100 C



R-32 Decomposition at 80 C
No decomposition with Trihydrate Alumina

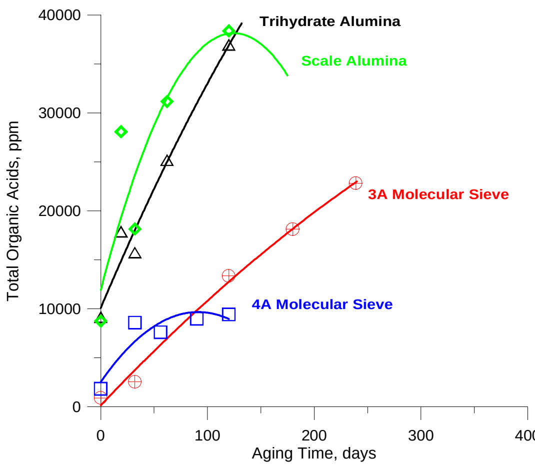


R-32 Decomposition at 60 C
No decomposition with Trihydrate Alumina

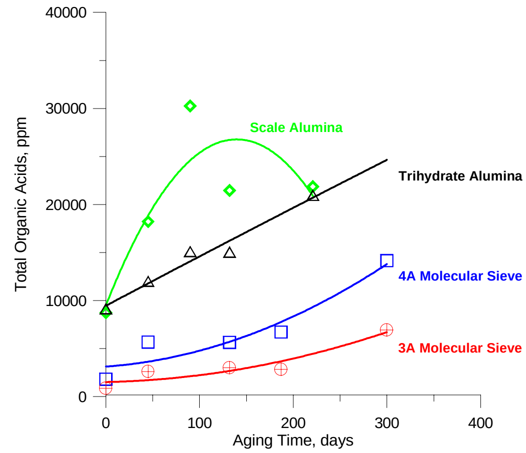


R-32 Decomposition at 40 C
No decomposition with Trihydrate Alumina, or Scale Alumina

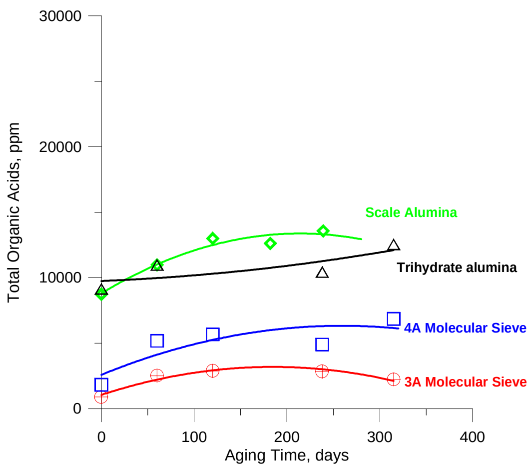
Figure 2.4: Effect of Type of Desiccant on R-32 Decomposition



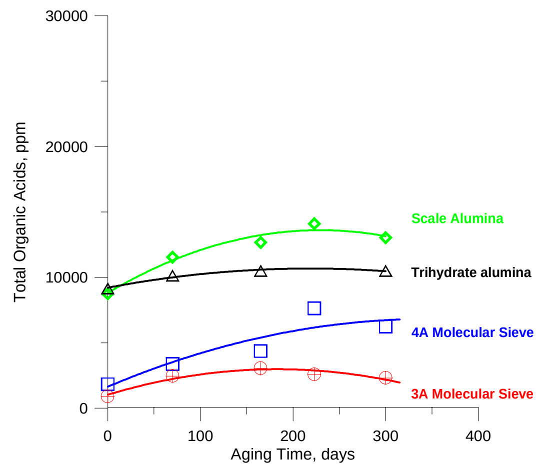
R-32/Mixed Esters at 120 C



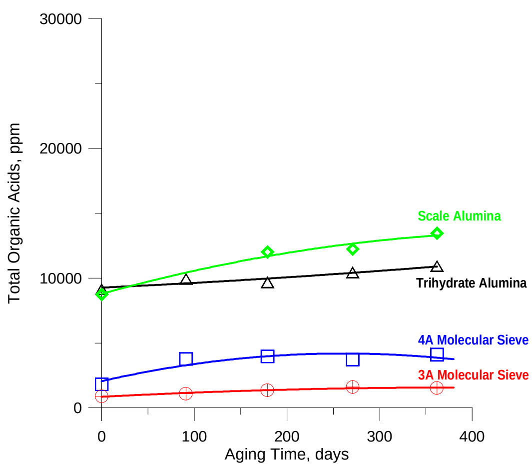
R-32/Mixed Esters at 100 C



R-32/Mixed Esters at 80 C

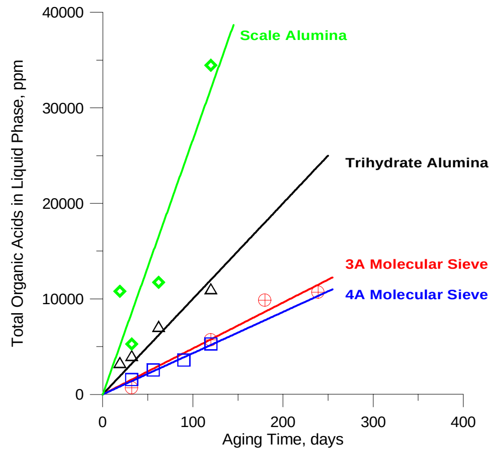


R-32/Mixed Esters at 60 C

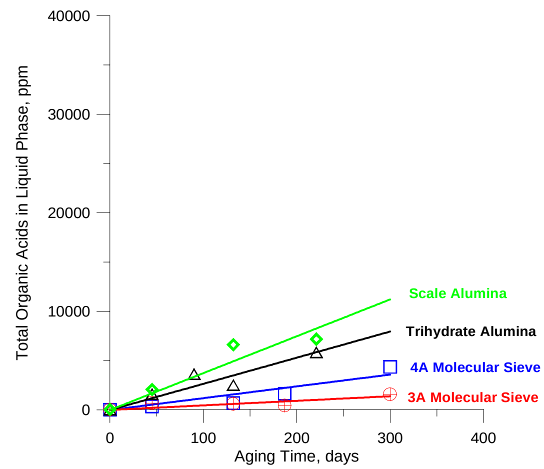


R-32/Mixed Esters at 40 C

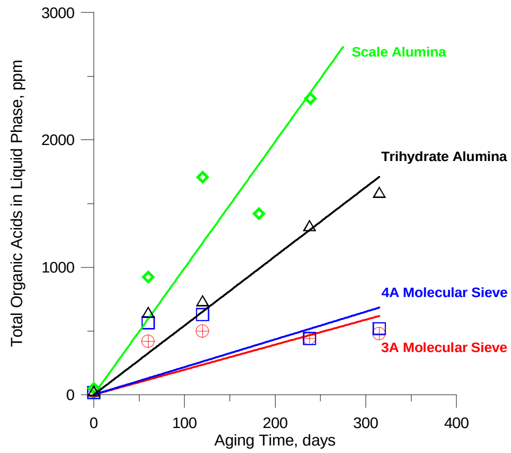
<u>Figure 2.5: Effect of Type of Desiccant on Total Organic Acids (in Liquid and in Desiccant) R-32/Mixed Esters</u>



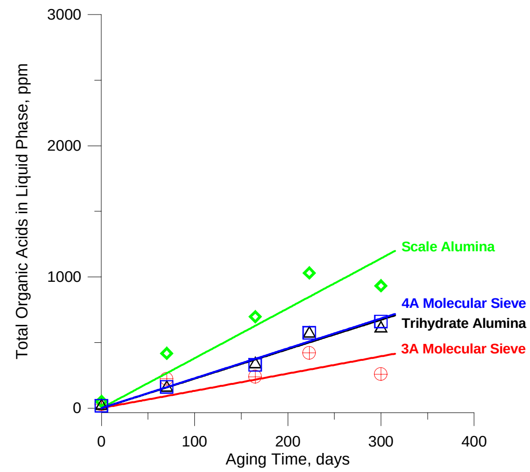
R-32/Mixed Esters at 120 C



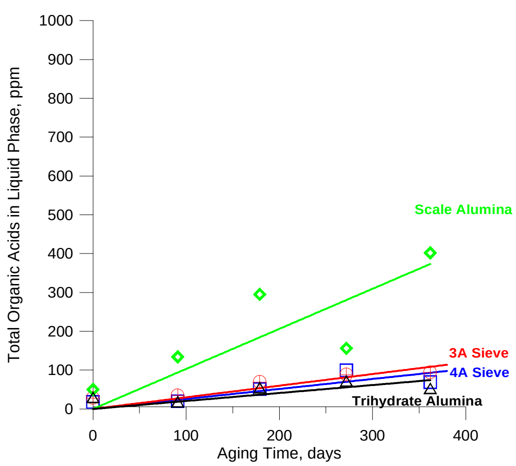
R-32/Mixed Esters at 100 C



R-32/Mixed Esters at 80 C



R-32/Mixed Esters at 60 C



R-32/Mixed Esters at 40 C

Figure 2.6: Effect of Type of Desiccant on Total Organic Acids in Liquid Phase R-32/Mixed Esters

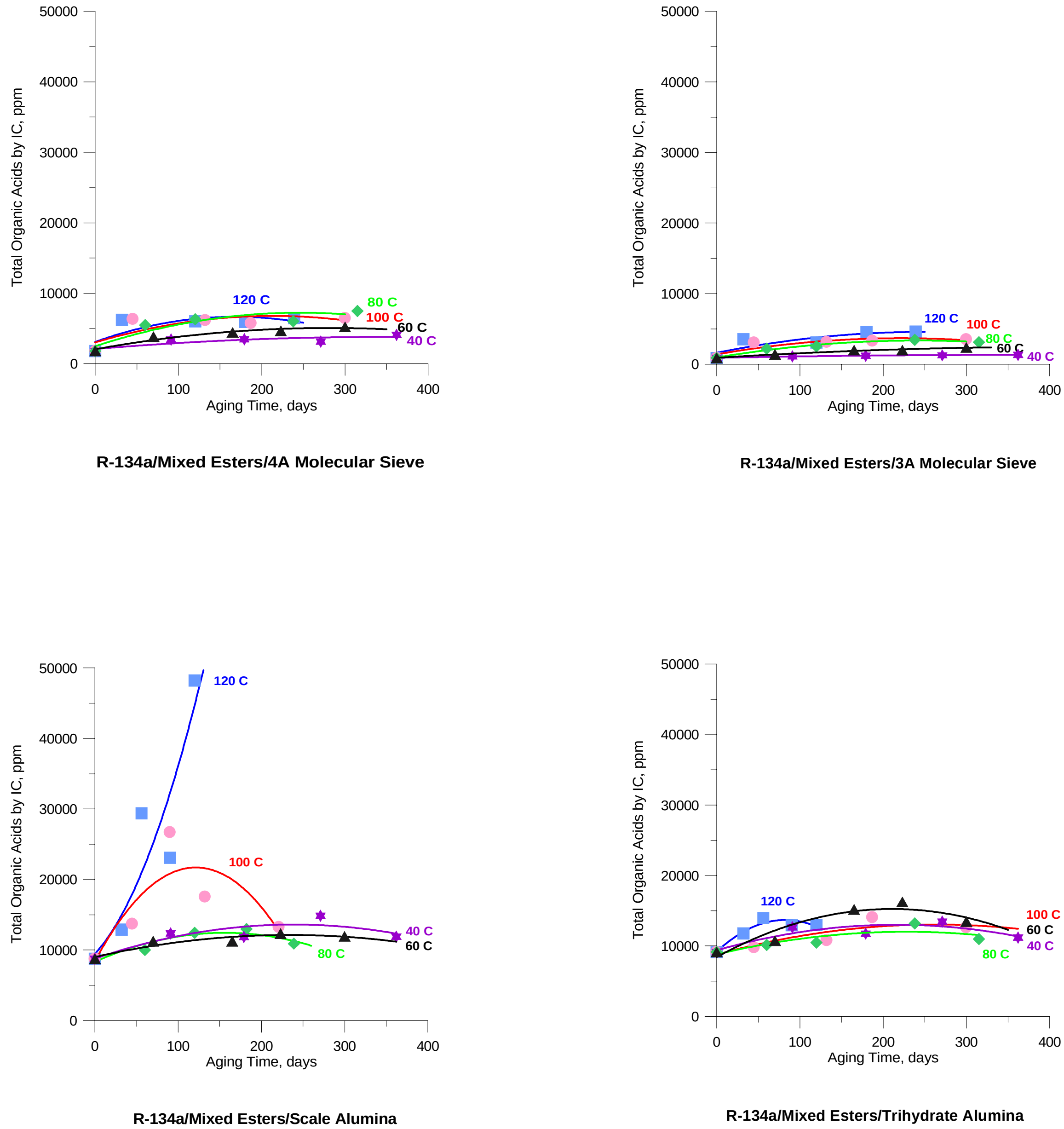
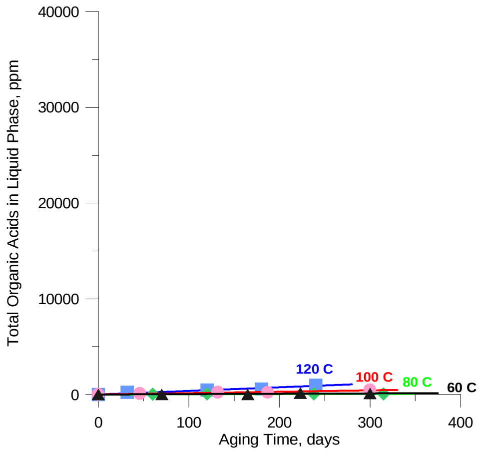
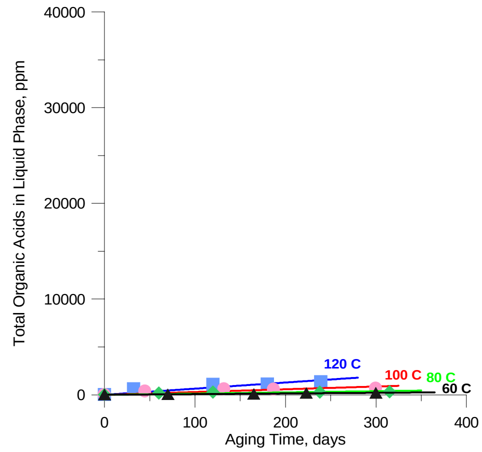


Figure 3.1: Effect of Temperature on Total Organic Acids (in Liquid and in Desiccant) R-134a/Mixed Esters



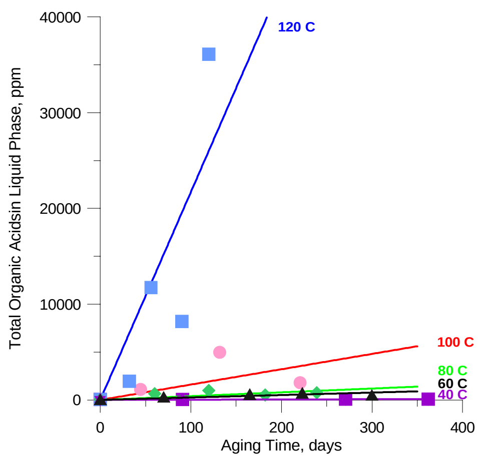
R-134a/Mixed Esters/4A Molecular Sieve

No organic acid in liquid phase at 40°C

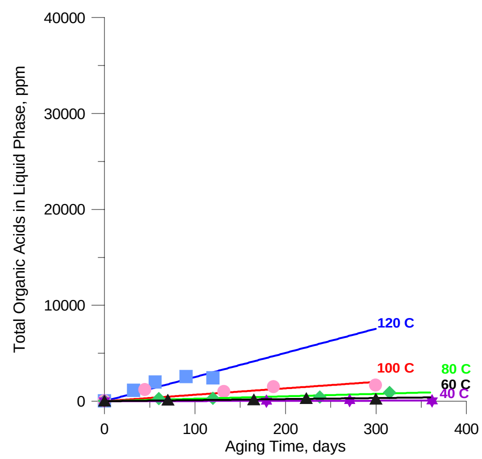


R-134a/Mixed Esters/3A Molecular Sieve

No organic acid in liquid phase at 40°C

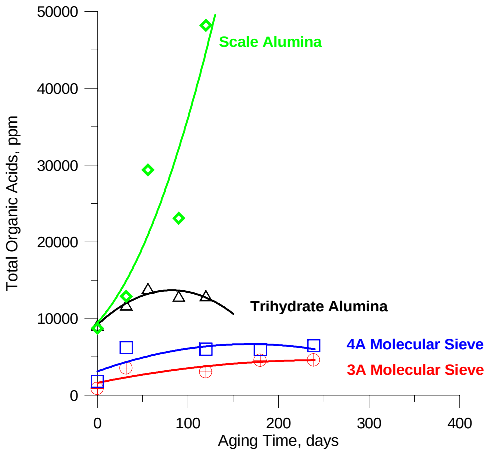


R-134a/Mixed Esters/Scale Alumina

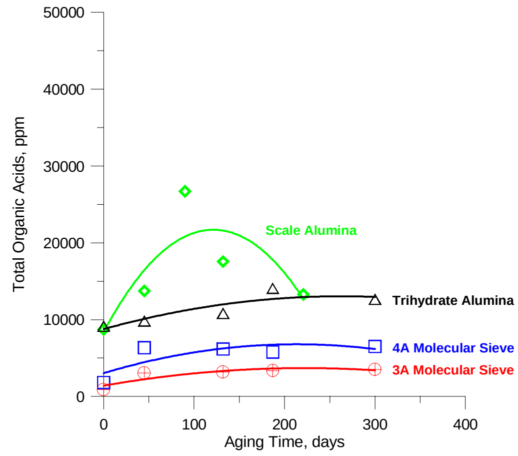


R-134a/Mixed Esters/Trihydrate Alumina

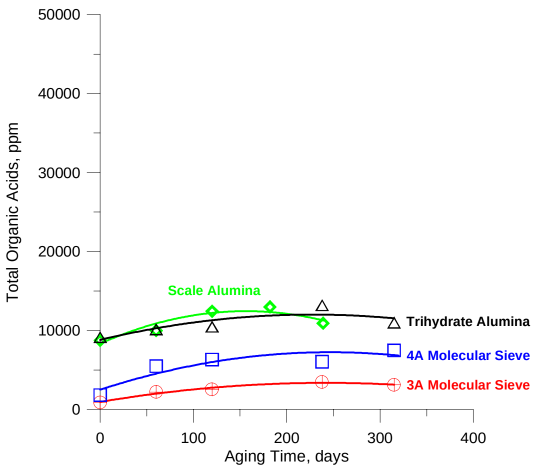
<u>Figure 3.2: Effect of Temperature on Total Organic Acids in Liquid Phase</u>
<u>R-134a/Mixed Esters</u>



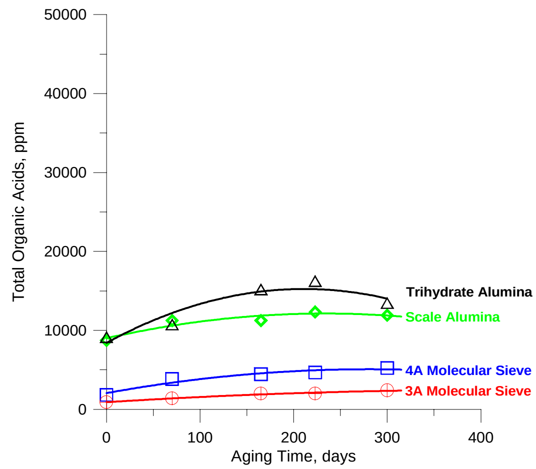
R-134a/Mixed Esters at 120 C



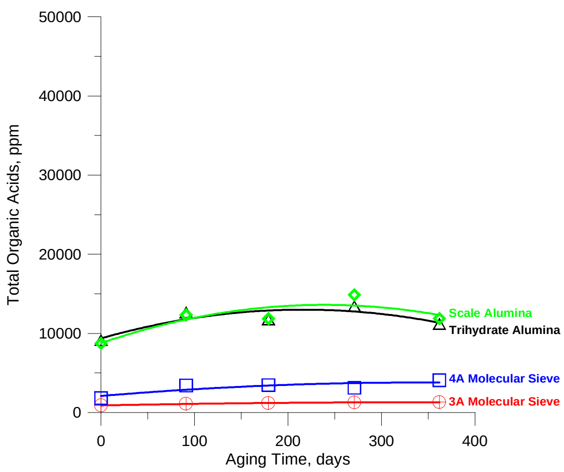
R-134a/Mixed Esters at 100 C



R-134a/Mixed Esters at 80 C

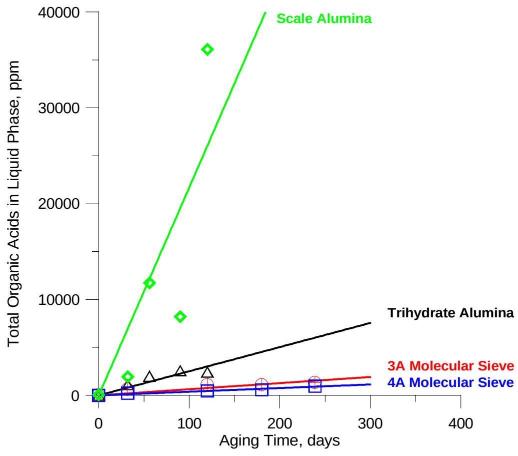


R-134a/Mixed Esters at 60 C

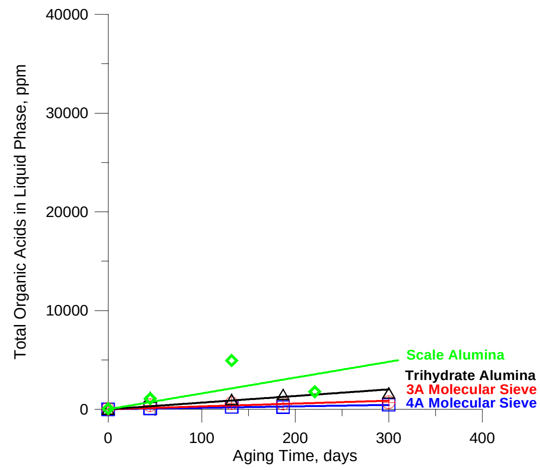


R-134a/Mixed Esters at 40 C

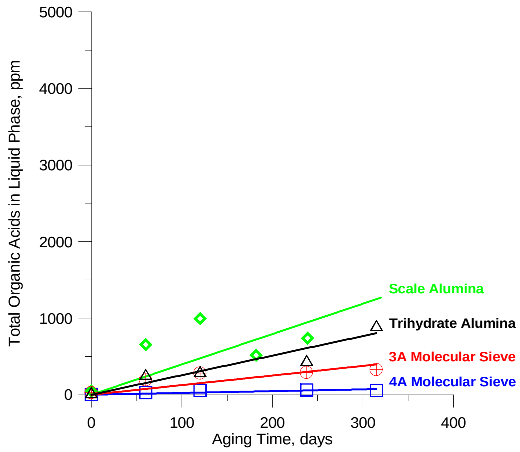
Figure 3.3: Effect of Type of Desiccant on Total Organic Acids (in Liquid and in Desiccant) R-134a/Mixed Esters



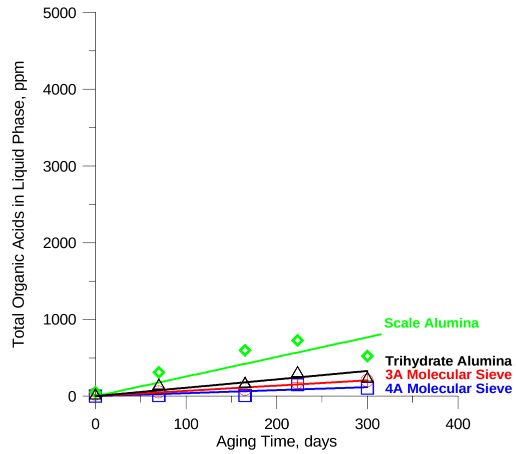
R-134a/Mixed Esters at 120 C



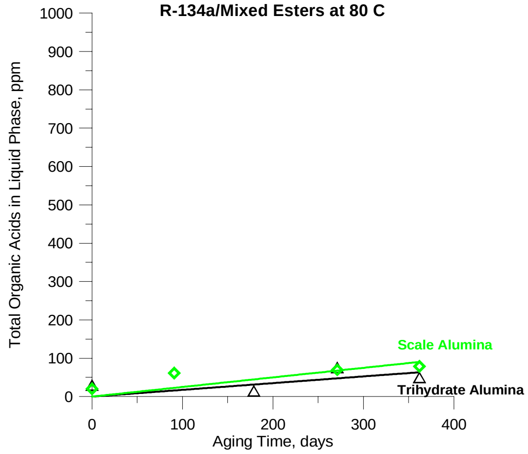
R-134a/Mixed Esters at 100 C



R-134a/Mixed Esters at 80 C



R-134a/Mixed Esters at 60 C



R-134a/Mixed Esters at 40 C

No organic acid in liquid phase with 3A and 4A molecular sieves

Figure 3.4: Effect of Type of Desiccant on Total Organic Acids in Liquid Phase R-134a/Mixed Esters

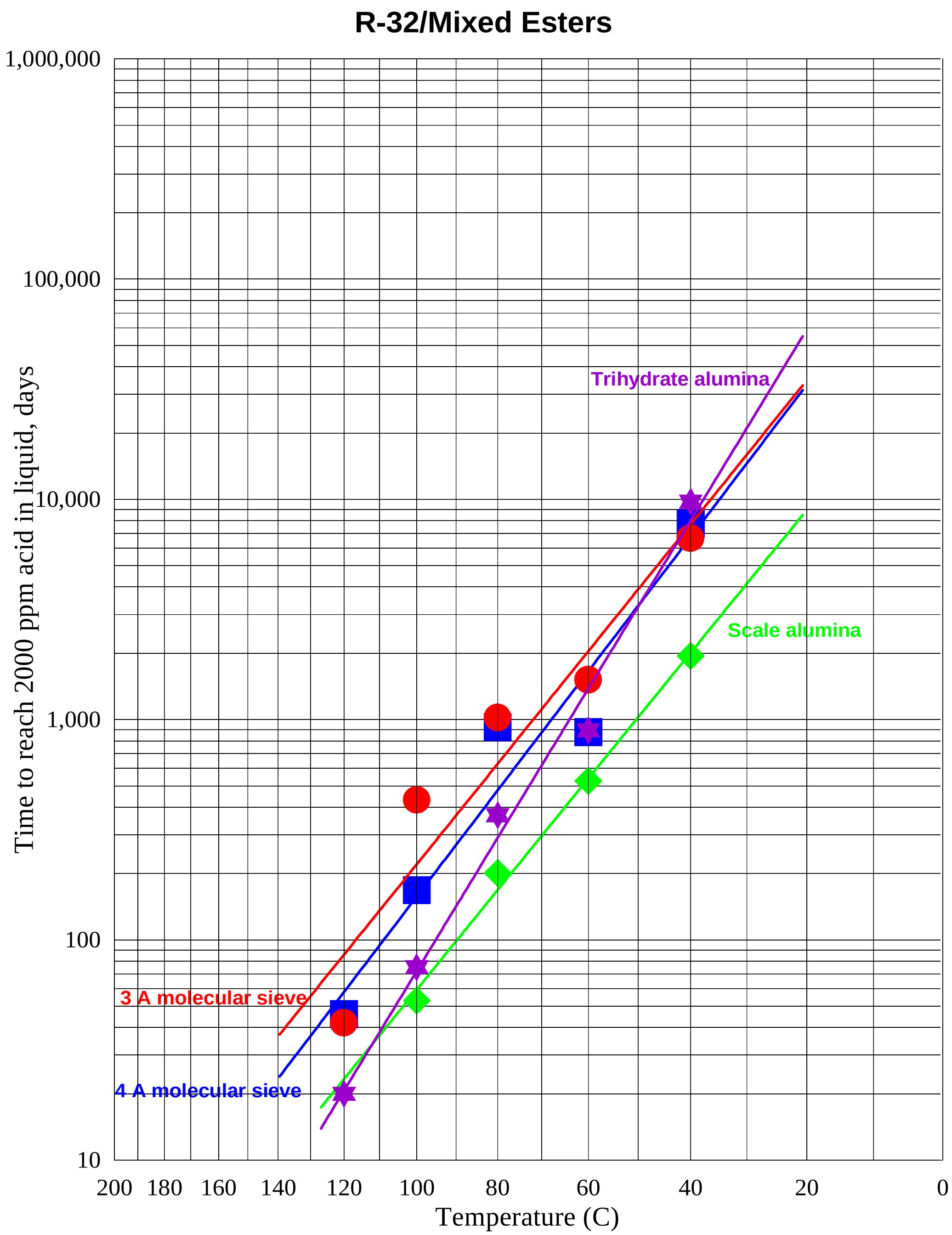


Figure 4.1: Time versus temperature curves for R-32/mixed esters sealed tubes
(Failure criterion: 2000 ppm organic acids in liquid phase)

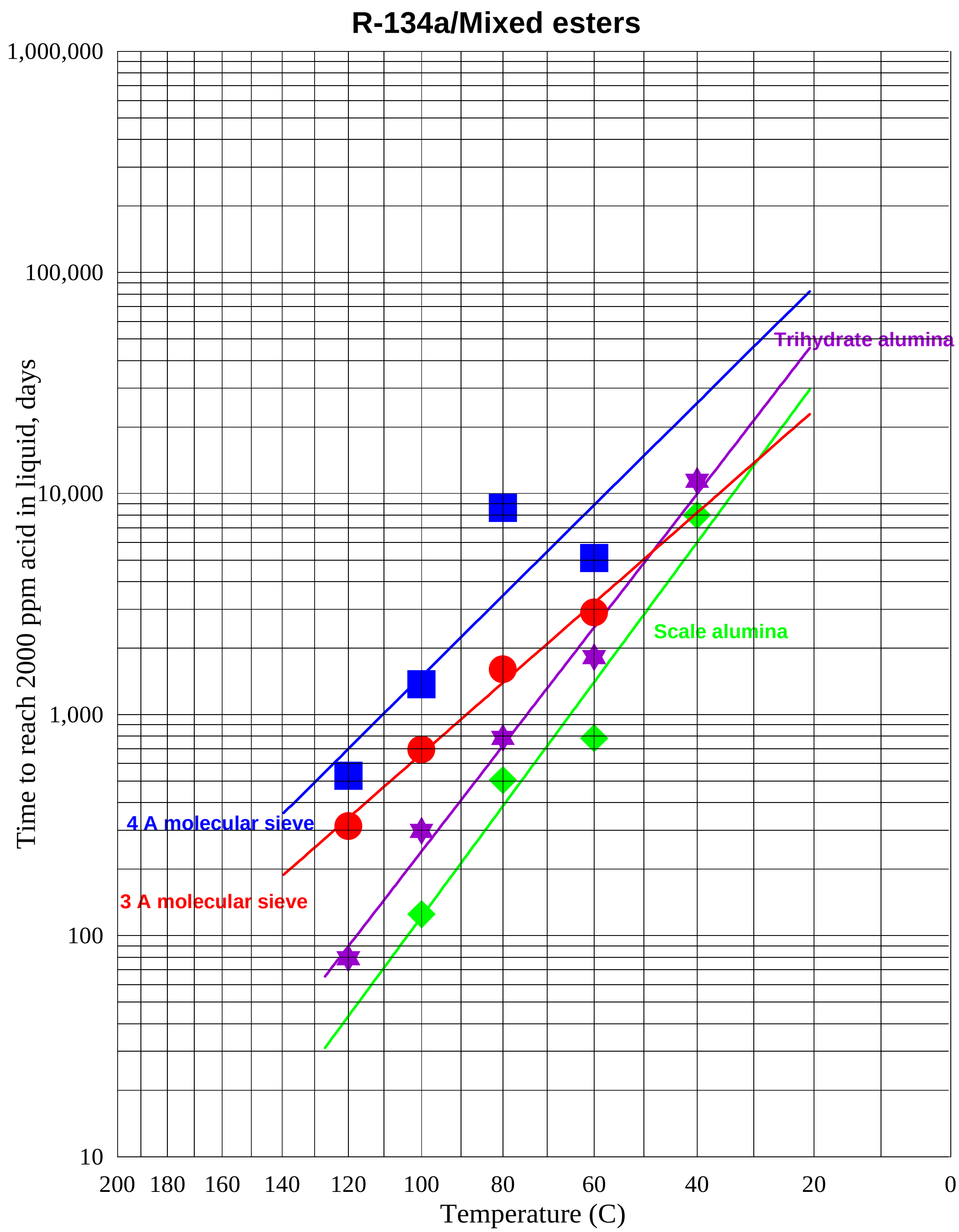


Figure 4.2: Time versus temperature curves for R-134a/mixed esters sealed tubes
(Failure criterion: 2000 ppm organic acids in liquid phase)

Code Key For Summary Test Results Tables

Liquid Color

Colors follow ASTM Standard D1500. However, 8 mm internal diameter is much less than that specified. Therefore, colors “0" through “2" appear the same.

- 2.0 Water clear
- 2.5 Very faint yellow
- 3.0 Pale yellow
- 3.5 Light yellow
- 4.0 Yellow
- 4.5 Yellow-orange
- 5.0 Light orange
- 5.5 Orange
- 6.0 Orange-brown
- 6.5 Brown
- 7.0 Dark brown
- 7.5 Brown-black
- 8.0 Black

Desiccant Color

- 0 No change
- 1 Darker
- 2 Very dark
- 3 Black
- 4 Darker with some black
- 5 Reddish-brown with some gray

Copper Plating

- 0 None
- 1 Spots on edges
- 2 Edges covered
- 3 Spots on surface
- 4 Partially coated surface
- 5 Fully coated surface

Solids Formation

- 0 None
- 1 Small amount
- 2 Medium amount
- 3 Heavy amount

Steel Corrosion or Copper Corrosion

- 0 None
- 1 Spot darkening
- 2 Complete darkening
- 3 Pitting or coating

Cl ion in liquid

The parts per million by weight of chloride ions in the liquid phase of the aged sealed tube, as determined by ion chromatography

Fl ion in liquid

The parts per million by weight of fluoride ions in the liquid phase of the aged tube

Cl ion on desiccant

The parts per million based on desiccant weight of chloride ions extracted from the desiccants after aging and determined by ion chromatography

Fl ion on desiccant

The parts per million based on desiccant weight of fluoride ions extracted from the desiccants after aging

Total Acid Number (TAN)

mg of KOH per gram of lubricant sample

Organic acid in Liquid

Sum of the parts per million results for all organic anions determined by ion chromatography in the liquid phase of aged sealed tubes

Organic acid in desiccant

Sum of the parts per million results for all organic anions determined by ion chromatography in the desiccants after aging

Appendix A

Baseline Data at Room Temperature

Table A.1: Summary Test Results, Baseline Data at Room Temperature

Lubricant/Desiccant	Sample Number	Cl ion in liquid (ppm)	Fl ion in liquid (ppm)	Cl ion in desiccant (ppm)	Fl ion in desiccant (ppm)	Total Acid Number (mg KOH/g)	Organic Acid in liquid (ppm)	Organic Acid in desiccant (ppm)
Mineral oil		1	0	---	---	---	0	---
Mixed esters		1	5	---	---	---	119	---
Mineral oil/4A sieve	1	0	0	74	82	0.01	0	15
	2	0	0	29	85	0.01	0	15
Mixed esters/4A sieve	1	0	2	24	91	0.04	18	1,761
	2	0	2	22	90	0.03	18	1,804
Mineral oil/3A sieve	1	1	0	7	9	0.01	0	426
	2	0	0	11	8	0.01	0	363
Mixed esters/3A sieve	1	0	2	7	14	0.06	24	492
	2	0	2	9	17	0.05	28	860
Mineral oil/Scale alumina	1	0	0	15	10	0.22	0	663
	2	2	0	17	12	0.02	0	723
Mixed esters/Scale alumina	1	1	2	19	2	0.05	20	8,153
	2	2	2	18	2	0.05	50	8,688
Mineral oil/Trihydrate alumina	1	0	0	40	7	0.01	0	1,850
	2	0	0	42	5	0.01	0	1,384
Mixed esters/Trihydrate alumina	1	0	1	19	1	0.02	6	9,140
	2	0	2	15	2	0.04	30	8,369

Table A.2 : Ion Chromatography Results, Baseline Data at Room Temperature

Lubricant/ Desiccant	Sample Number	Formate		Acetate		Propanoate		Butyrate		Pentanoate		Hexanoate		Heptanoate		2Ethylhexanoate		Sulfate		Number of Unknowns	
		Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic
Mineral oil																		11			
Mixed esters										71						48					
Mineral oil/4A sieve	1		15																178		
4A molecular sieve	2		15																159		1
Mixed esters/	1		7							18	1,653		101						164		1
4A molecular sieve	2		4							18	1,696		104					2	144		1
Mineral oil/	1		15								23				388			7	271		
3A molecular sieve	2		11		13										339			5	249		
Mixed esters/	1		2							24	188		92		210				257		
3A molecular sieve	2		5							28	203		92		560				258		
Mineral oil/	1		71		200										392				12		
Scale alumina	2		75		214										434				12		
Mixed esters/	1		34		145				11	20	7,963										
Scale alumina	2		38		149				12	50	8,489										
Mineral oil/	1		147				1,703												28		
Trihydrate alumina	2		145		1,239													9	32		
Mixed esters/	1		52		677					6	8,411										1
Trihydrate alumina	2	2	38		433						7,898			28				15			

Appendix B

Aging Temperature of 120°C

Table B.1: Summary Test Results, Aging Temperature = 120°C														
Refrigerant/Lubricant/ Desiccant	**Aging Time (days)**	**Liquid Color (2-8)**	**Desiccant Color (0-5)**	**Copper Plating (0-5)**	**Solids Formation (0-3)**	**Steel Corrosion (0-3)**	**Copper Corrosion (0-3)**	**Cl ion in liquid (ppm)**	**Fl ion in liquid (ppm)**	**Cl ion in desiccant (ppm)**	**Fl ion in desiccant (ppm)**	**Total Acid Number (mg KOH/g)**	**Organic Acid in liquid (ppm)**	**Organic Acid in desiccant (ppm)**
R-22/mineral oil/	32	3.0	3	0	0	0	0	2	5	9,771	814	0	37	2,768
4A molecular sieve	120	3.0	3	0	0	0	1	13	21	12,066	855	0.02	1	4,427
	180	3.0	3	2	0	0	1	7	1	12,261	880	0.01	26	5,217
	239	3.5	3	2	0	0	2	8	1	13,377	871	0.01	0	5,197
R-32/mixed esters/	32	3.0	2	0	1	0	0	1	2	30	991	0.21	1,543	7,036
4A molecular sieve	56	3.0	2	0	0	0	0	1	2	13	983	0.40	2,552	5,045
	90	3.0	2	0	1	0	0	2	3	15	1,610	1.54	3,589	5,381
	120	3.0	2	0	1	0	0	1	48	5	1,656	1.41	5,284	4,125
R-134a/mixed esters/	32	4.5	1	0	1	0	0	1	0	17	64	0.10	223	5,996
4 A molecular sieve	120	5.0	1	0	1	0	1	1	32	11	104	0.26	467	5,542
	180	5.0	1	0	0	0	2	1	2	21	89	0.22	582	5,374
	239	4.5	2	0	0	0	2	2	0	21	64	0.34	964	5,510
R-22/mineral oil/	32	3.0	3	0	0	0	0	3	1	10,693	815	0	1	4,189
3A molecular sieve	120	3.0	3	0	0	0	1	3	19	12,440	969	0.02	37	4,598
	180	3.0	3	2	0	0	1	6	3	14,463	1,242	0.01	29	5,397
	239	3.0	3	2	0	2	2	10	2	14,327	1,108	0.02	3	4,854
R-32/mixed esters/	32	3.0	2	0	0	0	0	1	1	37	1,245	0.32	672	1,855
3A molecular sieve	120	3.0	2	0	0	0	0	2	18	21	1,882	0.41	5,717	7,632
	180	3.0	2	0	0	0	0	0	13	14	2,164	0.18	9,861	8,261
	239	3.0	2	0	0	0	0	0	22	8	2,372	0.22	10,701	12,125
R-134a/mixed esters/	32	4.0	1	0	0	0	0	1	0	8	7	0.34	629	2,915
3A molecular sieve	120	4.5	2	0	0	0	0	2	7	4	4	0.61	1,093	1,969
	180	4.5	1	0	0	0	2	0	0	10	28	0.47	1,107	3,461
	239	4.5	2	0	0	0	2	2	0	11	24	0.52	1,341	3,275

Table B.1 (continued): Summary Test Results, Aging Temperature = 120°C														
Refrigerant/Lubricant/ Desiccant	**Aging Time (days)**	**Liquid Color (2-8)**	**Desiccant Color (0-5)**	**Copper Plating (0-5)**	**Solids Formation (0-3)**	**Steel Corrosion (0-3)**	**Copper Corrosion (0-3)**	**Cl ion in liquid (ppm)**	**Fl ion in liquid (ppm)**	**Cl ion in desiccant (ppm)**	**Fl ion in desiccant (ppm)**	**Total Acid Number (mg KOH/g)**	**Organic Acid in liquid (ppm)**	**Organic Acid in desiccant (ppm)**
R-22/mineral oil/	32	2.5	2	0	1	0	0	85	23	4,374	1,121	0.15	86	3,360
Scale Alumina	120	4.0	3	0	2	2	2	25	52	4,914	2,245	0.07	29	3,860
	180	3.0	2	3	0	2	1	11	9	6,592	2,102	0.01	12	4,309
	239	4.0	2	4	1	2	2	31	44	6,010	2,329	0.04	22	4,481
R-32/mixed esters/	19	3.0	1	0	1	0	0	3	6	10	17	12.49	10,801	17,287
Scale Alumina	32	2.0	1	0	1	0	0	1	5	31	80	2.57	5,258	12,890
	62	2.5	1	0	1	2	0	5	138	31	114	10.35	11,743	19,422
	120	7.5	3	0	2	2	0	7	5,435	38	6,128	>18.0	34,454	3,933
R-134a/mixed esters/	32	2.0	1	0	1	0	0	0	0	9	10	1.27	1,952	10,929
Scale Alumina	56	2.5	1	0	1	0	0	1	0	11	2	8.73	11,725	17,671
	90	2.5	1	0	1	0	0	2	1	10	0	9.01	8,206	14,888
	120	3.0	1	0	1	2	0	7	0	0	0	20.17	36,097	12,124
R-22/mineral oil/	32	2.5	2	0	0	1	0	11	6	5,114	1,041	0.06	36	3,002
Trihydrate Alumina	120	4.0	3	0	1	2	1	19	16	5,172	1,646	0.03	2	4,570
	180	4.5	3	4	1	2	2	17	6	5,913	2,259	0.03	4	4,168
	239	4.5	3	4	0	2	2	30	8	6,825	2,708	0.02	9	4.461
R-32/mixed esters/	19	3.0	1	0	0	0	0	2	6	14	9	3.70	3,344	14,540
Trihydrate Alumina	32	2.5	4	0	1	0	0	2	28	21	46	1.95	4,066	11,671
	62	3.5	3	0	1	0	1	4	149	23	246	6.37	7,127	18,056
	120	5.5	3	0	0	1	0	0	2578	20	4,522	>15.0	11,064	25,901
R-134a/mixed esters/	32	3.5	1	0	1	0	0	3	0.5	23	1	0.64	1,126	10,653
Trihydrate Alumina	56	2.5	1	0	0	0	0	2	0	11	1	1.03	2,066	11,930
	90	4.0	1	0	1	0	0	2	0	11	1	2.55	2,574	10,355
	120	2.5	1	0	1	0	0	0	30	5	1	1.97	2,428	10,564

Table B.2 : Ion Chromatography Results, Aging Temperature = 120°C

Refrigerant/ Lubricant/ Desiccant	Aging Time	Formate		Acetate		Propanoate		Butyrate		Pentanoate		Hexanoate		Heptanoate		2Ethylhexanoate		Sulfate		Number of Unknowns	
		Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic
R-22/mineral oil/	32	1	2,768							36								42	281		
4A molecular sieve	120	1	4,427															7	294		
	180	26	5,217																321	1	
	239		5,197																304		
R-32/mixed esters/	32	1,098	3,312				1,381			445	2,075				163		105		240		1
4A molecular sieve	56	1,385	2,494							1,167	2,330		99		122				161		1
	90	1,656	1,903		191					1,891	3,127		109	42	51				130		1
	120	3,219	2,802							2,065	1,204		36		83				234		
R-134a/mixed esters/	32		15							223	4,445		139		1,397				167		2
4 A molecular sieve	120		23					59		408	4,429		57		1,033				150		
	180	1	33							581	3,869				1,472			3	134		2
	239		16							964	3,962				1,532			6	149		
R-22/mineral oil/	32	1	4,189																298		
3A molecular sieve	120	5	4,598							32									321		
	180	3	5,397							26								6	347		
	239	3	4,854																306		
R-32/mixed esters/	32	51	715							621	845		153		142				317		1
3A molecular sieve	120	5,717	5,278								2,238						115	6	336		
	180	9,861	6,443								1,818								437		1
	239	10,70	5,632								5,578		915						256		
R-134a/mixed esters/	32	1	24		23					628	2,329		144		395				219		1
3A molecular sieve	120	20	33							1,073	1,733		77		126				203		
	180		58	13						1,094	2,741		140		522				243	1	1
	239		55							1,341	2,858		91		271				273		1

Table B.2 (continued) : Ion Chromatography Results, Aging Temperature = 120°C

Refrigerant/ Lubricant/ Desiccant	Aging Time	Formate		Acetate		Propanoate		Butyrate		Pentanoate		Hexanoate		Heptanoate		2Ethylhexanoate		Sulfate		Number of Unknowns	
		Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic
R-22/mineral oil/ Scale Alumina	32	75	3,265							11			95								
	120	19	3,860							10											
	180	12	4,309																		
	239	22	4,481																		
R-32/mixed esters/ Scale Alumina	19	18			111				2,710	10,783	14,466									1	
	32	220	1,096		44	8				5,038	11,750										1
	62	176	981		67					11,567	18,374										2
	120									32,737	3,040				175	1,717	718		7	2	2
R-134a/mixed esters/ Scale Alumina	32		119		92	10				1,942	10,718									1	
	56		77	9	180			106		11,610	17,414									1	
	90	11	88		207					8,195	14,593									2	
	120	162	32	63	111	29				35,174	11,981					669			2	1	1
R-22/mineral oil/ Trihydrate Alumina	32	11	3,002							25											
	120	2	4,570																		
	180	4	4,168																		
	239	9	4,275												186						
R-32/mixed esters/ Trihydrate Alumina	19	106	750	15	616					3,223	13,174									1	1
	32	331	738	10	275					3,725	10,658										1
	62	450	692		162					6,657	17,149			20	53					1	2
	120	1,885								6,575	24,758					2,604	1,143			2	2
R-134a/mixed esters/ Trihydrate Alumina	**32**	3	83		708	11			60	1,112	9,802									1	1
	56	3	64		433	19				1,901	11,433	83						6			1
	90		29	37	350	10			40	2,527	9,936									1	1
	120	5	33	18	145					2,377	10,386					27				2	

Appendix C

Aging Temperature of 100°C

Table C.1: Summary Test Results, Aging Temperature = 100°C														
Refrigerant/Lubricant/ Desiccant	**Aging Time (days)**	**Liquid Color (2-8)**	**Desiccant Color (0-5)**	**Copper Plating (0-5)**	**Solids Formation (0-3)**	**Steel Corrosion (0-3)**	**Copper Corrosion (0-3)**	**Cl ion in liquid (ppm)**	**Fl ion in liquid (ppm)**	**Cl ion in desiccant (ppm)**	**Fl ion in desiccant (ppm)**	**Total Acid Number (mg KOH/g)**	**Organic Acid in liquid (ppm)**	**Organic Acid in desiccant (ppm)**
R-22/mineral oil/	45	3.0	3	0	0	0	0	2	10	6,950	858	0.01	1	1,933
4A molecular sieve	132	3.0	3	0	0	0	0	3	1	9,166	800	0.00	30	3,855
	187	3.0	3	0	0	0	1	3	1	10,741	701	0.00	0	4,464
	300	3.5	3	0	0	0	0	4	1	11,288	798	0.01	0	4,675
R-32/mixed esters/	45	3.5	2	0	1	0	0	0	2	21	1,011	0.18	358	5,326
4A molecular sieve	132	3.0	2	0	0	0	1	1	4	45	1,527	0.13	691	4,960
	187	3.0	2	0	0	0	0	1	1	25	1,592	0.18	1,651	5,070
	300	3.0	2	0	0	0	0	1	3	66	1,697	0.34	4,368	9,797
R-134a/mixed esters/	45	4.0	1	0	1	0	0	1	1	25	136	0.07	88	6,255
4A molecular sieve	132	4.5	1	0	0	0	2	1	0	18	82	0.08	228	5,941
	187	4.5	1	0	1	0	2	1	1	28	79	0.08	217	5,561
	300	4.5	1	0	0	0	2	0	1	18	78	0.14	455	6,045
R-22/mineral oil/	45	3.5	3	0	0	0	0	2	1	7,662	1,127	0.01	0	3,622
3A molecular sieve	132	3.5	3	0	0	0	1	0	0	10,506	1,102	0.03	5	4,620
	187	3.0	3	0	0	1	1	4	1	11,805	1,147	0.00	0	5,504
	300	3.0	3	0	0	1	1	5	2	12,472	954	0.01	1	5,144
R-32/mixed esters/	45	3.0	2	0	0	0	0	3	17	22	1,159	0.28	687	1,920
3A molecular sieve	132	3.0	2	0	0	0	2	1	2	29	1,380	0.28	608	2,398
	187	3.0	2	0	0	0	2	2	1	23	1,243	0.54	432	2,426
	300	3.0	2	0	0	0	1	0	4	63	1,820	0.01	1,588	5,368
R-134a/mixed esters/	45	3.5	1	0	0	0	0	1	1	5	16	0.20	400	2,665
3A molecular sieve	132	4.0	1	0	0	0	2	0	0	7	9	0.23	603	2,558
	187	4.5	1	0	0	0	2	6	1	11	6	0.26	580	2,759
	300	4.5	1	0	0	0	2	0	0	7	61	0.30	698	2,827

Table C.1 (continued): Summary Test Results, Aging Temperature = 100°C														
Refrigerant/Lubricant/ Desiccant	**Aging Time (days)**	**Liquid Color (2-8)**	**Desiccant Color (0-5)**	**Copper Plating (0-5)**	**Solids Formation (0-3)**	**Steel Corrosion (0-3)**	**Copper Corrosion (0-3)**	**Cl ion in liquid (ppm)**	**Fl ion in liquid (ppm)**	**Cl ion in desiccant (ppm)**	**Fl ion in desiccant (ppm)**	**Total Acid Number (mg KOH/g)**	**Organic Acid in liquid (ppm)**	**Organic Acid in desiccant (ppm)**
R-22/mineral oil/	45	2.5	2	0	1	0	0	45	16	3,855	1,074	0.09	46	2,999
Scale Alumina	132	2.5	2	0	1	0	1	3	5	5,319	1,200	0.16	382	3,453
	187	3.0	2	0	1	0	1	55	15	5,912	1,308	0.01	65	3,895
	300	3.5	2	0	1	0	1	26	32	4,286	2,061	0.04	35	4,548
R-32/mixed esters/	45	3.0	1	0	1	0	2	5	5	31	74	1.20	2,072	16,143
Scale Alumina	90	3.0	1	3	0	2	0	3	13	8	31	7.13	16,635	13,616
	132	2.5	1	0	0	0	0	2	22	9	204	3.80	6,614	14,858
	221	2.5	2	0	0	0	0	2	58	14	3,905	2.39	7,179	14,687
R-134a/mixed esters/	45	2.5	1	0	1	0	0	2	1	12	6	0.57	1,080	12,635
Scale Alumina	90	2.5	1	0	1	2	0	3	10	6	6	5.68	13,326	13,387
	132	2.5	1	0	0	0	0	1	1	10	2	2.59	4,943	12,604
	221	2.5	1	0	0	0	0	1	3	10	2	0.71	1,777	11,476
R-22/mineral oil/	45	2.5	2	0	0	0	0	4	2	4,471	791	0.01	2	3,074
Trihydrate Alumina	132	2.5	2	1	0	1	1	1	1	4,884	1,042	0.01	47	3,098
	187	3.0	2	0	0	0	1	5	2	5,819	1,363	0.00	2	3,751
	300	3.5	2	0	0	2	2	12	2	6,004	1,691	0.02	1	4,406
R-32/mixed esters/	45	2.5	1	0	1	0	0	12	3	26	10	0.79	1,609	10,399
Trihydrate Alumina	90	3.0	4	0	0	0	0	2	5	11	81	1.51	3,647	11,460
	132	3.5	5	0	0	0	2	2	36	31	116	1.57	2,527	12,518
	221	3.0	2	0	0	0	1	3	99	18	117	2.79	5,842	15,114
R-134a/mixed esters/	45	3.5	1	0	1	0	2	9	2	11	7	0.29	1,208	8,612
Trihydrate Alumina	132	3.5	1	0	0	0	2	1	0	9	1	0.44	1,006	9,801
	187	2.5	1	0	1	0	0	1	1	22	2	0.62	1,508	12,563
	300	2.5	1	0	0	0	0	1	0	20	2	0.77	1,665	10,979

Table C.2 : Ion Chromatography Results, Aging Temperature = 100°C

Refrigerant/ Lubricant/ Desiccant	Aging Time	Formate		Acetate		Propanoate		Butyrate		Pentanoate		Hexanoate		Heptanoate		2Ethylhexanoate		Sulfate		Number of Unknowns	
		Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic
R-22/mineral oil/	45	1	1,933																224		
4A molecular sieve	132	1	3,855							29									316		
	187		4,464																362		
	300		4,675																364		
R-32/mixed esters/	45	42	3,031							316	1,270		102		923				186		
4A molecular sieve	132	435	3,146				58		2,997	256	1,179		91		531				478		3
	187	1,154	3,648							497	981		15		426				416		
	300	3,203	5,986							1,165	3,585				226			6	394		1
R-134a/mixed esters/	45		17							88	4,138		127		1,973				191		
4 A molecular sieve	132		21							228	4,239		185		1,496				161		2
	187	1	27							216	4,084		146		1,304				160		2
	300	3	24							452	4,536		68		1,417				145		1
R-22/mineral oil/	45		3,622																342		
3A molecular sieve	132		4,620							5									343		
	187		5,504																354		
	300	1	5,144																335		
R-32/mixed esters/	45	20	394	10						657	1,182		140		204				315		
3A molecular sieve	132	18	597							590	1,493		80		228				386		
	187	90	1,351							342	824		106		145				406		
	300	1,588	5,290										78						423		
R-134a/mixed esters/	45	1	15							399	2,122		146		382				236		
3A molecular sieve	132	1	23							602	2,028		198		309				232		2
	187		38	16						564	2,317		168		236				277		
	300	3	36							695	2,181		113		497				237		

Table C.2 (continued) : Ion Chromatography Results, Aging Temperature = 100°C

Refrigerant/ Lubricant/ Desiccant	Aging Time	Formate		Acetate		Propanoate		Butyrate		Pentanoate		Hexanoate		Heptanoate		2Ethylhexanoate		Sulfate		Number of Unknowns	
		Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic
R-22/mineral oil/	45	46	2,999																		
Scale Alumina	132	16	3,453					15						351							
	187	65	3,895																		1
	300	25	4,548							10											
R-32/mixed esters/	45	40	1,152		85					2,032	14,906										
Scale Alumina	90	36	591		136					16,599	12,889									1	
	132	35	1061		38					6,579	13,759										
	221	3,351	2,913							3,828	11,689				85			7			1
R-134a/mixed esters/	45		164		116					1,080	12,356										
Scale Alumina	90	50	54		111					13,276	13,222									1	
	132	6	106		117					4,937	12,381									1	
	221	4	210		148	8				1,685	11,118	80									
R-22/mineral oil/	45	2	2,505		569																
Trihydrate Alumina	132		3,098											47							
	187	2	3,751																		
	300	1	4,406																		
R-32/mixed esters/	45	66	735	11	669					1,532	8,994							137		1	
Trihydrate Alumina	90	61	651	13	425					3,573	10,384										
	132	18	194		348					2,509	11,976										1
	221	145	349		207					5,697	14,558									1	
R-134a/mixed esters/	45	50	79	9	386					1,149	8,147							100			
Trihydrate Alumina	132	3	63	**3**	180					1,000	9,558										1
	187		69			3	364			1,505	12,130									1	
	300		**35**		497	12				1,653	10,447									2	

Appendix D

Aging Temperature of 80°C

Table D.1: Summary Test Results, Aging Temperature = 80°C														
Refrigerant/Lubricant/ Desiccant	**Aging Time (days)**	**Liquid Color (2-8)**	**Desiccant Color (0-5)**	**Copper Plating (0-5)**	**Solids Formation (0-3)**	**Steel Corrosion (0-3)**	**Copper Corrosion (0-3)**	**Cl ion in liquid (ppm)**	**Fl ion in liquid (ppm)**	**Cl ion in desiccant (ppm)**	**Fl ion in desiccant (ppm)**	**Total Acid Number (mg KOH/g)**	**Organic Acid in liquid (ppm)**	**Organic Acid in desiccant (ppm)**
R-22/mineral oil/	60	3.5	3	0	0	0	0	2	1	1,570	996	0.02	0	1,616
4A molecular sieve	120	3.0	3	0	0	0	0	1	0	2,288	902	0.01	0	2,811
	238	3.0	3	0	0	1	0	2	1	5,783	918	0.01	1	3,194
	315	3.0	3	0	0	0	0	2	0	6,179	1,010	0.01	0	3,018
R-32/mixed esters/	60	3.0	1	0	0	0	2	3	2	19	310	0.29	565	4,609
4A molecular sieve	120	3.5	2	0	0	0	2	1	1	14	624	0.33	629	5,034
	238	4.0	2	0	0	0	2	1	0	12	1,054	0.18	441	4,449
	315	3.5	2	0	0	0	2	2	1	22	1,599	0.15	518	6,340
R-134a/mixed esters/	60	3.0	1	0	0	0	2	1	1	22	97	0.03	28	5,456
4A molecular sieve	120	3.5	1	0	0	0	2	2	0	21	96	0.04	55	6,256
	238	4.0	1	0	0	0	2	0	0	11	90	0.03	62	5,975
	315	4.0	1	0	0	1	2	1	0	58	131	0.01	55	7,423
R-22/mineral oil/	60	3.0	3	0	0	0	0	1	1	4,115	606	0.02	1	2,325
3A molecular sieve	120	3.5	3	0	0	0	0	1	0	5,374	437	0.02	8	3,418
	238	3.0	3	0	0	1	0	1	1	6,914	722	0.01	1	4,204
	315	2.0	3	0	0	0	0	2	0	7,834	753	0.02	0	4,741
R-32/mixed esters/	60	3.0	2	0	0	0	2	1	1	8	970	0.24	418	2,092
3A molecular sieve	120	3.0	2	0	0	0	2	1	1	16	1,181	0.39	500	2,374
	238	3.5	2	0	0	0	2	3	1	13	1,303	0.16	441	2,383
	315	3.5	2	0	0	0	2	1	0	24	1,561	0.16	480	1,741
R-134a/mixed esters/	60	3.0	1	0	0	0	2	2	1	8	15	0.12	192	2,012
3A molecular sieve	120	30	1	0	0	0	2	1	0	5	18	0.16	284	2,249
	238	3.5	1	0	0	0	2	1	0	4	17	0.09	290	3,173
	315	3.5	1	0	0	0	2	1	0	9	0	0.14	328	2,777

Table D.1 (continued): Summary Test Results, Aging Temperature = 80°C														
Refrigerant/Lubricant/ Desiccant	**Aging Time (days)**	**Liquid Color (2-8)**	**Desiccant Color (0-5)**	**Copper Plating (0-5)**	**Solids Formation (0-3)**	**Steel Corrosion (0-3)**	**Copper Corrosion (0-3)**	**Cl ion in liquid (ppm)**	**Fl ion in liquid (ppm)**	**Cl ion in desiccant (ppm)**	**Fl ion in desiccant (ppm)**	**Total Acid Number (mg KOH/g)**	**Organic Acid in liquid (ppm)**	**Organic Acid in desiccant (ppm)**
R-22/mineral oil/	60	3.0	2	0	1	0	0	8	3	3,629	658	0.07	6	2,880
Scale Alumina	120	3.0	2	0	1	0	0	10	4	3,980	728	0.02	14	2,976
	238	3.0	2	0	1	0	1	6	3	4,222	844	0.04	7	2,941
	315	3.0	2	0	1	0	1	10	6	4,149	959	0.02	11	3,147
R-32/mixed esters/	60	2.5	1	0	1	0	2	3	2	12	8	0.76	924	10,054
Scale Alumina	120	2.5	1	0	0	0	0	3	1	29	12	1.27	1,707	11,295
	182	2.5	1	0	0	0	0	0	2	23	38	0.39	1,422	11,197
	239	2.5	1	0	0	0	0	3	9	24	101	0.52	2,325	11,249
R-134a/mixed esters/	60	2.0	1	0	1	0	0	2	1	12	1	0.50	653	9,333
Scale Alumina	120	2.5	1	0	0	0	0	1	0	14	1	0.93	995	11,429
	182	2.5	1	0	0	0	0	1	0	11	2	0.22	515	12,457
	239	2.5	1	0	0	0	0	4	2	11	3	0.22	738	10,167
R-22/mineral oil/	60	2.5	2	0	0	0	0	4	2	3,942	453	0.03	3	2,275
Trihydrate Alumina	120	2.5	2	0	0	1	0	2	1	4,034	642	0.02	1	2,263
	238	2.5	2	0	0	0	0	2	1	4,478	783	0.02	1	2,466
	315	2.5	2	0	0	0	1	4	1	4,903	933	0.09	2	2,722
R-32/mixed esters/	60	3.5	1	0	1	0	2	2	2	27	6	0.40	647	10,321
Trihydrate Alumina	120	3.5	1	0	0	0	2	0	1	17	4	0.66	738	8,370
	238	2.5	1	0	0	0	0	1	1	12	6	0.46	1,328	9,101
	315	4.0	1	0	1	0	2	1	12	14	7	0.48	1,590	10,956
R-134a/mixed esters/	60	3.5	1	0	0	0	2	1	1	16	1	0.20	266	9,863
Trihydrate Alumina	120	3.5	1	0	0	0	2	1	0	17	1	0.30	303	10,159
	238	2.5	1	0	0	0	0	1	0	23	0	0.20	449	12,738
	315	4.0	1	0	0	0	2	2	0	12	0	0.25	904	10,083

Table D.2 : Ion Chromatography Results, Aging Temperature = 80°C																					
Refrigerant/ Lubricant/ Desiccant	**Aging Time**	**Formate**		**Acetate**		**Propanoate**		**Butyrate**		**Pentanoate**		**Hexanoate**		**Heptanoate**		**2Ethylhexanoate**		**Sulfate**		**Number of Unknowns**	
		Liq	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**
R-22/mineral oil/ 4A molecular sieve	60		1,616																155		
	120		2,811																179		
	238	1	3,194																280		
	315		3,018																219		
R-32/mixed esters/ 4A molecular Sieve	60		323							565	2,595		104		1,587			6	149		
	120		1,093							629	2,119		115		1,707				144		1
	238	8	2,589							433	657		8		1,195				126		
	315	17	4,143							501	1,396		85		716				163		
R-134a/mixed esters/ 4 A molecular sieve	60		15							28	3,838		134		1,469				170		1
	120		18							55	3,572				2,529		137		166		1
	238		8							62	4,545		129		1,293				178		
	315		29							55	4,755		164		2,475				208		
R-22/mineral oil/ 3A molecular sieve	60	1	2,325																337		
	120		3,418							8									307		
	238	1	4,204																326		
	315		4,741																322		
R-32/mixed esters/ 3A molecular sieve	60	6	1,118							412	663		155		156				279		
	120	5	987							495	1,119				102		166		300		
	238	14	961							427	1,033		141		248				293		
	315	12	827							468	712		133		69				346		
R-134a/mixed esters/ 3A molecular sieve	60		11							192	1,504		165		332				227		
	120		11							284	1,726				336		176		248		
	238		1							290	2,557		187		428			5	237		
	315		19		303					328	1,898		174		383				244		

Table D.2 (continued) : Ion Chromatography Results, Aging Temperature = 80°C

Refrigerant/ Lubricant/ Desiccant	Aging Time	Formate		Acetate		Propanoate		Butyrate		Pentanoate		Hexanoate		Heptanoate		2Ethylhexanoate		Sulfate		Number of Unknowns	
		Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic
R-22/mineral oil/	60	6	2,880																		
Scale Alumina	120	14	2,976																		
	238	7	2,941																		
	315	11	3,147																	1	
R-32/mixed esters/	60	5	459		136					919	9,459										
Scale Alumina	120	13	626		119					1,694	10,550										
	182	26	928		76					1,396	10,193										
	239	69	1,109		33					2,256	10,107										
R-134a/mixed esters/	60		49	5	135					648	9,149										
Scale Alumina	120		93		169					995	11,167										
	182		149						728	515	11,580										
	239		169	7	113					731	9,885										
R-22/mineral oil/	60	3	2,172		103																
Trihydrate Alumina	120	1	2,263																		
	238	1	2,466																		
	315	2	2,722																		
R-32/mixed esters/	60	7	442	6	926					634	8,953							7		1	
Trihydrate Alumina	120	22	388		264					716	7,718										
	238	27	468		263					1,301	8,370										
	315	9	312		89					1,581	10,555									1	
R-134a/mixed esters/	60	1	68		505					265	9,290										
Trihydrate Alumina	120	2	82	8	632					293	9,445										
	238		118		797					449	11,823										
	315	2	102		390					902	9,591									1	

Appendix E

Aging Temperature of 60°C

Table E.1: Summary Test Results, Aging Temperature = 60°C

Refrigerant/Lubricant/ Desiccant	Aging Time (days)	Liquid Color (2-8)	Desiccant Color (0-5)	Copper Plating (0-5)	Solids Formation (0-3)	Steel Corrosion (0-3)	Copper Corrosion (0-3)	Cl ion in liquid (ppm)	Fl ion in liquid (ppm)	Cl ion in desiccant (ppm)	Fl ion in desiccant (ppm)	Total Acid Number (mg KOH/g)	Organic Acid in liquid (ppm)	Organic Acid in desiccant (ppm)
R-22/mineral oil/	70	3.0	2	0	0	0	0	2	1	296	807	0.03	24	1,646
4A molecular sieve	165	3.0	2	0	0	0	0	1	1	1,425	966	0.03	1	1,854
	223	3.0	3	0	0	0	0	1	0	1,167	962	0.01	0	2,336
	300	3.0	3	0	0	0	0	1	1	1,678	1,057	0.01	0	2,835
R-32/mixed esters/	70	3.5	1	0	0	0	0	2	1	6	129	0.12	162	3,212
4A molecular sieve	165	3.0	1	0	0	0	0	2	0	56	260	0.12	329	4,026
	223	3.0	2	0	0	0	2	1	2	55	336	0.20	573	7,118
	300	3.5	2	0	0	1	2	1	0	23	947	0.23	660	5,568
R-134a/mixed esters/	70	3.5	1	0	0	0	0	1	1	20	102	0.03	8	3,830
4A molecular sieve	165	3.0	1	0	0	0	2	1	0	25	95	0.05	8	4,436
	223	3.0	1	0	0	0	2	2	1	25	110	0.04	152	4,510
	300	3.5	1	0	0	1	2	0	1	12	84	0.03	105	5,125
R-22/mineral oil/	70	3.5	3	0	0	0	0	1	1	1,332	301	0.03	19	1,319
3A molecular sieve	165	3.5	3	0	0	0	0	1	1	2,524	380	0.02	1	2,119
	223	3.5	3	0	0	0	0	1	1	3,822	822	0.02	0	2,568
	300	3.5	3	0	0	0	0	0	0	5,396	994	0.02	0	3,275
R-32/mixed esters/	70	3.0	2	0	0	0	0	2	2	7	648	0.15	223	2,221
3A molecular sieve	165	3.0	2	0	0	0	0	0	0	7	738	0.12	238	2,791
	223	3.0	2	0	0	0	0	1	1	8	969	0.16	421	2,144
	300	3.0	2	1	0	0	2	0	0	8	1,046	0.13	258	2,046
R-134a/mixed esters/	70	3.0	1	0	0	0	0	2	1	6	12	0.05	54	1,333
3A molecular sieve	165	3.0	1	0	0	0	0	1	0	5	20	0.03	90	1,892
	223	3.0	1	0	0	0	2	1	1	6	12	0.06	177	1,814
	300	3.0	1	0	0	1	2	1	0	5	19	0.06	202	2,175

Table E.1 (continued): Summary Test Results, Aging Temperature = 60°C														
Refrigerant/Lubricant/ Desiccant	**Aging Time (days)**	**Liquid Color (2-8)**	**Desiccant Color (0-5)**	**Copper Plating (0-5)**	**Solids Formation (0-3)**	**Steel Corrosion (0-3)**	**Copper Corrosion (0-3)**	**Cl ion in liquid (ppm)**	**Fl ion in liquid (ppm)**	**Cl ion in desiccant (ppm)**	**Fl ion in desiccant (ppm)**	**Total Acid Number (mg KOH/g)**	**Organic Acid in liquid (ppm)**	**Organic Acid in desiccant (ppm)**
R-22/mineral oil/	70	3.0	2	0	1	0	0	9	3	2,699	270	0.10	35	2,101
Scale Alumina	165	3.0	2	0	0	0	0	31	8	2,810	368	0.05	48	2,029
	223	3.0	2	0	1	0	0	6	3	3,160	609	0.06	8	2,178
	300	3.0	2	0	1	1	0	12	4	3,062	1,393	0.03	14	2,052
R-32/mixed esters/	70	3.5	1	0	0	0	0	3	3	14	5	0.23	417	11,128
Scale Alumina	165	2.5	1	0	0	0	0	2	1	23	4	0.17	696	11,971
	223	2.5	1	0	0	0	0	2	2	23	25	0.25	1030	13,073
	300	2.5	1	1	0	1	0	9	11	23	21	0.35	932	12,103
R-134a/mixed esters/	70	2.5	1	0	1	0	0	2	2	14	1	0.23	312	10,927
Scale Alumina	165	2.5	1	0	1	0	0	0	1	13	1	0.04	599	10,647
	223	2.5	1	0	0	0	0	2	1	11	2	0.15	728	11,596
	300	2.5	1	1	0	1	0	2	1	12	1	0.20	521	11,401
R-22/mineral oil/	70	3.0	2	0	0	0	0	2	1	2,922	205	0.02	5	1,580
Trihydrate Alumina	165	2.5	2	0	0	0	0	2	1	3,237	398	0.02	3	1,801
	223	2.5	2	0	0	0	0	1	1	3,705	549	0.01	2	2,124
	300	2.5	2	1	0	0	1	3	1	4,102	637	0.01	2	2,232
R-32/mixed esters/	70	3.5	1	0	1	0	0	3	2	23	5	0.11	169	9,958
Trihydrate Alumina	165	2.5	1	0	0	0	0	1	1	33	10	0.08	348	10,140
	223	2.5	1	0	0	0	0	0	1	22	2	0.13	582	8,091
	300	3.5	1	0	0	0	2	1	1	24	14	0.24	622	9,867
R-134a/mixed esters/	70	3.0	1	0	0	0	0	3	2	36	2	0.07	160	10,580
Trihydrate Alumina	165	3.0	1	0	0	0	0	1	1	24	4	0.06	183	14,998
	223	2.5	1	0	0	0	0	1	1	19	1	0.11	322	15,913
	300	3.5	1	0	0	0	2	0	0	24	1	0.15	251	13,212

Table E.2 : Ion Chromatography Results, Aging Temperature = 60°C

Refrigerant/ Lubricant/ Desiccant	Aging Time	Formate		Acetate		Propanoate		Butyrate		Pentanoate		Hexanoate		Heptanoate		2Ethylhexanoate		Sulfate		Number of Unknowns	
		Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic
R-22/mineral oil/	70	4	1,646							20								2	159		
4A molecular sieve	165	1	1,854																150		
	223		2,336																164		
	300		2,835																157	1	
R-32/mixed esters/	70		17						248	162	2,727		102		118				136		1
4A molecular Sieve	165							4	774	325	2,657		112				483	7	142		1
	223	1	786							572	5,002		26		1,304				137		
	300		1,116					5		655	3,156		66		1,230			5	113		
R-134a/mixed esters/	70								30	8	2,306		104		1,390				142		1
4A molecular sieve	165								44	8	2,852		100		1,440				155		1
	223		7							152	3,281		147		1,075				143		
	300		11							105	4,056		80		978			10	154	1	1
R-22/mineral oil/	70	1	1,138							18	105				76				260		
3A molecular sieve	165	1	1,403												716				180		
	223		2,568																384		
	300		3,275																308		
R-32/mixed esters/	70	3	1,030							220	893		129		169			3	241		
3A molecular sieve	165		1,525					17		221	1,164		102						247		1
	223	8	1,344							413	641		125		34				252		
	300	5	1,280							253	584		107		75				268		
R-134a/mixed esters/	70								24	54	1,017		125		167			8	218		
3 A molecular sieve	165		7							90	1,337		158		390				260		
	223		11							177	1,413		142		248				215		
	300		13							202	1,517		126		519				251		

Table E.2 (continued) : Ion Chromatography Results, Aging Temperature = 60°C																					
Refrigerant/ Lubricant/ Desiccant	Aging Time	Formate		Acetate		Propanoate		Butyrate		Pentanoate		Hexanoate		Heptanoate		2Ethylhexanoate		Sulfate		Number of Unknowns	
		Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic
R-22/mineral oil/ Scale Alumina	70	12	2,101							23											
	165	48	2,029																		
	223	8	2,178																		
	300	14	2,052																		
R-32/mixed esters/ Scale Alumina	70	3	196	4	165					410	10,767										
	165		385		143					696	11,443										
	223	7	641		113					1,023	12,319										
	300	18	807		85					914	11,211										
R-134a/mixed esters/ Scale Alumina	70		45		179					312	10,703										
	165		112		149					599	10,386										
	223		120		169					728	11,307										
	300	4	158	6	168					511	11,075										
R-22/mineral oil/ Trihydrate Alumina	70		1,492		88			5													
	165	3	1,801																		
	223	2	2,124																		
	300	2	2,232																		
R-32/mixed esters/ Trihydrate Alumina	70	1	289		666					168	9,003										
	165		413		478			12		336	9,249										
	223	2	356		643					580	7,092										
	300	8	469		519					614	8,879										
R-134a/mixed esters/ Trihydrate Alumina	70		41		837					160	9,702										
	165	1	190		821					182	13,987										
	223	4	172		855					318	14,886										
	300		118		1,114					251	11,980										

Appendix F

Aging Temperature of 40°C

Table F.1: Summary Test Results, Aging Temperature = 40°C														
Refrigerant/Lubricant/ Desiccant	**Aging Time (days)**	**Liquid Color (2-8)**	**Desiccant Color (0-5)**	**Copper Plating (0-5)**	**Solids Formation (0-3)**	**Steel Corrosion (0-3)**	**Copper Corrosion (0-3)**	**Cl ion in Liquid (ppm)**	**Fl ion in liquid (ppm)**	**Cl ion in Desiccant (ppm)**	**Fl ion in Desiccant (ppm)**	**Total Acid Number (mg KOH/g)**	**Organic Acid in Liquid (ppm)**	**Organic Acid in Desiccant (ppm)**
R-22/minerall oil/	91	2.5	2	0	0	0	0	1	1	91	452	0.01	0	1,655
4A molecular sieve	179	3.0	2	0	0	0	0	0	2	217	568	0.01	0	1,050
	271	3.0	2	0	0	0	0	1	2	248	655	0.00	21	1,342
	362	3.0	2	0	0	0	0	1	0	357	740	0.02	40	2,724
R-32/mixed esters/	91	3.0	1	0	0	0	0	1	1	23	105	0.02	20	3,746
4A molecular sieve	179	3.0	1	0	0	0	0	3	2	33	128	0.04	51	3,906
	271	3.0	1	0	0	0	0	1	2	20	266	0.02	100	3,630
	362	3.0	1	1	0	0	0	2	0	21	324	0.04	69	4,029
R-134a/mixed esters/	91	3.0	1	0	0	0	0	1	1	20	95	0.01	0	3,418
4A molecular sieve	179	3.0	1	0	0	0	0	2	2	37	95	0.06	0	3,462
	271	3.0	1	0	0	0	0	0	1	19	140	0.00	0	3,122
	362	3.0	1	0	0	0	0	2	0	28	99	0.02	0	4,084
R-22/mineral oil/	91	3.0	3	0	0	0	0	1	1	81	79	0.01	1	311
3A molecular sieve	179	3.0	3	0	0	0	0	0	1	165	152	0.02	0	601
	271	3.0	3	0	0	0	0	1	1	623	39	0.02	0	888
	362	3.0	3	1	0	0	0	1	0	445	328	0.04	0	894
R-32/mixed esters/	91	2.5	2	0	0	0	0	2	1	7	138	0.01	35	1,048
3A molecular sieve	179	2.5	2	0	0	0	1	0	2	6	282	0.03	69	1,274
	271	2.5	2	0	0	0	1	1	2	5	344	0.01	88	1,511
	362	3.0	2	0	0	1	0	2	0	5	476	0.06	94	1,432
R-134a/mixed esters/	91	2.5	1	0	0	0	0	1	0	10	18	0.01	0	1,119
3 A molecular sieve	179	2.5	1	0	0	0	0	0	2	7	13	0.02	0	1,202
	271	2.5	1	0	0	0	0	2	1	8	19	0.00	12	1,254
	362	2.5	1	0	0	0	0	1	0	5	14	0.02	13	1,313

Table F.1 (continued): Summary Test Results, Aging Temperature = 40°C														
Refrigerant/Lubricant/ Desiccant	**Aging Time (days)**	**Liquid Color (2-8)**	**Desiccant Color (0-5)**	**Copper Plating (0-5)**	**Solids Formation (0-3)**	**Steel Corrosion (0-3)**	**Copper Corrosion (0-3)**	**Cl ion in Liquid (ppm)**	**Fl ion in Liquid (ppm)**	**Cl ion in Desiccant (ppm)**	**Fl ion in Desiccant (ppm)**	**Total Acid Number (mg KOH/g)**	**Organic Acid in Liquid (ppm)**	**Organic Acid in Desiccant (ppm)**
R-22/mineral oil/	91	2.5	2	0	0	0	0	15	3	1,704	12	0.01	20	1,488
Scale Alumina	179	2.5	2	0	0	0	0	15	6	1,992	33	0.03	23	1,578
	271	2.5	2	0	0	0	0	7	4	2 ,304	28	0.01	17	1,453
	362	2.5	2	0	1	0	0	12	3	2,223	60	0.04	18	1,476
R-32/mixed esters/	91	2.5	1	0	1	0	0	2	1	19	3	0.07	134	14,117
Scale Alumina	179	2.5	1	0	0	0	0	0	2	21	3	0.07	295	11,718
	271	2.5	1	0	0	0	0	1	2	14	13	0.01	156	12,073
	362	2.5	1	0	0	0	0	3	1	19	10	0.03	402	13,058
R-134a/mixed esters/	91	2.5	1	0	0	0	0	4	1	15	2	0.02	61	12,268
Scale Alumina	179	2.5	1	0	0	0	0	0	6	14	2	0.06	322	11,534
	271	2.5	1	0	0	0	0	1	2	12	1	0.00	70	14,795
	362	2.5	1	0	0	0	0	3	0	10	2	0.03	79	11,799
R-22/mineral oil/	91	2.5	2	0	0	0	0	4	1	2,533	9	0.00	7	2,317
Trihydrate Alumina	179	2.5	2	0	0	0	1	1	2	2,616	38	0.02	0	2,311
	271	2.5	2	0	0	0	0	2	2	2,368	48	0.00	2	1,905
	362	2.5	2	0	0	0	0	2	1	3,480	163	0.01	1	2,185
R-32/mixed esters/	91	2.5	1	0	0	0	0	1	1	23	4	0.01	19	9,922
Trihydrate Alumina	179	2.5	1	0	0	0	0	0	3	27	3	0.04	55	9,623
	271	2.5	1	0	0	0	0	1	2	23	4	0.00	72	10,373
	362	3.0	1	0	0	0	0	1	1	30	6	0.03	53	10,871
R-134a/mixed esters/	91	2.5	1	0	0	0	0	2	1	30	3	0.01	0	12,643
Trihydrate Alumina	179	2.5	1	0	0	0	0	0	2	22	3	0.04	15	11,728
	271	3.0	1	0	0	0	0	2	3	21	1	0.00	76	13,359
	362	3.0	1	0	0	0	0	2	0	19	3	0.02	50	11,146

Table F.2 : Ion Chromatography Results, Aging Temperature = 40°C

Refrigerant/ Lubricant/ Desiccant	Aging Time	Formate		Acetate		Propanoate		Butyrate		Pentanoate		Hexanoate		Heptanoate		2Ethylhexanoate		Sulfate		Number of Unknowns	
		Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic	Liq	Desic
R-22/mineral oil/	91		759												896				149		
4A molecular sieve	179		1,050															9	142		
	271		1,342							21								2	150		
	362	1	1,551	6						33					1,173				157		
R-32/mixed esters/	91		15							20	2,301		110		1,320				165		1
4A molecular sieve	179		23							51	2,377		107		1,399				131		
	271								108	10	3,382		140						195		1
	362		35							58	2,520		113	11	1,361				146		
R-134a/mixed esters/	91		8								2,110		110		1,190				174		
4A molecular sieve	179		5								1,754		93		1,610			7	140		
	271								35		2,234		74		779				125		
	362		13								2,767		91		1,213				169		1
R-22/mineral oil/	91	1	212								18				81				271		
3A molecular sieve	179		401												200				256		
	271		509												379				58		
	362		689												205				254		
R-32/mixed esters/	91		39							35	681		127		201			0	214		
3A molecular sieve	179		108							69	816		112		238				217		
	271								522	88	885		104						236		
	362		165							94	906		106		255				228		
R-134a/mixed esters/	91		7								554		143		415			0	258		
3A molecular sieve	179		5								730		102		365			6	201		
	271		22		6					12	868		62		296				209		
	362		4								862		126	13	321				259		

Table F.2 (continued): Ion Chromatography Results, Aging Temperature = 40°C																					
Refrigerant/ Lubricant Desiccant	**Aging Time**	**Formate**		**Acetate**		**Propanoate**		**Butyrate**		**Pentanoate**		**Hexanoate**		**Heptanoate**		**2Ethylhexanoate**		**Sulfate**		**Number of Unknowns**	
		Liq	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**	**Liq**	**Desic**
R-22/mineral oil/ Scale Alumina	91	20	1,426		62																
	179	23	1,534		44																
	271	9	1,411		42					8											
	362	18	1,431		45																
R-32/mixed esters/ Scale Alumina	91		180		193					134	13,744										
	179		227		166					295	11,325										
	271				116				1,13	156	10,826										
	362	4	345		190					383	12,523			15							
R-134a/mixed esters/ Scale Alumina	91				183				25	61	12,060										
	179		119		164					322	11,251										
	271		114		197					70	14,484										
	362		137		213					59	11,449			20							
R-22/mineral oil/ Trihydrate Alumina	91	4	1,623	3	694																
	179		1,694				617														
	271	2	1,574		331																
	362	1	1,932		253																
R-32/mixed esters/ Trihydrate Alumina	91		96				997			19	8,829										
	179		205		744					55	8,674										
	271		229		833					72	9,311										
	362		272		737					53	9,862										
R-134a/mixed esters/ Trihydrate Alumina	91		54		1,294						11,295										
	179		121				775			15	10,832										
	271		54		895					76	12,410									1	
	362	1	134		804					49	10,208										