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# Foaming Characteristics Of HFC Refrigerants

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The air-conditioning and refrigeration industry is moving to HFC refrigerants due to graduated phaseout of CFC and HCFC refrigerants and concerns for the environment. The change in refrigerants has prompted the switch from mineral oil and alkylbenzene lubricants to polyolester-based lubricants. This change has created a need for lubricant, refrigerant and compressor manufacturers to understand the absorption, desorption and foaming properties of alternative refrigerant/lubricant mixtures, and the mechanisms that affect these properties. Absorption, desorption and

foaming characteristics of refrigerant/lubricant mixtures strongly affect sound absorption in the compressor and heat transfer throughout the system.

A detailed study was conducted at the University of Florida to experimentally determine the absorption and desorption rates of HFC and blended refrigerants in polyolester lubricant and to define the characteristics of the foam formed when the refrigerant leaves the refrigerant/lubricant mixture after being exposed to a pressure drop.

The alternative refrigerants examined include HFC-32 (R-32), R-125, R-134a, and R-143a. Also examined were blended refrigerants R-404A, R-407C, and R-410A. These refrigerants were tested with two ISO 68 polyolesters (Witco SL68 and ICI RL68H). To establish baseline results, refrigerants R-12 and R-22 were tested with mineral oils ISO32 (3GS) and ISO 68 (4GS).

## Lubricant Properties

Initially, properties of the pure lubricants were measured at room temperature

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to establish baselines for possible comparison with the refrigerant/lubricant pairs. The properties that were measured include density, viscosity and static surface tension. Viscosities of the four lubricants were measured using a cone-and-plate viscometer equipped with a temperature bath. Equilibrium surface tension measurements were taken using the Wilhelmy plate method. Theoretically, the lower the equilibrium surface tension, the less work that is needed to expand that surface (i.e. from aeration) and thus, form foam bubbles from that liquid.

Experimentally, it was found that the mineral oils have a density of approximately 0.8 g/ml while the two polyolesters (POEs) have densities closer to

Dynamic Surface Tension <i>Reduction</i>
R-12/3GS ~ R-22/3GS
R-12/4GS ~ R-22/4GS
R-12/4GS ~ R-134a/POE
R-22/4GS > R-407C/POE
R-22/4GS > R-410A/POE
Foamability
R-12/3GS ~ R-22/3GS
R-12/4GS ~ R-22/4GS
R-12/4GS > R-134a/POE
R-22/4GS >> R-407C/POE
R-22/4GS >> R-410A/POE
Foam Stability
R-12/3GS ~ R-22/3GS
R-12/4GS < R-22/4GS
R-12/4GS > R-134a/POE
R-22/4GS >> R-407C/POE
R-22/4GS >> R-410A/POE

**Table 1: Comparisons of interest. (H)CFCs with mineral oils and HFCs with POEs.**

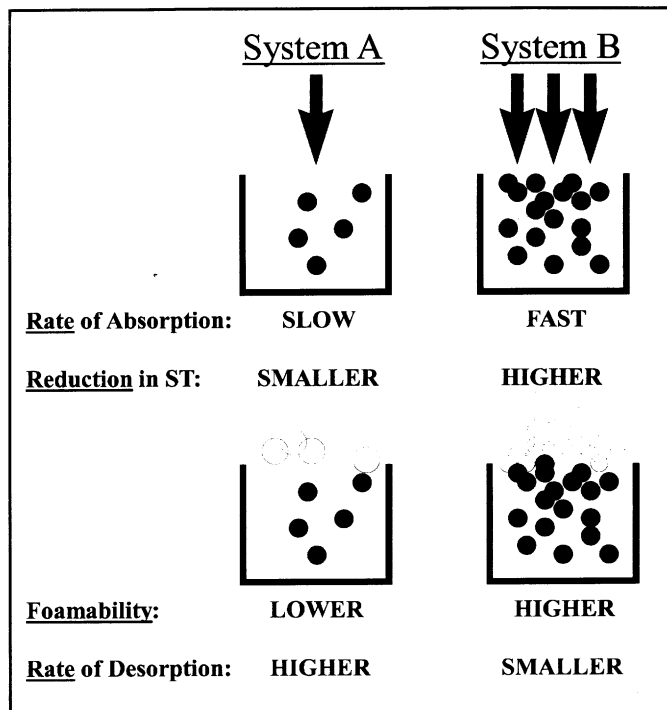
0.9 g/ml. The three ISO 68 lubricants (Witco 4GS, Witco SL68 and ICI RL68H) all exhibited viscosities around 100 cp, but the most important result from these trials was that the Witco POE appeared to be 20 cp more viscous than the ICI POE at room temperature. Static surface tension of both mineral oils had similar values (31 dynes/cm) that were greater than those of the POEs (29 dynes/cm).

### Dynamic Surface Tension

Dynamic surface tension measurements of the pure lubricants and the refrigerant/ lubricant pairs were experimentally determined using the maximum bubble pressure technique. This method involves injecting a gas phase (air for dynamic *surface* tension, refrigerant for dynamic *interfacial* tension) into a liquid (lubricant) while monitoring the pressure inside the bubbles formed. Theoretically, the greater the *reduction* in dynamic surface (or interfacial) tension, the greater *amount* of foam produced.

The dynamic surface tension tests with the pure lubricants (with air injection) revealed that the mineral oils behave quite differently compared to each other. The polyolesters, however, exhibit similar dynamic behavior.

The baseline dynamic *interfacial* tension experiments (oils aerated with refrigerant gas) revealed dynamic differences



**Figure 2: A schematic representation of the correlation between the relevant surface, foaming, absorption and desorption properties of refrigerant/lubricant mixtures.**

between the two mineral oils. 3GS exhibited lower surface tension values than 4GS at all bubble rates using R-12 as the injected gas phase.

The single-component HFCs, shown in *Figure 1*, revealed that the dynamic surface tension of POE lubricant paired with R-125 and R-143a (displayed in Region I) were higher than the curve for POE injected with air. This condition does not favor foaming as the influence of refrigerant appears to increase the amount of work required to expand the surface of the POE in these cases. R-134a and R-32 (displayed in Region II), on the contrary, lowered the dynamic interfacial tension curve and thus, appear to favor foam production more than R-125 and R-143a with POE lubricants.

The blended HFCs exhibited less deviant behavior from the control curve as both R-404A and R-407C curves were within 1 dyne/cm over a bubble frequency range from 0-30 bubbles/sec. R-410A exhibited a higher dynamic interfacial tension by approximately 5 dynes/cm over the aforementioned bubble frequency range. **In short, none of the blended HFC refrigerants appear to favor the foaming process from an interfacial standpoint.**

### Foaming Characteristics

Foam stability and foamability measurements were performed with a variety of techniques. The first method, aeration, was used to perform tests on the baseline CFC and HCFC refrigerants with the corresponding mineral oils. The HFC/polyolester pairs required a different approach to producing foam, in

\* Multiply psi by 6.895 to obtain kPa.

that a pressure drop was required to form the foams that could be measured and compared.

The foamability and foam stability tests for the baseline pairs were performed using 30 ml of lubricant aerated with air at standard room conditions, using flow rates between 250 and 1000 ml/min.

While the aeration column (with air injection) revealed that the 4GS/R-22 pair produced the largest amount of foam and the most persistent foam column, it also exposed a significant fact concerning the R-22 trials with both 3GS and 4GS lubricants.

In essence, both mineral oils were tested using a variety of air flow rates, however both lubricants exhibited maximum foaming ability and foam stability for one of the *middle* flow rates tested.

This suggests that there is an *optimum* amount of refrigerant needed to produce the most or longest lasting foam. It should also be noted that R-22 exhibited more foaming than R-12. In terms of bubble size, the bubbles produced were small (on the order of hundreds of microns), corresponding to slow drainage rates and higher foam stability.

The HFC pressure-release foaming apparatus was used to test the HFC/POE mixtures. The experimental variables considered and varied during these experiments are pressure drop (20, 50 and 70 psi\*), time of pressure drop (10, 30, 60 and 180 sec) and refrigerant/lubricant mixture ratio (1:1, 3:1 and 6:1).

The trials revealed that none of the HFC/POE pairs produced stable foam (foam lifetimes did not last longer than 10 seconds for any given trial). However, the trials did reveal that the R-134a/POE system was the most foamable system for "fast" (10 and 30 sec) pressure drops and low (20 psi) pressure drops, and this definitely corresponds to the dynamic interfacial tension data, as R-134a showed the greatest *reduction* in dynamic surface tension. In addition, bubble sizes were generally larger (on the order of 1 mm) than those observed for the baseline aeration study.

The American Society of Testing Materials (ASTM) Standard Method for Foaming Characteristics of Lubricating Oils (method D 892 - IP 146 alternative) was also performed on the HFC/POE

systems. This method involves the injection of air through a gas diffuser. However, since this method does not utilize a pressure drop to induce foaming, the HFC/POE pairs did not exhibit any foaming with this apparatus.

### Absorption & Desorption Rates

Desorption rates of the HFC/POE pairs were measured using a weight-loss method. It was found that the greater the refrigerant/lubricant ratio and the slower the pressure drop, the greater the desorption rate. Out of all the HFCs, R-134a desorbed out of the POE lubricant the slowest.

Absorption of refrigerant in the lubricant was studied by a weight gain method. An open container of lubricant in a pressure vessel is continuously weighed by a force transducer when the vessel is filled with a known refrigerant under predetermined pressure and temperature conditions.

The change in the weight is plotted as a function of time and absorption rate is calculated. R-134a was shown to have the greatest absorption rate in POE lubricant at both room temperature and 34°C (93°F) for pressure drops of 20, 50 and 70 psi.

### Summary

The measured surface properties, foaming characteristics, and absorption and desorption rates support each other in that slow absorption rates seem to correspond to a smaller reduction in surface tension, and thus, lower foamability.

Greater desorption rates are also characteristic of these systems as the refrigerant leaves the mixture before it can effectively enhance the foaming potential of the mixture.

The R-143a/POE system was indicative of these properties. On the contrary, R-134a/POE exhibited a fast absorption rate and a slow desorption rate, thus being able to reduce dynamic interfacial tension of the system the greatest, allowing for the greatest foamability. These conclusions are schematically presented in *Figure 2*.

Foamability and foam stability of the HFC/POE pairs were considerably lower than the baseline R-12, R-22/mineral oil pairs. R-134a was the only HFC that exhibited any kind of similarity dynamic interfacial tension reduction. Comparisons of the major foaming characteristics and dynamic surface tension reduction, between R-12 and R-134a as well as R-22 with both R-407C and R-410A are made in *Table 1*.

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