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INVESTIGATING AUTOMOTIVE GEAR LUBRICANT COPPER CORROSIVITY

Maurice E. LePera, et al

Coating and Chemical Laboratory
Aberdeen Proving Ground, Maryland

March 1973

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FINAL REPORT

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BY

MAURICE E. LEPERA

AND

JAMES V. SHIMEK

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U. S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT CENTER

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Maurice E. LePera
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13. ABSTRACT

An investigation was initiated to identify relationships between Copper Strip ratings and organic acidity/alkalinity values for gear oils meeting both military and commercial factory-fill specifications. No correlation was found to exist between organic acidity and Copper Strip ratings. As no other trends were evidenced, further modifications to the D130 technique were considered in an attempt to define gear oil corrosivity towards other ferrous and non-ferrous materials.

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I. INTRODUCTION

Automotive gear lubricants which meet the specification requirements of MIL-L-2105B Lubricating Oil, Gear, Multipurpose, are designed to provide satisfactory performance in hypoid gear axle environments where operation under boundary lubrication exists. To meet these hypoid gear lubricant requirements, the MIL-L-2105B oils must be formulated with chemically-active extreme pressure (EP) additives which provide the necessary boundary lubrication protection by their formation of chemically-reacted films between the rubbing gear surfaces. Providing these EP properties in MIL-L-2105B gear oil formulations is not a difficult task; however, the chemical activity of the EP additive must be carefully controlled in order to minimize any ferrous or non-ferrous corrosion. This "excess" chemical activity, reported to cause bearing and gear wear resulting in reduced axle life (1), in gear oils qualified under MIL-L-2105B is controlled by meeting specific laboratory test requirements; namely, the CRC L-33 Moisture Corrosion Test (Fed. Test Method Std. 5326) and the ASTM D130 test for Detection of Copper Corrosion from Petroleum Products by the Copper Strip Tarnish Test. This latter technique, the Copper Strip Test, involves the static heating of cold-finished 99.9 + percent purity copper at three hour periods of either 212°, 250°, or 300°F. to predict the reactivity of the oil/hydrocarbon towards copper alloys. However, copper alloy corrosion has not been completely predicted by using the D130 Copper Strip test as evidenced by several reports wherein laboratory versus dynamometer and/or field performance results differed appreciably (2,3). Gear oils meeting MIL-L-2105B are required to pass this D130 Copper Strip test (3 hours @ 250°F.) with the maximum rating being specified at 2c. The 2c rating in D130 is described under Table 1 Copper Strip Classification as "multicolored with lavender blue or silver, or both, overlaid on claret red". In a recent publication which described the methodology of the ASTM Copper Strip Corrosion Standards (4), the amount of oxidized copper in the corroded film of a 2c strip was found to be 0.85 milligrams whereas a 1a strip gave 0.40 milligrams. As was stated previously, the Copper Strip requirement under para. 3.4.8 of MIL-L-2105B was imposed to control the reactivity of additive ingredients with copper alloy or bronze bushings/components presents in transmission, power divider, and differential units. However, in recent procurement actions on MIL-L-2105B gear lubricants, the validity of this Copper Strip requirement was questioned in relation to the affect of 2d or above ratings on actual field service performance. The maximum 2c value, having been established after extensive field test programs were conducted prior to the issuance of MIL-L-2105B on 19 February 1962, was selected to eliminate potential copper alloy corrosion in military transmission/axle/transfer case environments (10). However, in light of developments in new hypoid gear lubricant additives, the significance of failing D130 rating (2d or higher) warranted an explanation. To provide the necessary input regarding the significance of D130 Copper Strip ratings as they relate to gear oil corrosivity, a study was initiated to define two objectives; initially establish a definition of D130

Copper Strip ratings in terms of organic acidity/alkalinity values and then, describe these determined acidity values in terms of their corrosivity/reaction towards other ferrous materials present in transmission/gear case environments.

II. DETAILS OF TEST

A. Sample Selection

Gear oils meeting the performance requirements of MIL-L-2105B have been formulated using one of two basic additive package systems; namely, sulfur-phosphorus-chlorine-zinc (SPClZn) or sulfur-phosphorus (SP). However, current formulations utilizing the SP package have now virtually eliminated the SPClZn system for present day applications as a result of their increased thermal stability and EP performance characteristics (5). Commercial gear oils, designed for factory-fill, off-highway equipment, or construction vehicles may be formulated with additive systems in addition to those previously mentioned such as sulfur-chlorine-zinc (SClZn), sulfur-chlorine-lead (SClPb), sulfur-phosphorus-zinc (SPZn), or lead-sulfur which is usually referred to as lead soap-active sulfur (LS-AS). It should be noted however, that many of these additive systems designed for commercial gear oil applications will not pass the performance requirements of MIL-L-2105B (10). For the purpose of encompassing many types of additive systems for this investigation, it was decided that commercial as well as military specification gear oils would be evaluated. As a result, a representative sampling of gear oils qualified under MIL-L-2105B and those marketed under various commercial factory-fill designations were obtained. In addition, one sub-zero gear oil meeting MIL-L-10324 was also included since this product was formulated using a synthetic ester base stock. To assist in the identification/characterization of the EP additive components, the gear oil samples were analyzed for sulfur, phosphorus, chlorine, zinc, and lead in addition to standard inspection requirements. The results of the analysis which describe the gear oil samples are presented in Table I (Appendix A).

B. Relationship of Copper Corrosivity with Acidity/Alkalinity

To meet the initial objective of this study, the twenty-one gear oil samples were evaluated to determine their D130 Copper Strip rating as specified uner MIL-L-2105B. However, in preparing the D130 Copper Strips prior to testing, a slight modification to this procedure was followed. The ASTM D130 procedure specified uner para 4.3.2 that all surface blemishes are to be removed with a 240-grit silicon carbide paper. The final polishing is then to be performed using 150-mesh silicon carbide grains. Because of the absence of these silicon carbide grains at the initiation of this study, the strip polishing procedure was performed using the following sequence of abrasive/polishing materials:

1) 240-grit silicon carbide paper.
2) 400-grit silicon carbide paper.
3) 600-grit silicon carbide paper.
4) No. 00 steel wool.

It should be noted that, later in this study when 150-mesh silicon carbide grains were available, the modified polishing procedure gave copper strip rating identical to those obtained after using the standard materials. Before and after the D130 Copper Strip test (3 hours @ 250°F.) the gear oils were analyzed for their acidity and alkalinity values. This was performed by D664 (Neutralization Number by Potentiometric Titration). In measuring these total acid numbers (TAN and total base number (TBN) which were determined using a Beckman Model 1062 Automatic Recording Titrameter, the method for defining the amount of titrant delivered (i.e., inflection paint or non-aqueous buffer end point) was maintained the same for the "before" and "after" test conditions to minimize any additional errors. The results for these twenty-one gear oils showing the copper strip ratings and neutralization values before and after testing are presented on Table II (Appendix A). To facilitate the reviewing of these data, the tabulation shows the listing in the sequence of increasing D130 Copper Strip ratings. To increase the possible severity of this corrosion requirement and accelerate the potential oxidation of the gear lubricants, the samples were re-tested using a 6 hour heating period @ 250°F. As before, the TAN value was determined after the 6 hour period to ascertain whether a significant increase was evidenced. The tabulated results showing the affect of the additional 3 hour heating period on both D130 Copper Strip rating and TAN value are presented on Table III (Appendix A). Because of the extremely subtle changes in TAN between 3 versus 6 hours heating, it was decided that one additional experiment be performed. Since the produced organic acids could be forming soluble copper complexes which may account for the low TAN values, five gear oils having been tested in the 6 hour heating period were analyzed for their copper content. To insure meaningful results, fresh (not tested) samples of the selected oil were also analyzed for soluble copper. The analysis for copper content was performed using a Perkin-Elmer Model 303 Atomic Absorption Spectrophotometer. The results of these analyses including the D130 Copper Strip ratings and TAN values are given on Table IV (Appendix A).

C. <u>Gear Oil Corrosivity Towards Other Metals</u>

Since the results obtained thus far had revealed the absence of a correlation between D130 Copper Strip ratings and TAN/TBN values, the second objective of this study involving the "reactivity" of these gear oils with other metals was initiated. To accomplish this, standard metal specimens used in laboratory corrosion tests were considered to simulate the metal environment of gear and transmission environments. Since SAE 1010 low carbon steel and SAE G 3000 automotive cast iron strip specimens are required for corrosion testing of automotive brake fluids qualified under Federal Specification VV-B-680B and also are standardized under SAE Standard J 1703c (6), these two metal specimens were selected for the corrosivity study on the basis of their similarity to metallurgy in present-day gear and transmission environments. In addition to the SAE 1010 and SAE G 3000 strips which have similar configurations to the D130 Copper Strip specimen, Bronze strips having a 90% copper-10% tin composition were also considered in this study. The Bronze strips were included to determine whether the various gear oils would exhibit a greater reactivity towards Bronze than Copper previously evaluated. Moreover, many transmission and gear units employ bronze components or bushings which have susceptibilities towards the thio-compounds present in EP additive packages. Prior to evaluating the three type of metal specimens in the D130 Copper Corrosion Bomb environment, each strip was polished in the same manner as the copper strips; namely, 240-grit, 400-grit, and 600-grit silicon carbide papers followed by final polishing with No. 00 steel wool. For defining the degree of "gear oil reactivity", the D130 Copper Strip Standards would be utilized for the Bronze strips whereas the degree of staining/pitting would be visually assessed in rating both the steel and cast iron strips. Using this approach, eighteen gear oils were individually evaluated using the three metals for 3 hours @ 250°F. and the results of these ratings are shown on Table V (Appendix A).

Since the absence of any significant staining of both cast iron and steel strips was indicated in a majority of the cases, a modification to this corrosivity test was considered. It had been recently reported (7) that corrosion protection offered by sulfur-phosphorus EP additives towards ferrous and non-ferrous materials was defined by the D130 technique (3 hours @ 212°F.) and a "Water Tolerance" test which consisted by introducing 2% water to a gear oil. The oil-water mixture was then exposed to a SAE 1010 strip and heated for 24 hours @ 212°F. Using this approach wherein water would be introduced as a test parameter, the "corrosivity" tests were repeated for the cast iron and steel strips. Prior to the immersing of the polished strip into the glass test tube containing the oil sample, 0.5% volume distilled water was introduced to the oil. The gear oil samples were subsequently evaluated in the presence of this water adulterant using the cast iron and steel strips and the results are presented on Table VI (Appendix A). Since the introduction of the 0.5% distilled water resulted in a significant increase in the additive's reactivity with the two metal standards, one additional experiment was performed. To ascertain whether the stain/pitting formations on some of the strips was indicative of corrosive tendencies of the reactive EP components, the gear oils were evaluated for their corrosion protection characteristics using ASTM 1748 (Rust Protection by Metal Preservatives in the Humidity Cabinet). Because of sample size requirements for the triplicate testing, only 13 samples were subsequently evaluated. The results of the Humidity Cabinet corrosion test which utilizes a sand-blasted low-carbon cold-rolled steel (SAE 1009) panel substrate are given on Table VII (Appendix A).

III. RESULTS OF TEST

The D130 Copper Strip ratings initially obtained on the sampling of commercial and specification gear lubricants revealed that seven of the MIL-L-2105B products did not meet the maximum 2c specified under para 3.4.8. In this regard, an interesting anomoly is worthy of comment. Gear oil samples D and E had been field-tested in a twenty thousand mile fleet test program at Southwest Research Institute (8). At the termination of this test program which involved military tactical-type vehicles, sample E which has a "borderline" D130 rating provided satisfactory performance in all vehicles; however, sample D which has a satisfactory D130 rating proved to have a rusting tendency in those vehicles in which it was used. To illustrate how the variability in gear oil formulations and resultant performance level will more or less limit the obtained strip ratings, a sampling of copper corrosion limits (D130) currently specified in automotive factory-fill and commercial gear oils is given on Table VIII (Appendix A).

The attempt to establish a possible correlation between Neutralization Numbers and D130 Copper Strip ratings was completely unsuccessful as evidenced by the absence of any maningful trend. It had been anticipated that as the D130 rating increased, the determined TAN values would also increase accordingly since thio-organic acids should be neutralized by the alcoholic potassium hydroxide. However, the results obtained revealed that gear oils giving D130 ratings of 1A and 1B gave TAN values from 1.14 to 6.18 whereas those oils having D130 ratings in the 3 to 4 range gave TAN values averaging around 1.5. The TBN which were determined provided little if any assistance. Determining the TAN/TBN values before and after the D130 test produced test results which had not been anticipated. Generally, five of the gear oils gave increases in TAN which should occur because of the temperature and presence of a catalyst. However, many of the other oils gave decreases in the TAN which may have resulted from the formation of copper complexes. Extending the time interval of the D130 Copper Strip test from 3 to 6 hours did not produce an overall significant change in the obtained strip ratings nor TAN values. More specifically, seven of the gear oils gave the same D130 Copper Strip rating for the two test intervals whereas a one increment increase in strip ratings was evidenced with six gear oils. Again, the TAN values obtained after the 6 hour interval remained somewhat constant eliminating any possible correlation for organic acidity with copper corrosivity. It should be noted however, that a recent paper on automatic transmission fluid requirements reported (9) that a correlation was obtained between Strong Acid Number (SAN) values and ratings using a "Bronze Thrust Washer" corrosion technique.

The evaluating of gear oils with the Bronze, SAE 1010 and SAE G 3000 materials produced some interesting results. To begin with, the substitution of the Bronze strip in place of the D130 copper strip resulted in a significant increase in the degree of staining. To illustrate this point, a graphical representation of D130 Copper Strip ratings versus "D130 Bronze" strip ratings is given on Figure I (Appendix B). It is evident that a 1:1 correlation between ratings does not exist and that the "Bronze ratings were significantly more severe. In reviewing these "Bronze" strip rating, exactly 50% gave a 3b rating. It was interesting to note that for the majority of gear oil samples, no visible reaction was evidenced in substituting the cold-rolled steel (SAE 1010) or cast iron (SAE G 3000) strips. In the case of the SAE 1010 strips, sample J produced a slight stain whereas sample L produced a heavy stain. These similar trends were observed with the SAE G 3000 strips. Sample L however, did produce a "positive-type" test with all three strip materials indicating its reactivity towards those metals as well as copper. It was interesting to note that all samples giving some degree of staining with the SAE G 3000 strips had been formulated using lead as one of the EP additive components. The addition of the 0.5% water contaminant to the reactivity tests greatly increased the staining and/or discoloration of the polished steel and cast iron strips. More specifically, only five gear oil samples gave essentially no reaction with the SAE 1010 strips in the presence of the water contaminant whereas this number of samples was reduced to one product for the SAE G 3000 strip tests. In reviewing these data, the SAE G 3000 generally were stained and/or discolored depending upon the particular gear oil formulation. However, with the SAE 1010 strips, two samples (J and U) produced light staining and a certain degree of surface pitting. Since this type of pitting was felt to be significant, one additional test was performed to ascertain the rust protection properties of these gear oils; namely, the ASTM D 1748 which utilizes the humidity cabinet conforming to Military Specification JAN-H-792. Lubricating oils having rust protection properties will generally provide corrosion protection for at least 20 days. In reviewing the results obtained on the gear oils evaluated, only four samples met this requirement. Four other samples (P, S, T, and U) failed after only one day indicating no rust protection properties whatsoever. The remaining five samples fell midway between the 1 and 20 day requirement indicating some degree of rust protection properties. It was interesting to note that samples J and U which gave slight pitting on SAE 1010 with the 0.5 % water contaminant produced distinctly different results in the Humidity Cabinet test. More specifically, sample J remained satisfactory after 20 days wheras sample U failed after one day. This apparent difference in corrosivity is probably the result of a thermal instability characteristic inherent in the particular additive package formulation.

IV. CONCLUSIONS

The copper corrosion requirement currently specified in MIL-L-2105B Lubricating Oil, Gear, Multipurpose, and other commercial gear oil specifications was found to have no correlation with organic acidity or alkalinity values as determined by potentimetric titrations (D 664). Modification of this procedure involving extending the test interval did not significantly affect the initial results. However, substituting Bronze strips in lieu of the D130 copper standards resulted in significantly higher or more severe ratings. Although the D130 copper corrosion test has been included in both military and commercial specifications to predict/control the reactivity of gear oils towards copper-containing alloys, other investigators have reported the copper strip test may not predict (2 and 3) copper alloy corrosion in gear or transmission systems. The substituting of steel and cast iron strips in place of the D130 copper standards did not permit the defining of gear oil corrosivity; however, those gear oils formulated with lead EP additives exhibited a marked tendency towards surface staining and/or pitting. Since the copper corrosion requirement of 2c maximum was originally specified for MIL-L-2105B gear oils formulated with a sulfur-phosphorus-chlorine-zinc additive system, this requirement may need further evaluation/investigation considering the recent introduction of MIL-L-2105B gear oils formulated with a sulfur-phosphorus additive package.

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APPENDIX A

TABLE I

Description of Gear Oil Samples

Sample Designation	Gear Oil Type	Additive Elements Present, % wt.					Ramsbottom Carbon Residue, % wt.	Kinematic Viscosity[2]	
		Sulfur	Phosphorus	Chlorine	Zinc[1]	Lead[1]		100°F.	210°F.
A	MIL-L-2105B	2.59	0.06	0.04	(13)	(1)	0.63	217	16.86
B	MIL-L-2105B	2.27	0.11	Nil	(20)	Nil	0.59	--	8.99
C	MIL-L-2105B	1.41	0.36	Nil	0.46	(4)	1.64	--	17.41
D	MIL-L-2105B	1.39	0.36	1.50	0.55	Nil	1.67	208	17.43
E	MIL-L-2105B	2.10	0.11	Nil	Nil	Nil	0.66	193	17.35
F	MIL-L-2105B	3.23	0.18	Nil	Nil	Nil	0.84	--	--
G	MIL-L-2105B	2.28	0.12	Nil	Nil	Nil	0.35	--	--
H	MIL-L-2105B	2.68	0.13	0.09	(6)	Nil	0.54	77.4	9.12
I	MIL-L-2105B	2.31	0.11	0.12	(5)	(2)	0.80	212	17.10
J	Commercial	3.13	Nil	1.19	Nil	1.88	5.14	245	18.20
K	Commercial	3.34	Nil	1.49	(4)	2.69	5.44	320	20.14
L	Commercial	3.42	0.09	0.41	Nil	0.29	2.06	212	16.40
M	Commercial	2.88	0.17	0.08	(12)	(3)	0.94	304	18.25
N	Commercial	3.37	Nil	1.38	(2)	1.82	7.40	237	19.48
O	Commercial	2.25	0.11	0.04	(2)	(2)	0.45	239	18.30
P	Commercial	2.32	0.12	0.06	(3)	(1)	0.68	201	17.47
T	Commercial	0.37	0.09	0.16	0.08	(4)	0.85	70.0	10.72
U	Commercial	3.35	Nil	Nil	(1)	1.78	4.03	--	19.47
R	MIL-L-10324	2.38	0.14	0.03	(5)	(1)	0.66	17.23	

1/Values in parenthesis are expressed in ppm.

TABLE II

D130 Copper Strip Ratings Versus D664 Neutralization Values

Sample Designation	D130 Strip Rating1/	D664 Neutralization No. — Total Acid No. — Fresh Sample	Total Acid No. — After Test	Total Base No. — Fresh Sample	Total Base No. — After Test
K	1A	2.39	4.28	11.21	10.80
N	1A	2.15	1.92	10.02	8.71
P	1A	1.14	1.08	2.18	1.67
T	1A	1.55	1.75	Nil	1.10
U	1B	2.32	1.03	8.72	7.31
C	1B	6.18	7.08	Nil	Nil
D	1B	6.10	5.76	Nil	Nil
S	1B	1.24	1.19	Nil	Nil
A	2A	Nil	0.97	Nil	Nil
O	2D	1.10	1.07	Nil	Nil
B2/	2E	1.01	1.11	Nil	Nil
E2/	2E	0.97	1.59	Nil	Nil
H2/	3A	1.33	1.11	Nil	Nil
I2/	3A	1.06	1.11	Nil	Nil
J	3A	3.49	2.94	9.32	Nil
M	3A	1.74	1.55	1.02	Nil
F2/	3B	1.63	1.90	Nil	0.98
G2/	3B	1.24	1.51	2.20	1.57
Q	3B	1.07	1.07	Nil	Nil
R2/	3B	1.69	1.75	Nil	Nil
L	4B	1.47	2.23	Nil	Nil

1/D130 rating obtained after 3 hours @ 250°F.

2/Military specification product had D130 Copper Strip rating in excess of specified maximum of 2c.

TABLE III

Effect of Increased Test Time on D130 and D664 Values

Sample Designation	D130 Copper Strip Ratings After: 3 hrs @ 250°F.	D130 Copper Strip Ratings After: 6 hrs @ 250°F.	D664 Total Acid Nos. After: 3 hrs @ 250°F.	D664 Total Acid Nos. After: 6 hrs @ 250°F.
K	1A	1B	4.28	4.26
N	1A	1A	1.92	2.67
P	1A	3B	1.08	0.90
T	1A	1A	1.75	1.58
U	1B	1A	1.03	1.51
C	1B	1B	7.08	6.77
D	1B	1B	5.76	6.93
A	2A	3B	0.97	0.88
O	2D	3B	1.07	1.00
B	2E	3B	1.11	1.73
E	2E	3B	1.59	1.37
H	3A	3B	1.11	1.48
I	3A	3B	1.11	1.31
J	3A	3A	2.94	2.34
M	3A	3B	1.55	1.66
F	3B	3B	1.90	2.02
G	3B	4B	1.51	1.75
Q	3B	3B	1.07	1.19
R	3B	4A	1.75	1.69
L	4B	4C	2.23	2.23

TABLE IV

Gear Oil D130 Ratings[1]

Versus Copper Solubilization

Sample Designation	D130 Copper Strip Rating	D664, TAN	Copper Content, ppm
A	(Not tested)[2]	Nil	3
A	3B	0.88	8
B	(Not tested)	1.01	1
B	3B	1.73	6
F	(Not tested)	1.63	1
F	3B	2.02	12
K	(Not tested)	2.39	1
K	1B	4.26	14
L	(Not tested)	1.47	1
L	4C	2.23	4

1/D130 copper strip ratings determined after 6 hours @ 250°F.

2/Fresh sample prior to test.

TABLE V

Gear Oil Reactivities with Other Metals

Sample Designation	Strip Rating/Appearance after 3 hrs @ 250°F. using: Bronze[1]	Cold-Rolled SAE 1010 Steel[2]	Cast Iron[3]
K	1A	ND[4]	Slight stain
N	1A	ND	Slight stain
S	1A	ND	ND
T	1A	ND	ND
C	1B	ND	ND
D	1B	ND	ND
P	2D	ND	ND
J	2E	Slight stain	Moderate stain
E	3B	ND	ND
F	3B	ND	ND
G	3B	ND	ND
H	3B	ND	ND
I	3B	ND	ND
M	3B	ND	ND
O	3B	ND	ND
R	3B	ND	ND
A	3B	ND	ND
L	4A	Heavy stain	Severe stain

1/Bronze strips are 90% Copper: 10% Tin and D130 Copper Strip Standards were utilized for their rating.

2/SAE 1010 low carbon steel, cold-rolled, hardness: 40-72 RB.

3/SAE G 3000 soft automtove cast iron, hardness: 89-96 RB.

4/No discoloration, same as freshly-polished.

TABLE VI

Gear Oil Reactivities with Metals in Presence of Water[1]

Sample Designation	Strip Appearance after 3 hrs @ 250°F. Cold-Rolled SAE 1010 Steel[2]	Cast Iron[3]
A	Moderate to heavy stain	Heavy stain
B	Heavy stain	Heavy stain
C	Light stain	Heavy stain
D	Light stain	Heavy stain
E	Moderate to heavy stain	Heavy stain
F	Light stain	Severe stain
G	Light stain	Severe stain
H	Moderate to heavy stain	Heavy stain
I	Light stain	Heavy stain
J	Light stain with light pitting	Heavy stain
K	ND[4]	Moderate stain
L	Heavy stain	Severe stain
M	Heavy stain	Heavy stain
N	ND	Moderate stain
O	Light stain	Heavy stain
P	Light stain	Heavy stain
Q	Moderate to heavy stain	Heavy stain
R	ND	ND
S	ND	Moderate stain
T	ND	Light stain
U	Light stain with light pitting	Heavy stain

1/ 0.5% vol. distilled water was introduced into gear oil prior to test.

2/ SAE 1010 low carbon steel, cold-rolled, hardness: 40-72 RB.

3/ SAE G3000 soft automotive cast iron, hardness: 89-96 RB.

4/ No discoloration, same as freshly-polished.

TABLE VII

Rust Protection Properties of Gear Oils

Sample Designation	ASTM D1748 Test Results
H	Failed after 13 days
I	Failed after 10 days
J	Satisfactory after 20 days
K	Satisfactory after 20 days
L	Satisfactory after 20 days
M	Failed after 12 days
N	Satisfactory after 20 days
O	Failed after 9 days
P	Failed after 1 day
R	Failed after 12 days
S	Failed after 1 day
T	Failed after 1 day
U	Failed after 1 day

TABLE VIII

Copper Corrosion Requirements For Commercial Gear Oils

Commercial Specification No.	Intended Use	Copper Strip Corrosion, 3 hrs @ °F.	Maximum Rating
AM-4046	Manual transmissions	212	1
JIC-150A	Trans. & differential	210	3
MS-862	Gear differential	212	1b
MS-3626	Gear differential	212 250	1b 3b
ESW-M2C28AA	Gear differential	72 210	1b 1b
ESW-M2C57A	Gear differential	72	4b
ESW-M2C104A	Gear differential	250	3a
GMC 9985 133	Synchomesh transmissions		1
0-72	Gear (worm gear type)	250[1/]	Negative
132 H EP	Gear differential	212	3
135 H EP	Gear differential	250	2
M2C84A	Transmission	210	2a

[1/]Bronze is substituted in place of the D130 Copper Strip.

APPENDIX B

FIGURE 1

D130 COPPER STRIP RATINGS: COPPER VS BRONZE STRIPS