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New and Unique Lubricants for Use in Compressors Utilizing R-134a Refrigerant

S. T. Jollev
The Lubrizol Corp.

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STATUS REPORT ON POLYALKYLENE GLYCOL LUBRICANTS FOR USE WITH HFC-134A IN REFRIGERATION COMPRESSORS

Sonny G. Sundaresan
Manager of Materials Engineering and Systems Chemistry
William R. Finkenstadt, Ph.D.
Senior Systems Chemist
Copeland Corporation
1675 W. Campbell Road
Sidney, Ohio 45365

ABSTRACT

The compound 1,1,1,2 tetrafluoroethane is the leading replacement refrigerant candidate for CFC-12 in air-conditioning and refrigeration applications. HFC-134a has thermodynamic properties similar to those of CFC-12 and has an Ozone Depletion Potential (ODP) of zero. Since currently available mineral oils are not miscible with HFC-134a, a series of alternative lubricants is being developed today. Polyalkylene glycol and esters are examples. This paper reviews results to date from compressor life testing of different types of polyglycols. Wear and copper plating characteristics were monitored and are presented.

INTRODUCTION

The role of chlorine in the depletion of the Antarctic Ozone levels (The Antarctic Ozone Hole) has been understood since the 1988 NASA Report. The phaseout of the fully halogenated chlorofluorocarbons and other chlorinated chemicals is expected to happen earlier and faster than called for by the Montreal Protocol (UNEP 1987). 1,1,1,2 tetrafluoroethane (HFC-134a) is the leading candidate to replace dichlorodifluoromethane (CFC-12) because its thermodynamic properties are relatively close to those of CFC-12; however, HFC-134a is immiscible in current naphthenic mineral oils as well as in other hydrocarbons used as lubricants in refrigeration systems. Polyglycols received the earliest attention by several manufacturers of the new refrigerant HFC-134a. Polyalkylene glycols have been extensively covered in the literature since the mid-1950s; the major applications are hydraulic brake and metalworking fluids (Gundarson, 1962). Recently, their use in refrigeration systems is reported by Sanvordenker (1989).

To begin with, four polyalkylene glycol (PAG) lubricants were evaluated for use in refrigeration systems. Their physical properties, compatibility with materials of construction, and lubricating ability were evaluated and reported from laboratory sealed tube test and compressor life tests (Sundaresan and Finkenstadt, 1989). Since then moisture sensitivity tests were conducted; and five more PAG lubricants were added for compressor life tests. The lubricants were in the viscosity range of 106 to 175 SUS at 100°F (32 CS nominal at 40°C), and they varied in chemical structure.

PAG CANDIDATES

Table 1 lists the properties of all the nine polyglycol lubricants that were evaluated in compressor life test. The miscibility profiles for candidates A, C, D, F, H, and I are presented in Figure 1. Candidates B, E, and G are completely miscible in the temperature range of -60°F to 190°F.

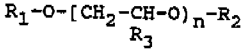
Table 1.
Properties of Polyalkylene Glycol Candidates

PAG	Number of Hydroxyls	Viscosity @ 100°F SUS	Viscosity @ 100°F cst	Viscosity Index	Miscibility	Moisture PPM by wt.	Acid Number[1]
A[2]	1	162	34.5	169	Inverse	1048	.44
B	2	158	33.7	30	Complete	404	.61
C	1	159	33.9	161	Inverse	423	<.032
D[3]	1	176	37.6	197	Inverse	448	.066
E	0	125	26.3	160	Complete	163	.026
F[4]	1	106	21.9	154	Inverse	1163	.22
G[2,4]	2	162	34.4	30	Complete	633	.62
H	1	135	28.5	165	Inverse	440	.33
I	1	165	35.2	169	Inverse	428	.32

[1] mg of KOH/g of oil
[2] Contains additive package
[3] Copolymer of ethylene oxide and propylene oxide
[4] Mixture of PAG materials

Chemically modified PAG indicates that both terminal hydroxyl groups are reacted to form either the diether, diester, or ether-ester as described by Gundarson (1962). Table 2 lists the generic PAG structure and estimated values of different parameters.

Table 2.
Structure of Polyalkylene Glycols



$$R_1\text{-O-}[CH_2\text{-}\underset{R_3}{CH}\text{-O})_n\text{-}R_2$$

Type	R1	R2	R3	Ave. n
Diol	H	H	CH_3	7
Monol	C_4H_9 or others	H	CH_3 or H	11-15
Mod. PAG	others	others	CH_3	12-17

WEAR AND COPPER PLATING

Experimental

Candidate lubricants were screened for miscibility prior to further evaluation. The base fluids were then compared an existing naphthenic mineral oil for boundary lubrication characteristics using bench tests for wear and lubrication such as the Pin and V-Block, Pin-on-Disk, Four-Ball Test, et al. In some cases additives were incorporated to improve the properties. Compressor manufacturers depend upon compressor life tests under normal load and accelerated test conditions for continued evaluation of the lubricant candidates.

Nine PAG candidates (See Table 1 for properties) were selected for evaluation. A 3/4-horsepower reciprocating semi-hermetic compressor with splash lubrication system was chosen as the test compressor. The reciprocating compressor consisted of cast iron piston, die cast aluminum connecting rod, hardened steel wrist pin, gray cast iron crankshaft, and steel-backed bronze main bearing.

The life testing was conducted at five different test conditions representing normal load, start/stop, high load, high-compression ratio, and flooded start conditions. The test condition, duration, and sequence are given in Table 3.

Table 3.
Compressor Life Test Sequence

Type of Test	Conditions[1]	Duration
Break in	-40/100/65	2 hours
Normal Load	-40/100/65	250 hours
Start/Stop	-40/100/65	80,000 cycles
High Load	-5/130/65	250 hours
High Compression Ratio	-40/130/65	250 hours
Flooded Start	-40/ 90/65	1,000 cycles

[1] Conditions: Evaporator, °F / Condensing, °F / Return Gas, °F

The 1,000-hour sequence test is intended to discover major problems and functions. It is the first in a series of tests designed to rank the candidates and to identify critical issues early in the development cycle of lubricant selection and optimization. As a baseline, one control compressor was tested with CFC-12 and mineral oil (150 SUS at 100°F viscosity or 32 CS at 40°C). Pressures and temperatures were monitored and controlled to ensure a valid comparison between candidates. Oil samples were taken at the completion of each step of the test sequence for the purpose of monitoring wear. The compressor sight glass enabled the test technicians to monitor the oil level and the contamination of the oil. The compressors were disassembled and inspected at the completion of the test sequence. The inspection focused on wear, copper plating, varnishing, and other known degradation mechanisms. The oil taken at each sampling time was analyzed for wear metals by emission spectroscopy using a rotating disk instrument.

Results

The results of testing of the nine lubricants are summarized in Table 4. The results include the total test hours, completion status, and tear down results. The wear index refers to the actual amount of wear measured per unit test time expressed in a normalized scale with baseline (mineral oil with CFC12) as one.

Table 4.
Connecting Rod Wear and Valve Plate Copper Plating

PAG	Test Hours	Test Status	Results	Wear Index (Normalized)	Copper Plating on Valve Plate
A	506	Failed	Rod Broken	1482	None
B	1076	Completed	OK	1	None
C	1069	Completed	OK	20	Heavy
D	813	Terminated	Oil Black	198	Trace
E	1188	Completed	OK	2	Light
F	1168	Completed	OK	50	Moderate
G	713	Terminated	Oil Opaque	101	Severe + Bearings
H	1131	Completed	OK	9	Moderate
I	1167	Completed	OK	5	Moderate
Pale Mineral Oil with CFC-12					
MO	1060	Completed	OK	1	None

The baseline (control) compressor and six other compressors (with Candidates B, C, E, F, H, and I lubricants) completed all life tests. The compressor with Lubricant A failed, with a broken connecting rod, during the high load portion of the test sequence. The connecting rod was worn through at the wrist pin end and fractured. The compressor with Candidate D was terminated during the high-compression ratio portion of the test sequence due to dark oil's being observed in the sight glass. The connecting rod wear was excessive in the wrist pin bore. The compressor with Candidate G was terminated after completing the high Load portion of the test sequence due to the oil becoming opaque. There was extensive copper plating on the valve plate and bearing along with evidence of extensive pitting corrosion on the connecting rods.

Although the compressors with Candidates B, C, E, F, H and I completed all life tests, they did exhibit varying degrees of connecting rod wear at the wrist pin end. The baseline control with mineral oil did <u>not</u> reveal any problem in this relatively short, 1,000-hour sequence test.

Oil analysis for wear debris was consistent with the results from visual inspection and wear measurements on compressor components. The aluminum concentration in the oil was the most relevant parameter, and the results are plotted in Figures 2 and 3. (Please note that they differ in the scale; the abscissa of Figure 2 is scaled to 100 ppm by weight aluminum whereas Figure 1 is 1,000 ppm.) As is seen, the baseline (control) compressor with mineral oil showed no evidence of aluminum after completion of all tests. THe candidates are ranked based on wear index and aluminum concentration in oil. Candidate E was the best. Candidates B , H, and I are close seconds. Candidates D and G were terminated due to observation of dark oil in the compressor sight glass. Candidates C and F exhibited a worse concentration of aluminum wear particles than did Candidates D and G, but they still completed all tests. This points out the lack of correlation between factors affecting sight glass conditions and techniques of sampling and analysis. The moisture and acidity were evaluated at the conclusion of all the tests. The acidity levels on these candidates measured in the range of 0.01 to 0.6 milligrams of KOH per gram of oil and did not correlate to wear or copper plating.

<u>Discussion</u>

The results indicate that, with CFC-12/mineral oil there is no connecting rod wear at the wrist pin end during limited (~1000-hour) life testing; however, all the PAG candidates (with HFC-134a) exhibit wrist pin distress, and there are differences among each of the nine polyglycol candidates. The modified PAG and unadditized (neat) diol, which are completely miscible in HFC-134a, had superior performance. The compressors exhibited nominal wear in comparison to the other candidates.

The exact cause and effect mechanisms for the behavior of the other seven candidates have not yet been established. The other diol, Candidate G, containing an additive had unacceptable wear. The role of the additive in contributing to the pitting corrosion of aluminum is suspected and is being evaluated further.

The role of moisture was investigated as follows: Candidate B (neat diol) and Candidate C (neat monol) were evaluated at different levels of moisture, and the results are summarized in Table 5.

Table 5.
Moisture Sensitivity

PAG	Test Hours	Moist. ppm wt	Test Status	Results	Wear Index (Normalized)	Copper Plating on Valve Plate
B(1)	1076	404	Completed	OK	1	None
B(2)	1141	1179	Completed	OK	19	Moderate
C(1)	1069	423	Completed	OK	20	Heavy
C(2)	1150	1084	Completed	OK	50	None

For neat lubricants (B & C), the increased moisture levels (from 400 to 1,100 ppm) did result in a small increase in wear as expected. Table 6 summarizes the effect of moisture with an additized lubricant.

Table 6.
Moisture Sensitivity with Additized Lube

PAG	Test Hours	Moist. ppm wt	Test Status	Results	Wear Index (Normalized)	Copper Plating on Valve Plate
A(1)	506	1048	Failed	Rod Broken	1482	None
A(2)	1099	1011	Completed	OK	20	Light
A(3)	405	184	Terminated	Black Oil	1304	Trace

For additized lubricant (A), the role of the additive seems to be more dominant than the role of moisture and is continuing to be studied.

SUMMARY

The investigation on the effect of the PAG structure, additives (if any), the moisture level and the acidity on the performance of the candidate as a suitable lubricant is continuing. The wear issues manifest themselves consistently as connecting rod wear at the wrist pin end. The miscibility of lubricant and refrigerant appear to be the dominant factor. Corrosion mechanisms with aluminum in the presence of polyglycols and/or additives is not completely understood. So far, there is no clear evidence of trends with copper plating in respect to polyglycols as base fluids.

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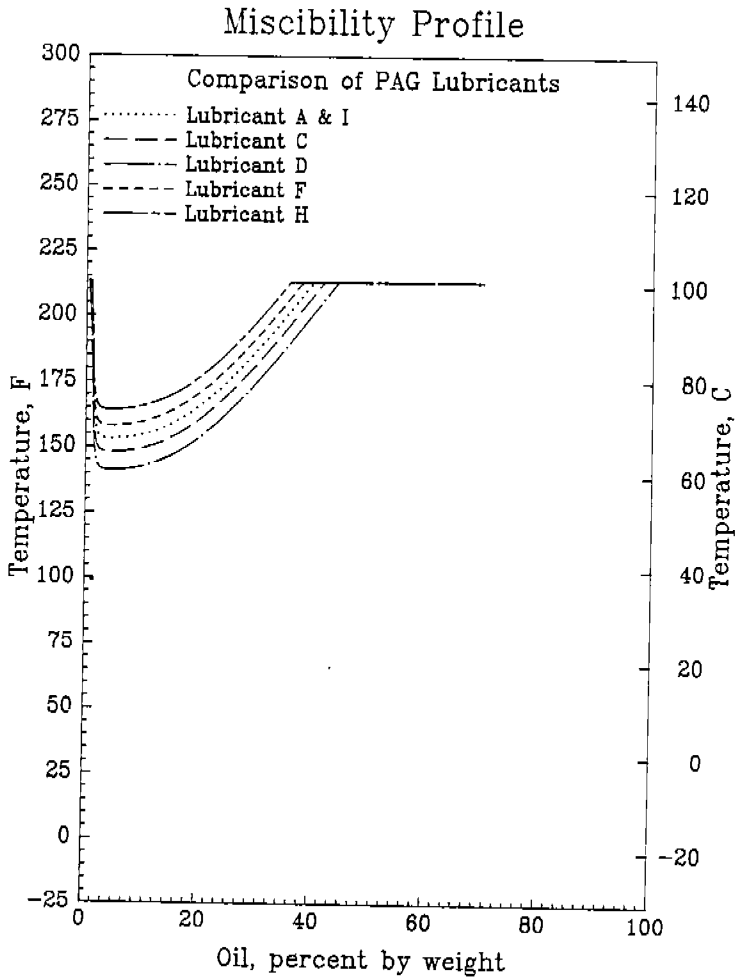

Figure 1. Miscibility Profile of PAG Lubricants with HFC-134a
Lubricant A - 165 SUS PAG Monoether
Lubricant C - 159 SUS PAG Monoether
Lubricant D - 176 SUS Polyethylenepropylene Glycol monoether
Lubricant F - 106 SUS PAG Monoether
Lubricant H - 135 SUS Polypropylene Glycol Monoether
Lubricant I - 165 SUS Polypropylene Glycol Monoether
Lubricants B, E and G are completely miscible
Measurements were conducted from 200 to -90°F.

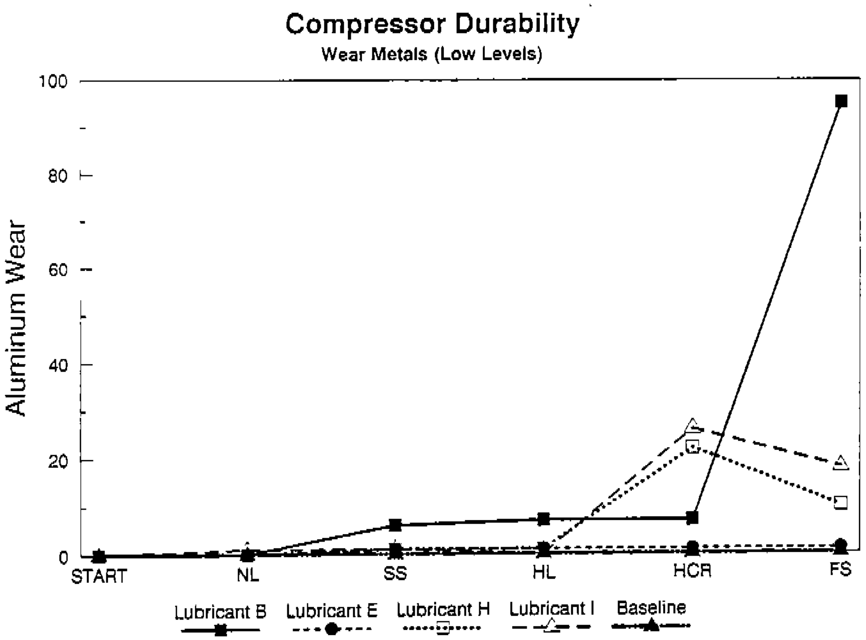

Figure 2. Compressor Durability as Determined from Aluminum Concentration in Lubricants. The Four Lubricants with Low to Moderate Levels of Aluminum.

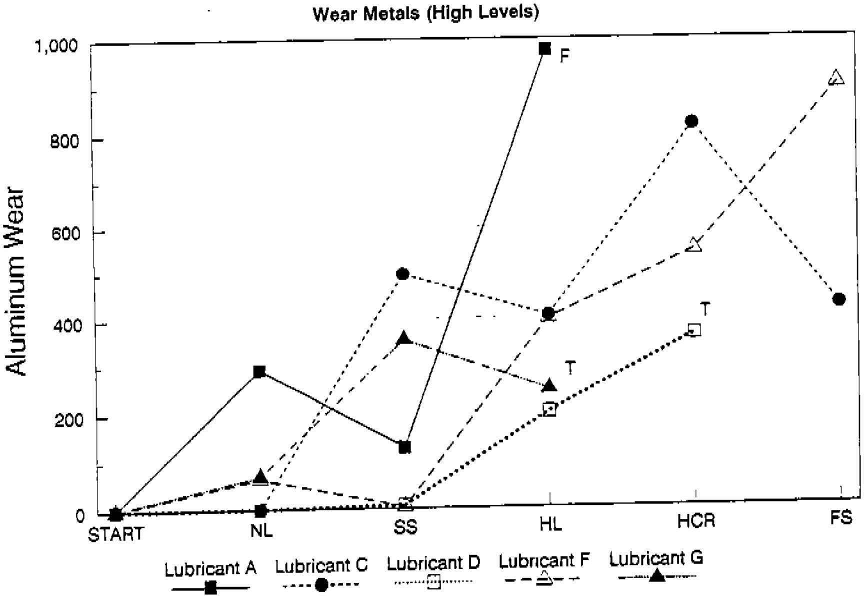

Figure 3. Compressor Durability as Determined from Aluminum Concentration in Lubricants. The Five Lubricants with High Levels of Aluminum.