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J. P. Lavelle
National Refrigerants

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James P. Lavelle
National Refrigerants, Inc.
11401 Roosevelt Blvd.
Philadelphia, PA 19154

(215) 698-6620 phone
(215) 698-7466 fax
info@refrigerants.com e-mail

ABSTRACT

Oil return in a refrigeration system usually depends on both physical factors (system design) and chemical factors (mixing of the refrigerant and lubricant). Oil which is blown out of the compressor will be carried through the system by the refrigerant, then returned to the compressor through a sloped suction line, for example. The chemical miscibility of the refrigerant-lubricant pair is a good indicator of how well the refrigerant will help move the oil around the system.

Miscibility is typically studied by mixing known concentrations of refrigerant and oil and lowering the temperature until a phase separation is observed. The results are used to plot a curve of temperature versus concentration which indicates how cold a mixture can go before causing separation of an oil-rich phase. This curve will also indicate how much refrigerant is still mixed with the oil-rich phase (solubility of refrigerant in oil). Knowing if a separate phase will form, and knowing how much refrigerant is contained to dilute an oil-rich phase, will help determine which types of lubricants are acceptable for use with a given refrigerant.

This paper reports the results of oil miscibility testing for several R-12 alternatives (R-134a, R-401A, R-406A, R-409A, and R-416A $_{\text{proposed AHRAE designation}}$) with mineral oil, alkylbenzene, and polyol ester lubricants. Miscibility with pure mineral oil was checked, several products were tested in "retrofit situations" with 50% mineral oil/50% alkylbenzene and others with 5% mineral oil in polyol ester. The results are correlated with miscibility test results for the individual components.

INTRODUCTION

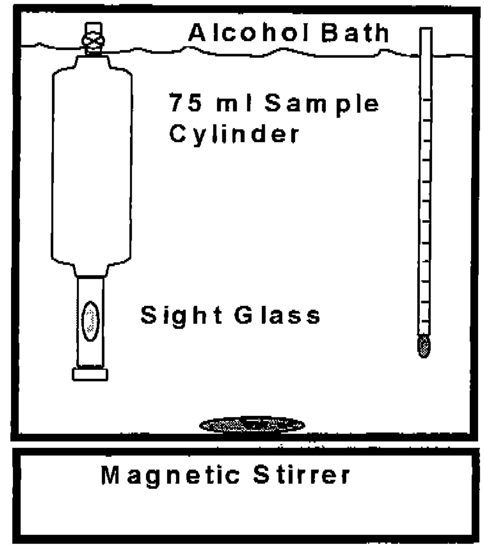
Two basic factors affect oil return in most refrigeration systems: physical design and mixing of refrigerant and oil. In a poorly designed system there may be some dead volume in the piping which might hold circulating lubricant away from the flowing refrigerant, or if the compressor is located above the evaporator a poorly designed suction line could leave oil trapped in the lower parts of the system. For the most part a well designed system uses refrigerant motion or gravity to get oil back to the compressor. For example, suction riser piping is sized to create enough vapor velocity to push oil back up to the compressor. (1)

Liquid R-12 mixes completely with all types of refrigeration oils (except for the separation of wax at very low temperatures). In an R-12 system, any mineral oil which escapes the compressor would be carried through the system by the liquid refrigerant to the point where it has all evaporated (at this point mechanical oil return takes over). This is not true of the R-12 alternatives.

R-134a and the blends intended for R-12 retrofitting have different abilities to mix with mineral oil and/or alkylbenzene. By studying oil-refrigerant miscibility, that is the temperature/concentration relationship where oil and refrigerant stay mixed or separate, we can predict whether an oil-rich phase will form at typical system temperatures for a given refrigerant/oil pair. Miscibility curves define this temperature boundary between miscible and immiscible conditions.

If an oil-rich layer forms it may stick to the evaporator walls or hold up in pockets where refrigerant flow will not carry it along. (This also depends on how much the oil phase is thinned by dissolved refrigerant.) As long as the refrigerant stays cold this oil may stay out in the system and not return to the compressor. When the liquid refrigerant stays mixed with the lubricant at all expected system temperatures, however, there should be no difference between the way an R-12 alternative returns oil to the compressor compared to R-12.

EXPERIMENTAL PROCEDURE



Apparatus

75 ml steel sample cylinders with a valve on one end and a sight glass on the other.

Alcohol bath on a magnetic stirrer (insulated) .

Dry ice.

Low temperature thermometer.

Refrigerant charging cylinder.

Procedure

- Fill a refrigerant charging cylinder with liquid refrigerant (important for zeotropic blends).
- Weigh the desired amount of oil into the cylinders, close and evacuate.
- Add the approximate desired volume of refrigerant. Disconnect and weigh exact amount of refrigerant added.
- *Mix well.*
- Place each sample cylinder in the alcohol bath so the sight glass is visible.
- Cool bath temperature by adding crushed dry ice directly to the alcohol bath. Initially the bath can be cooled quickly (several degrees per minute).
- Watch for sight glass to turn cloudy, indicating separation of an oil-rich phase. Remove sample cylinder, shake contents until cleared, then put back in bath to check separation again.
- Stabilize bath temperature and/or allow bath to warm until the sample no longer turns cloudy. Slowly lower bath temperature again until sample clouds. This process should take about 10 minutes per degree to insure that the sample comes to bath temperature.
- Record temperature, oil weight, and refrigerant weight (calculate percent oil in refrigerant).

Sample Matrix

Refrigeration systems typically circulate from 2% to 5% oil with the refrigerant. The low concentration side of the miscibility curve was drawn from running samples at about 2%, 3.5%, 5%, 10%, and 20% by weight oil in refrigerant. At lease two high oil concentration samples, which gave separation temperatures in the 40°F to -30°F range, were measured. These were typically above 50% oil in refrigerant.

Each R-12 alternative was run with 100% mineral oil and with 50% mineral oil/50% alkylbenzene. R-134a was tested with POE and residual mineral oil levels of 5% and 1%. These samples represent "recommended" oil change levels when retrofitting R-12 equipment.

Experimental Errors

- Accuracy of weighing the samples produced a maximum error of +/- 0.065 in the calculated value of weight percent oil.
- Accuracy of temperature measurement, considering thermometer accuracy and procedure, is +/- 1.5°F.

RESULTS

Figures 1, 2, and 3 show miscibility curves for the various samples. The region above each curve represents complete mixing of the refrigerant and oil. The region below each curve indicates two phases will be present at that temperature and concentration. The left side of the curves show separation behavior at low oil concentrations, which is representative of evaporator conditions, and the right side of the curve shows oil-rich concentrations and the relative amount of refrigerant dissolved in the oil.

R-12 Alternatives with Mineral Oil

Figure 1 represents the miscibility of each refrigerant with mineral oil. R-401A showed phase separation at the highest temperatures, with a maximum separation temperature above 80°F. The next best miscible product was R-409A, which showed a maximum separation temperature at 23°F. R-406A showed very good miscibility, indicated by a maximum separation temperature of -36°F. Each maximum occurred near a concentration of 20% oil in refrigerant. The products which show lower separation temperatures also show more refrigerant dilution at in the oil-rich phase, which overall indicates better chances for oil return.

R-134a and R-416A showed no sign of mixing with the mineral oil at temperatures up to 80°F. Even after vigorous shaking there was only a slight sign of cloudiness which soon cleared into two distinct liquid layers. Yudin et. al. (2) concluded that although R-134a and R-416A mixtures with mineral oil formed two liquid phases, there was dissolved refrigerant in the oil-rich phase which lowered the viscosity enough to promote acceptable oil return. Test results showed that R-416A oil-rich phases were diluted more than straight 134a, and also more than other blends containing 134a.

Overall the mineral oil test results correlate with results of single component refrigerant testing with mineral oil performed by Pate, et. al. (3). In that study miscibility data were obtained for the components which make up the blends tested here, namely R-142b, R-22, R-124, R-152a, and R-134a. (Hydrocarbons R-600 and R-600a were not tested by Pate, however they are known to mix completely with mineral oil at all test temperatures.) Table 1 shows the relationship between the observed miscibility of the blends compared to the miscibility of the individual components.

Table 1: Relative Degree of Miscibility for R-12 Alternative Blends with Mineral Oil Compared to Blend Components (table shows blend percentages)

		Individual Components: Decreasing Miscibility →							
		600	600a	12	142b	22	124	152a	134a
	R-406A		4		41	55			
Alternatives:	R-409A				15	60	25		
Decreasing	R-401A					53	34	13	
Miscibility	R-416A	2					38		58
↓	R-134a								100

Relative miscibility of blends can be determined from examining the individual components and reviewing the relative miscibility of those components. In general it can be stated that the R-12 alternative blends based on R-142b are more miscible with mineral oil than those based on R-152 (R-22 common to both), and both are more miscible than those based on 134a. The addition of hydrocarbons will also improve mineral oil miscibility, however since they are typically added in small amounts, in order to avoid flammability concerns, the miscibility over the base fluorocarbon is only improved a little.

Low Oil Concentrations: Evaporator Conditions

Figure 2 shows the same mineral oil miscibility data for the range 0 to 20 weight percent oil in refrigerant. The dashed box indicates the range from 1 to 5 weight percent oil in refrigerant, which is typical of the amount of oil circulating with the refrigerant in a running refrigeration system. This graph illustrates how miscibility data can be used to anticipate oil separation problems based on expected system evaporator temperatures and oil circulation rates.

In medium temperature refrigeration systems, or systems which the evaporator is maintained at about 20°F to 30°F, it is possible for a system containing R-401A to run at conditions where the temperature and oil concentration will allow two phases to form. The physical design of the system must then be considered to determine if the separate oil-rich phase will be returned to the compressor or stranded in the evaporator. R-409A would not be expected to form a separate oil phase until lower temperatures are reached, about -10°F to -30°F. R-406A is not expected to form a separate oil phase at any practical R-12 operating conditions. R-134a and R-416A will always form oil-rich phases with mineral oil, and therefore should not be used without replacement of the oil.

Retrofit Situations: 50% Alkylbenzene in Mineral Oil

Recognizing that the reduced mineral oil miscibility characteristics of alternatives, compared to R-12, would affect oil return in a system, early development by refrigerant manufacturers and OEMs focused on changing some of the mineral oil to alkylbenzene, which is more miscible with HCFCs. The results shown in Figure 3 indicate that the addition of alkylbenzene does improve miscibility for all of the R-12 alternative blends.

The value 50% became the industry standard for retrofits, although this is not a magic number. Replacing more than 50% of the mineral oil with alkylbenzene will lower the phase separation temperature even more. In general we could say that "more alkylbenzene is better," however once a certain level of miscibility is obtained, lowering the phase separation temperature more will not necessarily improve oil return any more in a given system. For example, replacing mineral oil in an R-409A system operating with a 30°F evaporator will not change the chemical situation - the refrigerant will mix with either mineral oil or alkyl benzene at this condition. At colder temperatures (-20°F) it would be necessary to change some mineral oil for both 401A and 409A, however Figure 3 indicates that a 50% change may not be enough for R-401A.

Addition of alkylbenzene to mineral oil with R-416A did show a slight improvement in miscibility, however this blend still does not mix well enough with these lubricants at practical system temperatures. R-134a and R-416A will require the use of polyol ester lubricants to insure oil return.

Retrofit Situations: Residual Mineral Oil in Polyol Ester

When retrofitting with an HFC it is necessary to flush as much mineral oil out of the system as possible and refill with polyol ester. The amount of residual mineral oil left in the system can still have an impact on system operation. Tests with pure 134a and POE with 5% mineral oil showed phase separation at 75°F for 20 wt% oil in refrigerant, and the separation temperature was 39°F for 2.8 wt% oil in refrigerant. When the amount of residual mineral oil was reduced to 1% in POE, the separation temperature was 19.5°F for 20 wt% oil in refrigerant.

The oil which separated from the mixture was almost all mineral oil, which means the majority of the oil charge (95 to 99% POE) was still mixed with the liquid refrigerant. It is not likely that the system would suffer from oil return problems in this situation. The mineral oil which separates, however, could still coat evaporator tube surfaces and reduce heat transfer.

ADDITIONAL TESTING

At the time of preparation of this paper testing was not complete for these refrigerants with 100% alkylbenzene oil, mixtures of 50% mineral oil with 50% POE, and only some data were collected for residual mineral oil in POE. In addition, this study will be duplicated for R-502 and its relevant alternative blends.

CONCLUSIONS

1. In retrofit situations the physical or design factors which affect oil return often can not be changed or improved. Chemical miscibility, or separation of oil from refrigerant, is therefore the most important factor for judging potential oil return problems in a system.
2. Different R-12 alternatives have different miscibility profiles with mineral oil. The miscibility of the blend can be correlated to the miscibility of the individual components, and general comparisons can be made between blends by reviewing their components.
3. Oil return problems can be predicted by checking system conditions against the temperature/concentration miscibility curve for the refrigerant. Products with oil separation temperatures below expected system conditions should not behave differently from pre-retrofit oil return performance.
4. Replacing mineral oil with alkylbenzene will improve oil miscibility with R-12 alternatives.
5. The industry standard recommendation for replacing 50% mineral oil may be too conservative for blends which show good mineral oil miscibility. If complete mixing of mineral oil and refrigerant is already achieved at the expected temperatures, replacing mineral oil with alkylbenzene does not further improve mixing.
6. When retrofitting from R-12 to an HFC refrigerant or HFC-based blend the residual mineral oil in POE will separate from the refrigerant. Residual mineral oil levels should be as low as possible to minimize the impact on system operation.

REFERENCES

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(2) Yudin, Boris, Mikhail Boiarski, Colin Munday, "Influence of HCFC and Hydrocarbon Components in Blend Refrigerants on Oil-Refrigerant Miscibility," Proceedings of the International Conference on Ozone Protection Technologies, Baltimore MD, Nov. 1997, pages 106-114.

(3) Pate, Michael, Steven Zoz, Lyle Berkenbosch, "Miscibility of Lubricants with Refrigerants," ARTI MCLR Project Number 650-50300, Final Report 1993, ARTI Refrigerant Database #RDB4502.

Figure 1: R-12 Alternatives
Miscibility with Mineral Oil (150 SUS)

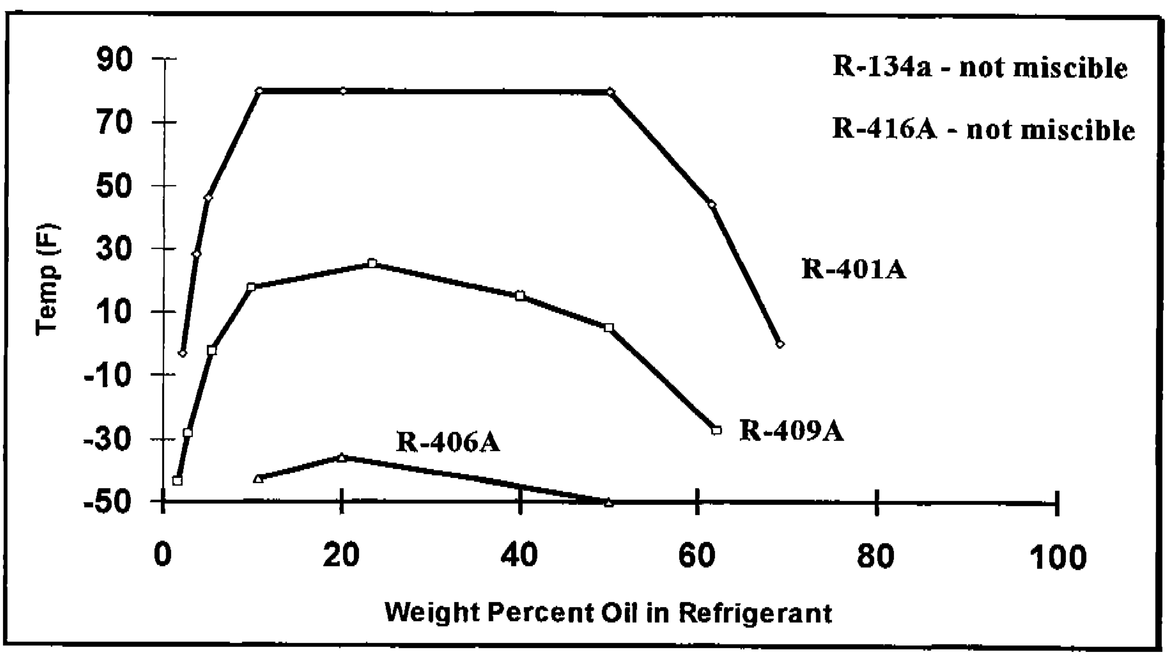

Figure 2: Miscibility at Low Oil Concentration (Evaporator Condition)

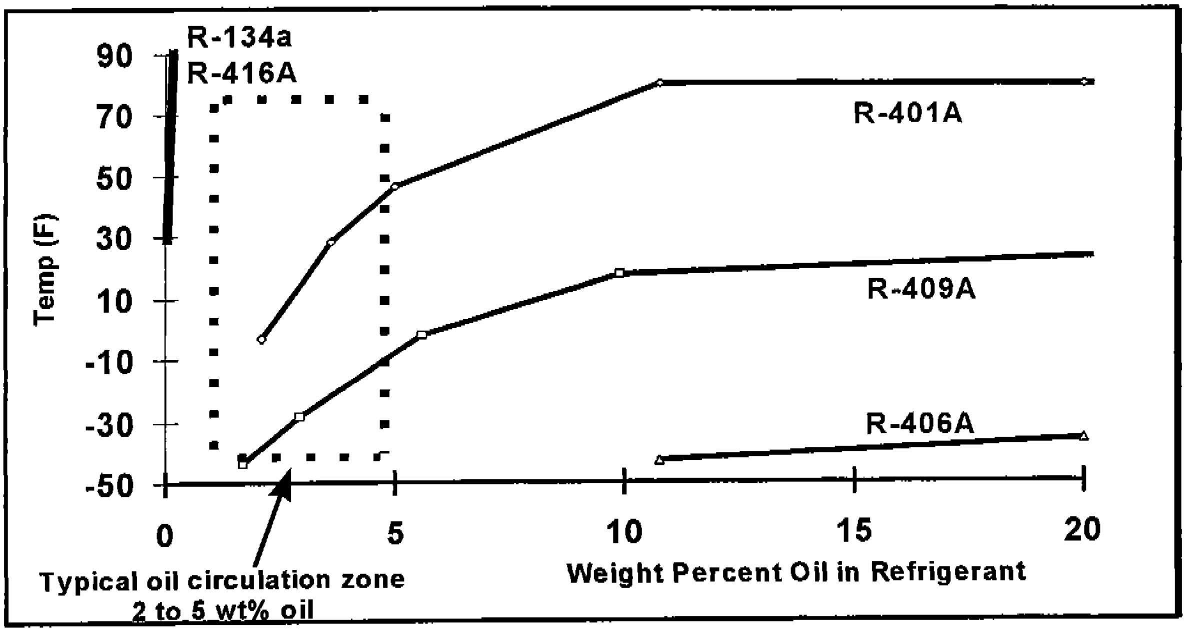

Figure 3: Effect of 50% Alkylbenzene in Mineral Oil