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WADC TECHNICAL REPORT 53-88

SYNTHETIC LUBRICANTS

W. E. McTURK

STANDARD OIL DEVELOPMENT COMPANY

OCTOBER 1953

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WADC TECHNICAL REPORT 53-88

SYNTHETIC LUBRICANTS

W. E. McTurk

Standard Oil Development Company

October 1953

Materials Laboratory
Contract AF 33(038)-14593
RDO No. 613-15

Wright Air Development Center
Air Research and Development Command
United States Air Force
Wright-Patterson Air Force Base, Ohio

Mc Gregor & Werner, Inc., Dayton, Ohio
250- March, 1954

FOREWORD

This report was prepared by the Standard Oil Development Company, under USAF Contract No. AF 33(038)-14593. The contract was initiated under Research and Development Order No. 613-15, "Hydraulic Fluids and Lubricants MX 1576", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Capt L. D. Christensen and Lt J. A. King acting as project engineers. This is the final report on this work, and it presents all the information obtained during the contract period, July 8, 1950 - August 7, 1952.

ABSTRACT

This report is a compilation of all the information obtained under Contract No. AF 33(038)-14593, concerned with means of increasing the availability of synthetic lubricants for use at low and high temperatures.

The diesters of straight-chain dibasic acids lead the field of esters suitable as lubricants for use at both low and high temperatures, because of their desirable combinations of properties and potentially good availability. Adipic, azelaic, and sebacic acids are the most readily available dibasic acids suitable for ester lubricant production, while the petroleum derived Oxo alcohols appear to be the most available alcohols for this application. In addition, however, certain diesters of polypropylene glycols appear equivalent to dibasic acid esters in all the characteristics studied so far, and this type of ester therefore represents a promising source of synthetic oil. Mono-esters may be satisfactory lubricants where high temperatures are not encountered. The presence of small quantities of impurities are believed to cause variations in the oxidation and thermal stability of esters. The SAE E.P. Lubricants Tester is capable of measuring the load-carrying ability of synthetic lubricants, but further work is required to develop a completely reliable test for predicting full-scale gear performance.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Directorate of Research

TABLE OF CONTENTS

		Page
I	INTRODUCTION.	1
II	RAW MATERIALS AVAILABILITY.	2
III	LITERATURE SURVEY	3
IV	ESTER EVALUATION.	5
	A. Synthesis	5
	B. Properties Desired in Synthetic Lubricants.	5
	C. Viscosity-Temperature Characteristics and General Properties	6
	D. Viscosity-Volatility Characteristics.	6
	E. Stability	7
	F. Lubrication Characteristics	8
V	CONCLUSIONS	10
APPENDIX I	. . . . .	12
	Tables - Compilation of Physical Properties Found in the Literature for Esters.	12
APPENDIX II.	. . . . .	48
	A. Tables - Results of Ester Evaluation Carried Out Under Contract AF 33(038)-14593.	48
	B. Figures	74
APPENDIX III	FIFTH QUARTERLY PROGRESS REPORT.	101
APPENDIX IIIA	METHOD FOR VAPOR PRESSURE DETERMININATION	117
APPENDIX IV	SIXTH QUARTERLY PROGRESS REPORT	124
APPENDIX V	SEVENTH QUARTERLY PROGRESS REPORT	148

LIST OF TABLES

Table		Page
1	Bibliography	13
2	Adipates	14
3	Adipates	15
4	Adipates	16
5	Substituted Adipates	17
6	Sebacates	18
7	Sebacates	19
8	Azelates and Pimelates	20
9	Azelates and Pimelates	21
10	Esters of Other Dibasic Acids	22
11	Esters of Other Dibasic Acids	23
12	Mono-Esters	24
13	Mono-Esters	25
14	Diesters From Glycols	26
15	Diesters From Glycols	27
16	Diesters From Glycols	28
17	Esters From Polyhydric Alcohols	29
18	Esters From Polyhydric Alcohols	30
19	Esters From Polyhydric Alcohols	31
20	Esters From Dibasic Acids Containing Ether-Oxygen Atoms	32
21	Esters Containing Ring Structures	33
22	Esters Containing Ring Structures	34
23	Esters From Hydroxy-Acids	35
24	Esters From Alkenylsuccinic Acids	36
25	Compounds Containing Sulfur	37
26	Compounds Containing Phosphorus	38
27	Other Phosphates And Borates	39
28	Carbonated And Urea Derivatives	40
29	Other Compounds Containing Nitrogen	41
30	Complex Esters - Acid Center	42
31	Complex Esters - Glycol Center	43
32	Complex Esters - Glycol Center	44
33	Complex Esters From Hydroxy Acids	45
34	Complex Esters From Hydroxy Acids	46
35	Complex Esters	47
36	Properties of Mono-Esters	49
37	Properties of Dibasic Acid Esters	50
38	Properties of Other Mono-, Di-, and Tribasic Acid Esters	51
39	Properties of Polyhydric Alcohol Esters	52
40	Properties of Other Polyhydric Alcohol Esters	53
41	Properties of Miscellaneous Synthetic Lubricant Materials	54

LIST OF TABLES (CONT'D)

Table		Page
42	Low Temperature Properties of Esters.	55
43	Viscosity-Volatility Properties of Mono-, Di-, and Tribasic Acid Esters	56
44	Viscosity-Volatility Properties of Polyhydric Alcohol Esters.	57
45	Oxidation Inhibitors In Di-2-Ethylhexyl Sebacate. . .	58
46	Oxidation Inhibitors In Di-2-Ethylhexyl Sebacate. . .	59
47	Oxidation Inhibitors In Di-2-Ethylhexyl Sebacate. . .	60
48	Performance of Oxidation Inhibitors At 347°F. In Di-2-Ethylhexyl Sebacate	61
49	Oxidation Stability of Esters At 347°F. (175°C.). . .	62
50	Hydrolytic Stability of Synthetic Lubricants.	63
51	Thermal Stability-Studies At 392°F.	64
52	Thermal Stability Studies At 392°F.	65
53	Thermal Stability of Esters At 455°F.	66
54	SAE-SOD Test Conducted in SAE E. P. Lubricant Testing Machine	67
55	Effect of Operating Conditions Of Failure Load In SAE Machine	68
56	Effect of Operating Conditions On Failure Load in SAE Machine	69
57	Lubrication Studies in 4-Ball E.P. Tester	70
58	Lubrication Studies in 4-Ball E.P. Tester	71
59	Oxidation Stability of Esters At 347°F.	72
60	Properties of Di-C8 Oxo Adipate (Plexol 244).	73

LIST OF ILLUSTRATIONS

Figure		Page
1	Effect of 0.3% $NaSHO_4$ Catalyst on Esterification Rate of C_{10} OXO Adipate.	75
2	Effect of Catalysts on Esterification Rate of C_{10} OXO Azelate.	76
3	Low Temperature Viscosities of Dibasic Acid Esters . . .	77
4	Vapor Pressure - Temperature Characteristics of Synthetic Lubricants	78
5	Vapor Pressure - Temperature Characteristics of Synthetic Lubricants	79
6	Vapor Pressure - Temperature Characteristics of Synthetic Lubricants	80
7	Vapor Pressure - Temperature Characteristics of Synthetic Lubricants	81
8	Vapor Pressure - Temperature Characteristic of Synthetic Lubricants	82
9	Vapor Pressure - Temperature Characteristics of Synthetic Lubricants	83
10	Vapor Pressure - Temperature Characteristics of Synthetic Lubricants	84
11	Vapor Pressure - Temperature Characteristics of Synthetic Lubricants	85
12	Vapor Pressure - Temperature Characteristics of Synthetic Lubricants	86
13	Vapor Pressure - Flash Point Relationship of Synthetic Lubricants	87
14	Evaporation of Synthetic Esters - 392°F Evaporation Test	88
15	392°F Evaporation Test - Evaporation Versus Vapor Pressure at 400°F.	89
16	Effect of Viscosity and Chemical Structure on Failure Load in SAE-SOD Test	90
17	Effect of Surface-Active Ingredients on Failure Load in SAE-SOD Lubricant Test	91
18	Correlation of Load Carrying Ability in SAE-SOD vs IAE Gear Machine Test.	92
19	Correlation of Failure Load in SAE-SOD Test Using Different Loads During Run-In and Test Cups From Different Batches	93
20	Effect of Shaft Speed on Failure Load in SAE Machine . .	94
21	Effect of Loading Rate on Failure Load in SAE Machine. .	95
22	Effect of Loading Schedule on Failure Load in SAE Machine at 750 and 1000 RPM.	96
23	Effect of Loading Schedule on Failure Load in SAE Machine.	97

LIST OF ILLUSTRATIONS (CONT'D)

Figure		Page
24	Effect of Run-In Schedule in SAE Machine on Failure Load	98
25	Effect of Run-In Schedule on Failure Load in SAE Machine	99
26	Effect of Acid Chain Length on Viscosity-Volatility Properties of Dibasic Acid Esters	100
27	General Appearance of the Vapor Pressure-Boiling Point Apparatus	119
28	Apparatus for Vapor Pressure-Boiling Point Measurement	120
29	Vapor Pressure-Temperature Relationship for n-Butyl Phthalate	123

I — INTRODUCTION

The work done under this contract has been defined in a general way as a study of means for increasing the availability of ester-type synthetic lubricants suitable for aircraft application. This study has been approached in two ways: (1) A survey of the potential availability of raw materials; and (2) evaluation of many types of esters in an effort to find a wider selection of suitable products from which finished oils could be developed. It is believed that the most worthwhile contribution of this work has been obtained from the second approach, which has resulted in the cataloguing of some critical properties of a wide variety of esters. This project involved, first, an extensive survey of data already available in the literature and some unpublished reports, and, second, expansion of these data by evaluation of more critical properties for known types of esters. All of the information obtained during the two years' work is compiled in the Appendix to this report. Appendix I covering the literature survey, Appendix II, the results of the additional work, and Appendix III, IV, & V giving the more important conclusions reached during these studies.

In this report the salient points and important conclusions revealed by each phase of the work carried out will be mentioned and referred to in the appropriate appendix. For a detailed discussion of the data the reader will be referred to the proper appendix. The reader will also be referred to the Appendix tables of this report for the complete data on a given phase of work or type of ester.

II — RAW MATERIALS AVAILABILITY

An attempt was made to estimate the potential availabilities of some of the more prominent ester raw materials. However, it was quickly apparent that it was impossible in certain cases for a private company to make reliable estimates, since proprietary information was involved. The best availability figures possible, without access to the actual production capacities, were presented in the AF Technical Report No. 6663. It was understood that the Aircraft Production Resources Division was making a more complete and reliable survey.

Some generalizations on availability are possible without actual production statistics. Of the chain-type dibasic acids suitable for ester lubricant manufacture, sebacic, azelaic, and adipic acids lead the field from the standpoint of availability. Potentially the most available of these is adipic acid because it can be derived from petroleum. For the same reason the Oxo alcohols have the best potential availability among the alcohols suitable for ester lubricants. Alcohols such as 2-ethylhexanol are also usually regarded as suitable for this application. However, it is possible that the starting raw materials for producing this alcohol (ethanol or acetylene) may have other strategic uses in time of emergency, and it is not certain that 2-ethylhexanol can be counted on for ester production. Glycols produced from ethylene oxide or propylene oxide will probably be available in reasonable quantities, although once again, ethylene and propylene may be required in other critical applications.

III - LITERATURE SURVEY

In Appendix I to this report, data have been compiled from various literature sources for over 800 compounds (mostly esters) of possible interest as synthetic lubricants. Appendix I Table 1 presents the bibliography for this report, and a number is assigned to each literature data source. The appropriate reference numbers are then found in the first column of the succeeding tables of data in Appendix I. Following is a list of the types of compounds for which the literature data may be found in the designated tables:

Compound Type	Appendix Table Number
Adipates	2, 3, 4
Substituted Adipates	5
Sebacates	6, 7
Azelates and Pimelates	8, 9
Esters of Other Dibasic Acids	10, 11
Mono-esters	12, 13
Diesters from Glycols	14, 15, 16
Esters from Polyhydric Alcohols	17, 18, 19
Esters from Dibasic Acids Containing Ether-Oxygen Atoms	20
Esters Containing Ring Structures	21, 22
Esters from Hydroxy-Acids	23
Esters from Alkenylsuccinic Acids	24
Compounds Containing Sulfur	25
Compounds Containing Phosphorous	26, 27
Carbonates and Nitrogen Compounds	28, 29
Complex Esters	
Acid Center	30
Glycol Center (without ether oxygens)	31
Glycol Center (with ether oxygens)	32
From Hydroxy-Acids	33, 34
Three Ester Groups Per Molecule	35

Along with providing a useful compendium of available information on ester-type lubricants, the literature survey furnished the necessary background for the further studies required. It was concluded from

this survey that esters, in general, had very desirable combinations of properties and warranted the serious consideration they have received as synthetic lubricants. It was also apparent that ester lubricants of nearly any desired viscosity could be made from widely available or potentially available raw materials. However, a considerable amount of further work appeared necessary to determine if esters were satisfactory as lubricants from all critical standpoints and if there were preferred types of esters among those of wide availability. To answer these and related questions, it was evident that the data available in the literature required expansion to include volatility, low temperature, stability, and lubrication properties of promising materials. Efforts were therefore turned toward the ester evaluation phase of the project.

IV – ESTER EVALUATION

All of the evaluation results obtained during the two years under the contract are presented in detail in Appendix II. For this work it was necessary to synthesize some esters in the laboratory to supplement those procured from commercial suppliers. These materials, designated in the tables as "laboratory preparations" were for the most part specific members of homologous series already known in the art. A search for new types of esters was not an object of this project.

A. Synthesis

The techniques used in preparing esters in the laboratory were thoroughly discussed in the AF Technical Report No. 6663. In general, the products were synthesized in the conventional manner employing commercial grade reactants. Either p-toluene sulfonic acid monohydrate or sodium hydrogen sulfate (usually 0.3 to 0.5% based on the ester) was used as catalyst. The effect of the catalyst on esterification rate is depicted in Figures 1 & 2 of Appendix II. The esters prepared in the laboratory were generally refined by vacumn distillation to produce a wide heart-cut for evaluation. The most effective acidity reduction method, employed after distillation, was adsorption on animal charcoal. High quality esters were prepared in this fashion.

B. Properties Desired in Synthetic Lubricants

The ever widening temperature range over which a lubricant must perform all of its functions has led to a steady increase in the use of synthetic oils. In many kinds of aviation equipment, and particularly in high-power gas turbine aircraft engines, synthetic lubricants are replacing inadequate mineral oils. Each piece of equipment may require some specific properties in the lubricant, but nearly all applications there are some fundamental lubricant properties which are important. In general, it is these fundamental properties which have been evaluated for the variety of esters studied in this project. These desired characteristics include:

1. Good viscosity-temperature relationship
2. Good viscosity-volatility relationship
3. Low melting and pour points
4. Stability toward oxidation, hydrolysis, and heat
5. Good lubrication characteristics

The following sections of the report designate in what Appendix tables and figures the data relating to these properties may be found. Pertinent conclusions arising from this work are discussed in Section V.

C. Viscosity-Temperature Characteristics and General Properties

The kinematic viscosities from 210° to -65°F of all lubricant materials either procured from commercial suppliers or synthesized in the laboratory are presented in Appendix II Tables 36 through 60. Viscosity-temperature relationships are expressed by three systems: ASTM Slope, V.I., and Hardimann and Nessen V.I.* Other general properties, including neutralization numbers, flash, fire, pour, and melting points, are also shown in these tables. Although flash points, and in some cases, vapor pressures, are presented, the subject of volatility is more adequately covered in succeeding tables. The effects of ester structure on viscosity-temperature characteristics are discussed thoroughly in the AF Technical Report No. 6663 and in Appendix IV.

The properties obtained for esters of mono-, di-, and tri-basic acids are given in Tables 36, 37, and 38. Polyhydric alcohol esters are covered in Tables 39 and 40, and some miscellaneous synthetic lubricant materials are given in Table 41. The low temperature viscosities for a series of adipates, azelates, and sebacates are depicted graphically in Appendix II Figure 3, and some other important low temperature properties for a variety of esters are shown in Table 42.

D. Viscosity-Volatility Characteristics

There are three common ways of measuring volatility: by determining vapor pressure, flash point, or evaporation rate. All three have been studied and employed to some extent in this program. The vapor pressure apparatus and procedure used are described in detail in Appendix III. It is a boiling point method which included distilling off an initial portion of the sample to avoid errors due to volatile contaminants. The evaporation apparatus and technique are described in Appendix IV.

The vapor pressure-temperature relationships for the esters on which vapor pressures were obtained are shown graphically in Appendix II Figures 4 through 12. The experimental points are plotted as log vp vs. 1/(t+230), with t being °C. In most cases the experimental data would conform just as well to lines representing log vp vs. 1/(t+273). However, the constant 230, as proposed by Cox,** should provide a better fit for the data over a larger portion of the liquid range and allow more accurate extrapolation. Vapor pressure-temperature data, taken from these figures, are also presented in Tables 43 and 44, along with viscosity

* Described in AF Technical Report No. 6663
** Cox, Ind. Eng. Chem., 28, 613 (1936)

data for the same materials. The boiling point of each compound at 2 mm. pressure is one measure of its volatility. The temperature at which each compound has thickened to 10,000 cs. (obtained from ASTM viscosity–temperature plots) is presented in Tables 43 and 44 as one measure of that compound's low temperature viscosity. The difference between these two temperatures is then an indication of the viscosity–volatility properties of the material, and may have some practical significance as an indication of the acceptable operating temperature range possible with the lubricant. This temperature difference, or Viscosity–Volatility Index as it might be termed, depends considerably on viscosity level, as would be expected. Therefore, comparisons of various compound types should be made at common levels of viscosity. The Viscosity–Volatility Indices are also tabulated in Tables 43 and 44. The significance and shortcomings of the Viscosity–Volatility Index are described in detail in Appendix III.

Flash point is a much simpler determination than vapor pressure. However, flash point is likely to reflect the presence of a small quantity of volatile contaminant rather than the volatility of the synthetic lubricant itself. Therefore, the correlation of flash point with vapor pressure gives some badly scattered points, as shown in Appendix II Figure 13. This correlation is improved, as shown, if two lines are drawn – one for carefully distilled esters (volatile contaminants removed), and one for esters which do not get this careful refinement.

Evaporation rate is probably a more realistic measure of lubricant volatility than either vapor pressure or flash point. The evaporation data obtained for a number of lubricants are presented in Figure 14. The amount of material evaporated (wt. % after 1 hr. at 392°F.) was found to correlate rather well with the vapor pressure of the lubricant (mm. at 400°F.), as shown in Figure 15.

E. Stability

1. Oxidation Stability

In order to study the oxidation stability of a variety of esters, it was necessary first to select an effective inhibitor which could be used in these esters, in common, and thus allow direct comparisons. Consideration was devoted toward screening a number of inhibitors for this purpose. These inhibitors, in di–2–ethylhexyl sebacate, were first evaluated in the Oxidation/Corrosion Stability Test at 250°F. (MIL–O–6081) and in an oxygen absorption rate test at 392°F. Results are presented in Appendix II Tables 45, 46, and 47. Promising inhibitors were next examined in a modification of the MIL–L–6387 Oxidation/Corrosion Stability Test at 347°F. The results, shown in Table 48, indicated phenothiazine to be superior

to the other inhibitors evaluated. Because of this performance, and the fact that phenothiazine was finding expanding application in the synthetic lubricant field, it was selected as the inhibitor for the ester evaluation work.

The oxidation stability of esters (inhibited with phenothiazine) was found to be affected to a large extent by apparently small quantities of impurities in the esters. This fact complicated the stability work and made reliable comparisons difficult. The data obtained on the stability of esters to oxidation are shown in Table 49. These data are discussed in Appendix IV.

2. Hydrolytic Stability

A limited number of esters were examined in the MIL-L-6387 Hydrolytic Stability Test. Results are presented in Table 50, and are discussed in AF Technical Report 6663.

3. Thermal Stability

A simple test was used to study thermal stability. The ester was maintained at 392°F for 48 hours under nitrogen, and decomposition was calculated from the change in acidity. A large number of esters were investigated in this test and the data are tabulated in Tables 51 and 52. When it became known that temperatures above 392°F were being attained in some aircraft equipment, some similar thermal stability tests were run at 455°F. The results are presented in Table 53. Thermal stability is discussed thoroughly in Appendix IV.

F. Lubrication Characteristics

Nearly all simple, uncompounded esters are similar in lubrication characteristics. Good load-carrying and anti-wear properties therefore require proper compounding. However, development of finished lubricants with good load-carrying ability is hampered by the lack of reliable laboratory test methods, which could be used for initial exploratory work. The last few months of this project were devoted to a study of laboratory test machines, primarily the SAE E.P. Lubricants Tester. It was desired to learn more about what lubrication qualities these machines would measure, and this perhaps led the way toward development of a test for predicting lubricant performance in high-speed, highly loaded gears, - the critical area of new design aircraft engines. The results of these lubrication studies are described in detail in Appendix V.

In the SAE machine the effects of varying operating conditions such as speed, shaft speed ratio, loading rate, and run-in schedule were first investigated. Based on this work, a test technique (designated

the SAE-SOD Test) was chosen for additional study. The operating conditions of this test are summarized in the following table:

SAE-SOD Test in SAE E.P. Lubricants Tester

Main Shaft Speed	1000 RPM
Shaft Speed Ratio	3.4/1
Test Cups	Timken T-48651
Run-in Schedule (several were used)	50 to 200 lbs. for 2 minutes
Loading After Run-in	Manual, stepwise, 50 lbs. at 10 second intervals.
Failure Load	Minimum load at which scuffing of test cups occurs.

This test was found to be sensitive to the viscosity and chemical structure of the lubricant, as shown in Appendix II Figure 16. Surface-active ingredients in the lubricant could also be detected, as shown in Figure 17. As depicted in Figure 18, the SAE-SOD appeared to correlate rather well with the IAE Gear Machine test. However, after Figure 18 was drawn, some contradictory results were obtained on two lubricants from the Petroleum Refining Laboratory at the Pennsylvania State College. In the SAE machine PRL 3313 gave 1300 lbs. failure load, while PRL3312 (similar composition of lower viscosity) did not fail up to 2000 lbs. load. It is difficult to explain these results when viscosity level is considered.

All of the data obtained in the work with the SAE machine are presented in Appendix I Tables 55 and 56. The effects of differences in test cups (batch to batch), shaft speed, loading rate, and run-in schedule are shown graphically in Appendix II Figures 19 through 25. This information is presented since it may be of value to other workers who wish to continue the development of this type of test.

Tables 57 and 58 show the limited amount of data obtained in the Shell 4-Ball E.P. Tester. There does not appear to be a viscosity function in this machine, but surface-active agents are readily detected.

V - CONCLUSIONS

The more important conclusions reached during these studies have been stated in previous reports and are reiterated below:

(1) Esters, in general, conform to some common rules concerning structure. Side-chain branching gives low pour points, but is detrimental to viscosity-temperature and viscosity-volatility characteristics. Unbranched esters have high pour points but good viscosity-temperature and viscosity-volatility properties. Optimum branching therefore gives the best combination of properties.

(2) Esters, in general, have very desirable combinations of properties, and it is apparent that ester-type synthetic lubricants of nearly any desired viscosity could be made from raw materials of potentially wide availability.

(3) Adipic, azelaic, and sebacic acids are the most readily available dibasic acids suitable for synthetic ester manufacture, while the petroleum derived Oxo alcohols appear to be the most available alcohols for ester production. The diesters of these straight-chain dibasic acids lead the field of esters suitable as lubricants for use at both low and high temperatures, from the standpoint of outstanding properties as well as potentially high availability. However, diesters of certain polypropylene glycols, in which the terminal groups are composed of straight-chain monobasic acids, are equivalent to dibasic acid esters in all the characteristics studied under this project. If this type of glycol ester is not deficient from some other performance standpoint, it represents a promising alternate source of synthetic oil base stock.

(4) Mono-esters with the optimum degree of branching should be useful lubricants when flash points of 300-325°F. are adequate but excellent low temperature properties are essential. Optimum branching can be obtained through the esterification of a straight-chain acid with a branched alcohol.

(5) Unlike other alcohols produced by the Oxo process, C_9 Oxo alcohol produced from diisobutylene is not suitable as a raw material for synthetic oils. The esters prepared from this alcohol invariably have unexplainably poor low temperature properties.

(6) A large number of esters do not have linear viscosity-temperature lines on an ASTM chart. Most deviations from linearity are upward at low temperatures; a few are downward. The only generalization which can be stated at present is that molecules of the "dense center" configuration give the downward curvature.

(7) The persistence of the liquid state at low temperatures is not accurately described by pour point for most esters. These materials supercool considerably below their actual melting point. Service experience with ester-type oils will disclose whether this supercooling can always be expected and relied on.

(8) Flash point is the simplest measure of ester volatility, but it is markedly influenced by relatively unimportant quantities of volatile contaminants. Vapor pressure is the most fundamental measure of volatility, but complex apparatus is required for this determination. Evaporation rate is probably the most realistic volatility measurement, and the results correlate with the fundamental property of vapor pressure.

(9) Significant variations in oxidation stability are obtained among different batches of the same ester (inhibited). The same is true, to a lesser degree, of thermal stability. Impurities are believed to be the major cause of these differences.

(10) The esters of carboxylic acids are stable to hydrolysis under the conditions of the MIL-L-6387 Hydrolytic Stability Test.

(11) Most esters show very little thermal decomposition up to at least 392°F. Significant exceptions are the dibasic acid esters of secondary alcohols, which have relatively poor thermal stability. However, diesters of certain polypropylene glycols, despite their secondary hydroxyl linkages, are thermally stable at least up to 455°F.

(12) The SAE E.P. Lubricants Tester is capable of measuring the load-carrying ability of synthetic lubricants. A promising test, which is sensitive to viscosity, chemical structure, and surface-active ingredients, has been developed in the SAE machine. However, further work is required before this test can be relied on to predict full-scale gear performance.

(13) The 4-Ball E.P. Test is sensitive to surface-active ingredients but not to the viscosity of the lubricant.

APPENDIX I TABLES

COMPILATION OF PHYSICAL PROPERTIES FOUND IN LITERATURE FOR ESTERS

TABLE I

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TABLE 2

ADIPATES

Ref.	Alcohol	Viscosity /°F., Cs 210	100	0	-40	V.I.	ASTM Slope 210-100°F.	Freezing Point °F.	Pour Point °F.	Sp. Gr. 20°C.	Flash Point °F.	Almen wts. carried Grad. Loading
(1)	Isopropanol	1.16	2.92	Froze	-	-	0.86	+30		0.955		
(1)	Pentanol-3	1.53	4.54	41.6	-	-	0.85	+1		0.928		
(1)	Pentanol (Sharples)	1.56	4.58	40.3	255	-	0.84	<-108		-		
(1)	3-Methylbutanol-1	1.73	4.94	36.8	-	125	0.78	-44		0.938	325	
(1)	1,3-Dimethylbutanol-1	1.79	5.64	67.9	623	96	0.82	+36		0.919	320	
(1)	2-Ethylbutanol	1.89	5.68	51	297	123	0.77	-15		0.934	-	
(4)	"	1.77	5.35			-	0.80	<-98		0.946	-	
(1)	2-Ethylhexanol	2.38	8.22	107	807	121	0.763	-90		0.922	380	
(4)	"	2.39	8.28		819	120	0.763		<-70	-	360	
(4)	"	2.26	7.83			109	0.782		<-98	0.925		
(4)	" (Harlube DA)	2.31	8.13			108	0.783		-94	0.927	425	
(4)	" (Bisol)	2.39	8.28			120	0.763		<-70			
(4)	n-Octanol	2.85	8.75			187	0.652		+50	0.919		
(5)	C_8 Oxo	2.80	10.01			140	0.724		<-70	0.917	450	
(7)	C_8 Oxo (Plexol 244)	2.84	10.15		990	143	0.720		-110		410	
(5)	Octene-2-ol-1	2.45	9.46			86	0.804		<-75			5
(5)	Branched Chain Alcohols (E-504)	2.47	8.96		1245	111	0.774		<-60		300	
(5)	I.C.I. Alcohols	2.51	8.85			124	0.755		<-75		325	2
(6)	C_9 Oxo (Esso)	3.34	13.3			141	0.720		<-70		365	
(6)	" "	3.47	13.1			162	0.688		<-70			
(8)	C_9 Oxo (Harlube NA)	3.40	12.87			160	0.694		-85	0.917	450	
(4)	C_9 Oxo Leuna	3.21	12.70			136	0.728	<-98	<-70	0.918		
(5)	C_{10} Oxo	3.60	14.74			147	0.710		<-75		390	10
(5)	C_{10}-C_{12} Oxo	3.17	12.27		1617	149	0.723		-45		420	12
(5)	C_{12}-C_{14} Oxo	4.64	20.93			156	0.680		-5		435	12
(1)	1-Methyl-4-ethyloctanol-1	3.72	17.5	548	8310	112	0.754		<-80	0.901		
(1)	1-(2-methylpropyl)-4-ethyloctanol-1	5.14	34.3	2300	65000	80	0.783		-60	0.885	445	
(1)	1-(3-ethylamyl)-4-ethyloctanol-1	6.22	42.6	2300	50000	102	0.743		-60	0.884	-	
(5)	1-m-2-ethylhexanol + 1-m-OPE-5	11.60	97.40			113	0.668		-20		470	12
(4)	Cyclohexanol	4.42	12.90 (122°F.)			-	0.672		+104			
(4)	3 and 4 Methyl Cyclohexanol	4.64	27.70			87	0.774		-62	1.002		
(4)	C_9 Oxo Leuna	3.21	12.70			136	0.728	<-98		0.918		
(4)	C_9 Oxo Leuna + 1-m-Ethyleneoxide	4.30	18.30			165	0.678	-85		0.948		
(4)	" + 2-m " " "	5.74	27.40			154	0.640	-72		0.976		
(4)	+ 4-m " " "	7.72	40.90			147	-0.622	-62		1.002		
(4)	+ 6-m " " "	10.00	54.10			148	0.581	-36		1.021		
(4)	Leuna Alcohol (356-482°F.) E-515	3.65	16.40			122	0.741	-92	-87	0.930		
(4)	" " + 2-m Ethylene Oxide	4.96	24.60			141	0.696	-74		0.972		
(5)	Butyl Cellosolve	2.26	7.41			129	0.754		<-35		415	4
(1)	Ethylbutyl Cellusolve	2.68	9.23	134	1290	144	0.723		<-80	0.966		
(5)	Hexyl Cellosolve	2.82	9.94			146	0.716		+5		415	6
(5)	Etnyl Carbitol	5.99	30.32			147	0.661		-45			10
(1)	Butyl Carbitol	3.29	12.2	205	2105	159	0.695	+12		1.010		
(5)	Butyl Carbitol	3.47	13.34			158	0.695		<-35		450	13
(5)	Dowanol 50B (Dipropylene Glycol mono methyl ether)	2.82	11.01			113	0.760		<-75		390	3
(5)	Dowanol 62B (Tripropylene Glycol mono methyl ether)	4.30	19.72			146	0.705		-65		-	15
(5)	Dowanol 36A (Propylene Glycol mono isopropyl ether)	2.08	6.99			102	0.796		<-75		325	4
(5)	Dowanol 53A (Dipropylene Glycol mono isopropyl ether)	3.52	14.70			137	0.724		-65		380	6

TABLE 3

ADIPATES

Ref.	Acid	Alcohol	Viscosity /°F., Cs. 210	Viscosity /°F., Cs. 100	V.I.	ASTM Slope 210-100°F.	Freezing Point °F.	Pour Point °F.	Sp. Gr. 20°C.	Flash Point °F.	Almen wts. carried Grad. Loading
(4)	Alpha-Methyl Adipic	n-Octanol	2.66	9.33	137	0.734	-26		0.927		
(4)	" " "	Leuna Alcohols (356-482°F.)	4.07	20.29	104	0.759	-76		0.933		
(4)	" " "	n-Dodecanol	4.28	17.30	177	0.660	+61		0.913		
(4)	" " "	Leuna Alcohols + 2 m Ethylene Oxide	6.25	32.80	143	0.663	-65		0.980		
(4)	" " "	n-Dodecanol + 2 m Ethylene Oxide	4.53	12.40 (122°)	-	0.632	+97		-		
(6)	Methyl Adipic (from Sextol)	C_9 I.C.I. Alcohol	3.51	13.97	-	0.706	-	<-60	-		
(4)	Beta-Methyl Adipic	2-Ethylbutanol	2.02	6.49	113	0.784	-98		0.943		
(4)	" " "	n-Octanol	2.90	9.22	180	0.663	-33		0.920		
(4)	" " "	2-Ethylhexanol	2.61	9.43	124	0.753	-98		0.910		
(4)	" " "	C_9 Oxo Alcohol (Leuna)	3.52	14.60	139	0.721	-94		0.916		
(4)	" " "	n-Dodecanol	4.71	18.60	183	0.630	+50		0.898		
(4)	" " "	Leuna Alcohol (356-482°F.)	4.16	21.20	111	0.751	-74		0.913		
(4)	" " "	Cyclohexanol	4.48	27.27	72	0.790	-58		1.025		
(4)	" " "	3 and 4-methylcyclohexanol	4.28	25.73	63	0.798	-51		0.993		
(4)	" " "	C_9 Oxo Alcohol (Leuna)	3.52	14.60	139	0.721	-94		0.916		
(4)	" " "	" " + 1-m-Ethylene Oxide	4.73	21.90	152	0.685	-76		0.950		
(4)	" " "	" " + 2-m " "	6.16	29.07	157	0.633	-67		0.974		
(4)	" " "	" " + 4-m " "	8.31	42.30	151	0.596	-58		0.998		
(4)	" " "	" " + 6-m " "	12.50	75.20	142	0.574	-3		1.038		
(4)	Dimethyl Adipic	C_9 Oxo (Leuna)	3.53	15.00	133	0.730	-90		0.916		
(4)	" "	Leuna Alcohols (356-482°F.)	4.29	24.20	85	0.777	-71		0.932		
(5)	Trimethyl Adipic	C_8 Oxo Alcohol (Esso)	3.20	13.79	108	0.764		<-35			3
(5)	" "	C_9 Oxo Alcohol (Esso)	4.32	22.71	110	0.751		<-35			5
(5)	" "	n - Decyl Alcohol	3.79	16.68	154	0.724		<-35			3
(5)	" "	n - Dodecyl Alcohol	4.75	21.42	158	0.674		+5		465	10
(5)	" "	Ocenol	14.08	89.30	140	0.568		+30		415	4
(5)	" "	tert. $C_8H_{17}S$ CH_2CH_2OH	41.94	616.9	111	0.595		0		-	-
(5)	" "	Phenyl Cellosolve	6.97	117.3	-108	0.945		+20		-	1
(5)	" "	Butyl Carbitol	3.70	16.05	136	0.724		<-35		-	4
(5)	" "	2-Ethylhexyl carbitol	3.99	17.64	145	0.711		<-35		320	13
(5)	" "	Dowanol 50B (Dipropylene Glycol mono methyl ether)	3.09	14.12	79	0.798		-55		-	-
(5)	" "	Dowanol 65A (Tripropylene Glycol mono isopropyl ether)	18.13	170.0	118	0.618		-20		310	2
(5)	n-Octadecyl Adipic	C_9 Oxo	8.16	46.84	140	0.635		+25		550	7
(5)	" "	C_{10} Oxo	7.20	44.13	137	0.657		+60		420	10
(5)	" "	1-m n-Amyl + 1-m C_{13} Oxo	10.53	85.00	114	0.676		+55		425	4
(5)	Beta Carboxy Adipic	C_8 Oxo Alcohol	4.64	24.27	122	0.731		-50		425	4
(5)	" " "	2-m n-Decyl + 1-m n-Butyl	4.41	19.64	155	0.689		-20		435	8

TABLE 4

ADIPATES

Ref.	Alcohol	Viscosity, Cs. @ °F. 210	Viscosity, Cs. @ °F. 100	V.I.	ASTM Slope 210/100°F.	Pour Point, °F.	Specific Gravity, 20°C.	Flash Point, °F.
(10)	Methyl	0.85	2.14	--	1.013	+41	1.062	282
(10)	Ethyl	0.99	2.31	--	0.877	-8		280
(10)	n-Butyl	1.49	3.68	--	0.748	-13		338
(10)	Isobutyl	1.56	4.08	--	0.766	+32	0.952	325
(9)	" (duPont)	1.46	4.00	--	0.81	0*	--	--
(9)	Sec.-Butyl (Rohm and Haas)	--	3.64	--	--	--	--	--
(9)	Sec.-Amyl (Rohm and Haas)	---	4.48(a)	--	0.83	<-100*	--	355
(9)	3-Methylbutyl (Rohm and Haas)	1.70	4.87	122	0.78	<-80*	--	--
(10)	C_5 Alcohol (Synth.)	1.75	4.76	--	0.745	<-108	0.948	329
(9)	Hexyl (Hardesty)	1.77	5.53	97	0.83	+30*	--	335
(10)	Isohexyl	1.98	5.68	--	0.729	-54	0.935	372
(10)	2-Ethylbutyl	1.77	5.35	--	0.799	<-98	0.946	361
(10)	n-Octyl	2.85	8.75	187	0.652	+39	0.919	419
(10)	2-Ethylhexyl	2.26	7.83	109	0.783	<-108	0.925	419
(9)	" (Ohio Apex)	2.35	8.11(b)	118	0.77	<-80*	--	375
(10)	1m. n-Octyl + 1m. 2-Ethylhexyl	2.52	8.50	139	0.734	-11	0.922	405
(10)	1m. n-Octyl + 1m. Leuna Alcohol (329-392°F.)	2.66	9.39	135	0.737	-20	0.919	406
(10)	C_8-C_9 Oxo (Ruhrchemie Cracked Olefins)	2.90	10.1	155	0.703	-9	0.922	419
(10)	C_9 Oxo (Diisobutylene)	3.21	12.7	136	0.728	<-98	0.918	417
(10)	" + 1m. C_2H_4O	4.30	18.3	165	0.678	-85	0.948	419
(10)	C_9 Oxo + 2m. C_2H_4O	5.74	27.4	154	0.640	-72	0.976	464
(10)	" + 4m. "	7.72	40.9	147	0.622	-62	1.002	437
(10)	" + 6m. "	10.0	54.1	148	0.581	-36	1.021	437
(10)	C_9-C_{12} (Duftschmid)	3.52	12.6	180	0.662	-15	0.914	446
(10)	C_{10}-C_{11} Oxo (Ruhrchemie Cracked Olefins)	3.38	13.1	151	0.705	+36	0.914	450
(10)	C_8-C_{10} Oxo + C_{10}-C_{11} Oxo (Ruhrchemie Cracked Olefins)	3.18	11.8	153	0.705	+16	0.918	460
(10)	n-Dodecyl	4.53	12.4 (122°F.)	--	0.632	+97	--	491
(10)	C_{13} Oxo (Triisobutylene)	6.31	42.7	105	0.736	-56	0.907	415
(10)	1m. C_{13} Oxo (Triisobutylene) + 1m. 2-Ethylbutyl	3.34	14.7	110	0.760	-80	0.922	428
(10)	C_{11}-C_{14} Oxo (Ruhrchemie Olefins)	4.46	18.8	170	0.666	+55	0.905	473
(10)	C_{11}-C_{14} Oxo (Ruhrchemie Olefins) + 1m. Leuna Alcohol (356-482)	4.38	19.2	159	0.685	-6	0.917	455
(10)	C_{13} Oxo (Ruhrchemie Olefins)	4.90	21.3	166	0.654	+68	Solid	486
(10)	C_{13} Oxo (Ruhrchemie Olefins) + 1m. Leuna Alcohol (356-482)	4.47	19.8	161	0.680	+41	0.910	446
(10)	C_{16} Oxo (Ruhrchemie Olefins)	6.62	21.1 (122°F.)	--	0.488 (122°F.)	+122	Solid	482
(10)	C_{16} Oxo (Ruhrchemie Olefins) + 1m. Leuna Alcohol (356-482)	5.34	25.3	153	0.666	+72	Solid	464
(10)	C_{16}	7.07	33.4	158	0.605	+90	--	491
(10)	C_{17} Oxo (Tetraisobutylene)	6.38	48.6	84	0.767	-2	0.904	360
(10)	C_{17} Oxo (Tetraisobutylene) + 1m. 2-Ethylbutyl	4.44	23.3	114	0.743	-9	0.922	396
(10)	Leuna Alcohol (284-320) Half Ester + Leuna Alcohol + 5.6m C_3H_6O	4.41	20.6	144	0.805	-83	0.962	399
(10)	Leuna Alcohol (284-329)	2.11	6.90	115	0.778	<-108	0.937	365
(10)	" " (284-356)	2.24	7.86	102	0.791	<-98	0.934	374
(10)	" " (284-392)	2.46	8.39	131	0.747	-105	0.933	367
(10)	" " (284-482)	2.59	8.92	138	0.734	<-98	0.933	374
(10)	" " (320-356)	2.39	8.04	130	0.749	<-98	0.927	361
(10)	" " (320-392) + Synol (320-608) (30%)	2.37	8.42	110	0.778	-47	0.923	342
(10)	" " " " " " " (20%)	2.44	8.71	114	0.770	-62	0.945	356
(10)	" " " " " " " (10%)	2.48	8.45	133	0.744	-80	0.927	383
(10)	" " " " " " " (5%)	2.50	8.46	137	0.738	<-98	0.924	374
(10)	" " (329-392)	2.70	10.0	122	0.753	-94	0.932	392
(10)	" " (329-482)	2.93	11.4	122	0.748	-92	0.930	332
(10)	" " (356-482)	3.65	16.4	122	0.741	-92	0.930	352
(10)	" " " " + 1m. C_2H_4O	4.21	20.6	125	0.734	-78	0.959	410
(10)	" " " " + 2m. C_2H_4O	4.96	24.6	141	0.696	-74	0.972	432
(10)	" " " " + 3m. C_2H_4O	6.16	32.7	141	0.670	-69	0.991	451
(10)	" " " " + Synol (320-608) (5%)	3.30	14.0	119	0.749	-92	0.926	419
(10)	" " (374-482)	3.91	18.0	129	0.732	-81	0.932	374
(10)	" " (392-482)	4.33	21.6	124	0.732	-83	0.930	392
(10)	Gelböl Oxo Alcohol (320-392)	3.40	12.7	163	0.688	-24	0.926	428
(10)	" " " (320-572)	2.75	9.25	156	0.703	<-98	0.932	424
(10)	" " " (360-446)	3.23	12.3	148	0.711	<-98	0.932	403
(10)	" " " (392-572)	3.59	14.9	143	0.716	-51	0.931	446

(a) 246 Cs./-40

(b) 798 Cs./-40

* Melting Point

TABLE 5

SUBSTITUTED ADIPATES

Ref.	Alcohol	Acid	Viscosity, Cs. @ °F. 210	100	V.I.	ASTM Slope 210/100	Pour Pt., °F.	Specific Gr./20°C.	Flash Pt., °F.
(10)	n-Octyl	Alpha-Methyl Adipic	2.66	9.33	137	0.734	-26	0.927	406
(10)	n-Dodecanol	"	4.28	17.3	177	0.660	+61	0.913	448
(10)	Leuna Alcohol (284-356)	"	2.36	8.65	97	0.794	<-98	0.944	358
(10)	" " (284-392)	"	2.36	8.65	97	0.794	<-98	0.945	356
(10)	" " (356-482)	"	4.07	20.3	104	0.759	-76	0.933	385
(10)	Isobutanol	Beta-Methyl Adipic	1.47	4.6	--	0.901	<-98	0.914	320
(10)	Isobutanol + 1m.C_2H_4O	"	2.84	10.8	124	0.747	-90	0.983	387
(10)	Isobutanol + 2m.C_2H_4O	"	4.20	17.9	162	0.685	-76	1.020	459
(10)	Isobutanol + 4m.C_2H_4O	"	6.92	34.2	153	0.624	-47	1.041	448
(10)	Isobutanol + 6m.C_2H_4O	"	8.72	42.7	155	0.577	+9	1.054	500
(10)	2-Ethylbutanol	"	2.02	6.49	113	0.784	<-98	0.943	374
(10)	Cyclohexanol	"	4.48	27.3	71	0.791	-58	1.025	388
(10)	3 and 4-Methylcyclohexanol	"	4.28	25.7	64	0.798	-51	0.993	397
(10)	n-Octanol	"	2.90	9.22	180	0.663	-33	0.920	441
(10)	2-Ethylhexanol	"	2.61	9.43	124	0.753	<-98	0.910	414
(10)	C_8-C_9 Oxo (Ruhrchemie C_7-C_8 Cracked Olefins)	"	2.81	10.8	118	0.755	-69	0.921	401
(10)	C_9 Oxo (Diisobutylene)	"	3.52	14.6	139	0.721	-94	0.916	403
(10)	" + 1/2 m. C_2H_4O	"	6.47	32.8	149	0.645	-65	0.973	496
(10)	" 1 m. "	"	4.73	21.9	152	0.685	-76	0.950	405
(10)	" 2 m. "	"	6.16	29.1	157	0.634	-67	0.974	455
(10)	" 3 m. "	"	6.92	34.9	151	0.630	-65	0.988	442
(10)	" 4 m. "	"	8.31	42.3	151	0.596	-59	0.998	473
(10)	" 5 m. "	"	7.94	42.6	146	0.620	-71	1.001	435
(10)	" 7.5 m. "	"	9.13	50.8	145	0.604	-45	1.011	464
(10)	C_9-C_{12} Oxo (Duftschmid)	"	3.80	14.3	179	0.666	-53	0.911	446
(10)	C_{10}-C_{12} Oxo (Ruhrchemie C_9-C_{11} Cracked Olefins)	"	3.71	14.8	160	0.693	-33	0.909	453
(10)	C_{10}-C_{12} + C_8-C_{10} Oxo (Ruhrchemie Cracked Olefins)	"	3.42	12.9	161	0.691	-56	0.916	430
(10)	C_{11}-C_{14} Oxo (Ruhrchemie)	"	4.64	20.1	165	0.667	-13	0.906	442
(10)	n-Dodecyl	"	4.71	18.6	183	0.630	+50	0.898	464
(10)	C_{13} Oxo (Ruhrchemie) + 1m. Leuna Alcohol (356-482)	"	4.29	19.9	143	0.710	-27	0.910	406
(10)	" " " + 1m. 2-Ethylbutanol	"	4.43	23.3	113	0.744	-72	0.915	381
(10)	C_{16} Oxo (Ruhrchemie)	"	6.79	33.6	153	0.628	+41	0.894	536
(10)	" " " + Leuna Alcohol (356-482)	"	5.08	25.7	126	0.718	-13	0.915	473
(10)	C_{17} Oxo (Tetraisobutylene)	"	6.89	56.4	81	0.768	-2	0.908	360
(10)	Leuna Alcohol (284-320)	"	3.18	13.6	109	0.763	<-94	0.951	374
(10)	" " (284-320) + 5.6m. C_3H_6O	"	7.57	45.1	134	0.661	-69	0.978	441
(10)	" " (284-392)	"	2.51	8.91	122	0.758	<-98	0.926	365
(10)	" " (320-392)	"	2.63	10.5	90	0.794	<-98	0.928	338
(10)	" " (356-482)	"	4.10	21.2	103	0.760	--	0.913	387
(10)	" " (356-482) + 1m. C_2H_4O	"	4.50	23.2	121	0.733	-71	0.955	414
(10)	" " (356-482) + 2m. "	"	6.25	32.8	143	0.663	-65	0.980	396
(10)	" " " + 3m. "	"	8.27	47.4	140	0.631	-47	1.004	424
(10)	" " " + 46% Synol (C_9-C_{13})	"	5.10	28.9	116	0.734	-42	0.943	419
(10)	" " (320-392) + 30% Synol (320-608)	"	2.91	10.7	139	0.726	-92	0.945	319
(10)	" " " + 20% " "	"	2.71	10.9	94	0.787	-71	0.942	356
(10)	" " " + 10% " "	"	2.66	10.7	90	0.794	-98	0.945	396
(10)	" " " + 5% " "	"	2.70	10.6	102	0.778	-78	0.926	365
(10)	Synol (363-399)	"	2.60	9.05	135	0.737	-94	0.922	410
(10)	Gelbol Oxo Alcohol (320-392)	"	2.94	10.7	144	0.719	-94	0.929	392
(10)	" " " (320-572)	"	3.76	16.9	129	0.734	-82	0.933	410
(10)	" " " (360-446)	"	3.40	14.1	132	0.731	-90	0.928	415
(10)	" " " (392-572)	"	3.98	19.1	122	0.740	-76	0.932	433
(10)	C_9 Oxo (Diisobutylene)	Dimethyl Adipic	3.53	15.0	133	0.725	-90	0.916	392
(10)	" " + 1m. C_2H_4O	"	4.67	23.4	133	0.714	-76	0.948	453
(10)	Leuna Alcohol (356-392)	"	4.29	24.2	85	0.777	-71	0.932	435
(12)	2-Ethylhexanol	β-tert Butyl Adipic	3.09	15.1	55	0.824	<-70*	--	--
(12)	"	β-tert Octyl Adipic	5.03	34.4	68	0.795	<-70*	--	--
(10)	Hexanol	3, 4-Dicarboxy Adipic	8.37	57.9	121	0.680	-24	1.044	--

* Melting Point.

TABLE 6

SEBACATES

Ref.	Alcohol	Viscosity/°F., cs. 210	100	0	-40	V.I.	ASTM Slope, 210-100°F.	Freezing Point °F.	Pour Point °F.	Sp. Gr. d 25/4	Flash Pt °F. C.O.C.	Almen Wts. Carried Grad. Loading
(1)	Isopropanol	1.74	4.98	37.6	Froze	125	0.778	+30	--	0.931	--	--
(1)	Butanol-1	2.11	6.11	Solid	--	157	0.715	+14	--	0.932	365	--
(5)	Butanol-1	2.10	6.09	--	--	155	0.718	+20	--	--	365	--
(5)	Sec. Butanol	2.09	6.42	--	--	136	0.749	<-35	--	--	355	--
(1)	Pentanol-3 (sec. amyl)	2.27	7.51	solid	--	123	0.758	-6	--	0.919	380	--
(1)	Pentanol-3 (Sharples)	2.28	7.38	80	504	133	0.746	-108	--	--	--	--
(1)	3-Methyl butanol-1	2.51	7.95	71.4	Froze	158	0.705	+1	--	0.921	--	--
(5)	Pentanol-1	2.38	7.34	--	--	157	0.720	+20	--	--	380	--
(1)	4-Methyl pentanol-2	2.60	9.29	132	1210	125	0.749	+8	--	0.910	--	--
(1)	2-Ethyl butanol-1	2.73	9.13	97.5	Froze	158	0.703	-8	--	0.920	--	--
(1)	2-Ethyl hexanol	3.32	12.6	187	1410	154	0.702	-67	--	0.912	450	--
(6)	"	3.26	12.35	--	1367	--	0.706	--	<-60	--	400	--
(5)	"	3.31	12.64	--	1532	152	0.702	<-90	--	--	430	--
(7)	2-Ethyl hexanol (Plexol 201)	3.31	12.50	5700 (-60)	1450	154	0.701	-70	--	--	430	--
(5)	1-Methyl heptanol (Caprylic)	3.29	12.94	--	--	151	0.719	-10	--	--	410	--
(6)	"	3.53	14.05	--	--	150	0.704	-10	--	--	--	--
(6)	C_8 Oxo Esso	3.94	15.34	--	1280	177	0.667	<-65	--	--	410	--
(6)	C_9 Oxo Esso	4.66	19.78	--	3310	170	0.658	<-60	--	--	--	--
(5)	C_9 Oxo	4.07	16.13	--	--	177	0.665	--	<-35	--	--	--
	C_9 Oxo Leuna	4.71	19.50	--	--	175	0.647	-76	--	0.911	--	--
(5)	Nonyl ICI C_9Oxo	4.61	19.58	--	2220	--	0.661	<-60	--	--	425	--
(5)	C_{11} Oxo	4.50	19.91	--	--	155	0.684	--	+10	--	--	--
(1)	1-Methyl-4-ethyl octanol	4.92	24.5	740	6700	139	0.700	--	<-80	0.890	--	--
(5)	1-Methyl-4-ethyl octanol	4.66	22.83	--	8000	139	0.710	--	-85	--	--	--
(4)	Leuna Alcohol (356-482°F.)	4.45	20.70	--	--	146	0.701	-94	--	0.916	--	--
(1)	Tetradecanol	6.53	44.4	2680	65000	107	0.730	--	-60	0.884	--	--
(1)	Heptadecanol	8.42	60.0	3030	59000	118	0.687	--	-60	0.886	--	--
(5)	Octadecyl phenol	73.57	3121	--	--	71	0.689	--	+35	--	465	--
(6)	Cellosolve	2.63	--	--	530	--	0.713	--	--	--	--	--
(1)	Ethylbutyl Cellosolve	3.59	13.3	207	1880	175	0.671	+9	--	0.950	--	--
	Leuna Alcohols + 2m Ethylene Oxide	8.96	50.60	--	--	143	0.601	-67	--	0.969	--	--
(5)	Dowanol 36A (isopropanol + 1m propylene oxide)	3.00	10.69	--	--	154	0.703	--	<-35	--	400	5
(5	Dowanol 53A (Isopropanol + 2m propylene oxide)	4.77	21.03	--	--	162	0.666	--	<-35	--	440	9
(5)	Dowanol 65A (Isopropanol + 3m Propylene oxide)	8.93	52.65	--	--	139	0.624	--	<-35	--	475	3

TABLE 7

SEBACATES

Ref.	Alcohol	Viscosity, Cs. @ °F. 210	100	-40	V.I.	ASTM Slope 210/ 100°F.	Melting Point, °F.	Flash Pt., °F.	Fire Pt., °F.
(9)	Methyl (Rohm and Haas)	1.39	3.71	--	106	0.82	+75	--	--
(9)	Butyl (Rohm and Haas)	2.10	6.10	--	155	0.70	+25	385	430
(10)	Butyl	2.09	6.02	--	--	0.70	0**	385	--
(9)	Isobutyl	2.22	7.02	--	137	0.72	+25	340	415
(12)	Isobutyl	2.22	7.02	--	137	0.74	-10	--	--
(9)	Sec-Butyl (Rohm and Haas)	--	6.21	308	--	0.75*	<-50	350	400
(12)	Sec-Butyl	2.06	6.2	303	140	0.74	<-70	--	--
(9)	1/3 Each: Butyl, n-Amyl, 2-Ethylhexyl	--	--	--	--	--	+15	--	--
(9)	1-Methylbutyl (Rohm and Haas)	--	7.25	473	--	0.75*	<-100	375	425
(9)	2-Methylbutyl (Rohm and Haas)	2.48	8.00	--	150	0.70	-35	390	450
(9)	n-Amyl (Rohm and Haas)	2.38	7.34	--	157	0.69	+30	380	445
(9)	Dibutyl (50%) + Di-n-Amyl (50%)	--	--	--	--	--	+20	--	--
(9,12)	Sec-Amyl (Plexol 202) (Rohm and Haas)	2.27	7.42	498	129	0.75	<100	370	425
(9)	Mixed Sec-Amyl (Rohm and Haas)	2.25	7.30	483	131	0.74	<100	410	425
(9)	Pentasol	2.45	7.88	--	149	0.70	-30	385	435
(9)	Butyl, benzyl (Hardesty)	2.88	9.82	--	160	0.69	+35	380	460
(9)	1, 3-Dimethylbutyl (Rohm and Haas)	--	9.29	1210	--	0.78*	0	--	--
(12)	1, 3-Dimethylbutyl	2.64	9.24	1500	136	0.74	<-70	--	--
(9)	2-Ethylbutyl (Rohm and Haas)	2.70	9.10	--	152	0.71	-10	385	475
(12)	2-Ethylbutyl	2.70	9.10	--	152	0.71	-40	--	--
(9)	2-Methylpentyl	--	10.8	955	--	0.71*	-35	385	455
(9)	Hexyl (Hardesty)	2.64	9.34	1200	132	0.74	0	400	420
(9)	Heptyl	3.25	11.3	--	174	0.66	+60	425	495
(9)	1-Methylhexyl (Rohm and Haas)	--	10.8	1130	--	0.73*	-15	--	--
(9)	Capryl, benzyl (Hardesty)	3.17	11.9	--	148	0.70	+35	335	430
(9)	Capryl	3.35	13.0	--	149	0.70	+5	--	--
(12)	Octyl	3.56	12.7	--	183	0.66	+72	--	--
(9)	2-Ethylhexyl (Rohm and Haas)	3.28	12.3	1400	155	0.70	<-55	440	495
(10)	2-Ethylhexyl	3.30	12.2	--	--	0.69	<-98**	445	--
(9)	2-Ethylhexyl Sebacate (80%) + n-Amyl Sebacate (20%)	--	--	--	--	--	0	--	--
(9)	2-Ethylhexyl Sebacate (90%) + n-Amyl Sebacate (10%)	--	--	--	--	--	-25	--	--
(9)	2-Ethylhexyl Sebacate (95%) + n-Amyl Sebacate (5%)	--	--	--	--	--	-35	--	--
(12)	Isooctyl (Oxo)	3.83	15.5	220(0°)	163	0.69	-35	--	--
(9)	Isononyl (Oxo)	4.6	18.9	--	176	0.64	-30	--	--
(9)	β-Methoxyethyl	2.47	8.75	--	119	0.75	+35	405	440
(9)	β-Ethoxyethyl	2.79	9.91	--	142	0.71	+25	385	460
(9)	β-Butoxyethyl (Hardesty)	3.02	10.8	--	161	0.70	+5	340	455
(10)	Leuna Alcohol (356-482°F.)	4.45	20.7	--	146	0.70	-94**	469	--
(10)	" " " + 2m. C_2H_4O	8.96	50.6	--	143	0.61	-67**	534	--
(10)	" " " + 4m. C_2H_4O	11.3	79.9(122°)	--	--	0.80*	+72**	491	--

* Slope for widest temperature range for which viscosities are reported.

** Pour Point.

TABLE 8

AZELATES

Ref.	Alcohol	Viscosity, Cs. @ °F. 210	100	-40	V.I.	ASTM Slope*	Melting Point, °F.	Flash Point, °F.	Fire Point, °F.
(9)	Sec-Butyl (Rohm and Haas)	--	5.40	251	--	0.77	<-100	--	--
(9)	Sec-Amyl (Rohm and Haas)	--	6.48	417	--	0.77	<-100	365	395
(9)	Capryl (Rohm and Haas)	3.01	11.22	1350	141	0.73	-10	--	--
(9)	2-Ethylhexyl (Rohm and Haas)	3.01	11.10	1164	144	0.72	<-100	415	495

* Slope for widest temperature range for which viscosities are reported.

TABLE 9

AZELATES AND PIMELATES

Ref.	Acid	Alcohol	Viscosity/°F. cs. 210	100	0	-40	V.I.	ASTM Slope 210-100 °F.	Freezing Point, °F	Pour Pt., °F.	Sp. Gr. d 25/4	Flash Pt., °F. C.O.C.	Almen Wts. Carried Grad. Loading
(1)	Azelaic	1-Ethyl butyl (sec. amyl)	2.09	6.77	72.0	449	117	0.776	<-108	--	0.921	370	--
1)	"	1-Ethyl butyl (Sharples)	2.10	6.66	68.8	429	125	0.764	<-108	--	--	--	--
1)	"	3-Methyl butyl	2.29	7.03	58.5	286	153	0.718	-53	--	0.920	--	--
1)	"	2-Ethyl butyl	2.51	8.17	83.0	500	149	0.718	-49	--	0.928	--	--
1)	"	2-Ethyl hexyl	3.06	11.4	(156)	1190	146	0.717	<-108	--	0.915	445	--
(1)	"	Butyl Cellosolve	2.80	9.49	110	--	156	0.701	+1	--	0.971	--	--
(4)	4-Acetyl-4-methyl pimelic	N-Decyl Alcohol	16.06	195.8	--	--	91	0.659	--	-15	--	420	7
(4)	" "	Lorol B	8.68	55.25	--	--	131	0.651	--	+65	--	375	11
(4)	" "	Butyl Carbitol	7.33	50.95	--	--	113	0.710	--	-35	--	430	5
(4)	4-Acetyl-4-(2-carboxy) ethyl pimelic	Lorol B	0.25	65.66	--	--	122	0.669	--	+55	--	--	12

TABLE 10

ESTERS OF OTHER DIBASIC ACIDS

Ref.	Acid	Alcohol	Viscosity/°F., cs. 210	100	0	-40	V.I.	ASTM Slope 210-100°F.	Pour Point, °F.	Sp. Gr. d 20/4	Flash Pt., °F. C.O.C.	Almen Wts. Carried Grad. Loading
(1)	Glutaric	2-Ethylhexyl	2.17	7.40	94.7	715	106	0.787	-80	0.922	--	--
(1)	"	Undecyl	3.45	15.9	485	7430	101	0.767	-80	0.901	--	--
(1)	"	Tetradecyl	4.84	32.1	(2100)	65000	67	0.796	-60	0.899	--	--
(5)	Maleic	Ocenol + Lorol B	16.25	108.8	--	--	137	0.559	+35	--	470	8
(5)	Maleic	O.P.E.5 (Octylphenoxytetraethoxyethanol)	29.52	633.0	--	--	73	0.705	+25	--	480	8
(5)	Oxalic Acid	n-Decyl Alcohol	2.87	9.97	--	--	154	0.706	+80	--	380	14
(5)	"	C_{12}-C_{13} oxo Alcohol	3.58	14.89	--	--	142	0.718	-25	--	380	12
(5)	"	Butyl Carbitol	2.75	11.05	--	--	98	0.780	-20	--	340	6
(6)	"	2-Ethylhexanol	1.79	5.63	--	--	--	0.816	<-60	0.936	315	--
(5)	"	Adduct 1 m-n-Butylhydroxystearate 1 m-Ethylene oxide	8.23	38.49	--	--	158	0.574	+30	--	445	15
(6)	"	Butyl Alcohol	1.00	2.33	--	--	--	0.872	-20	0.993	230	--

TABLE 11

ESTERS OF OTHER DIBASIC ACIDS

Ref.	Compound	Vis., cs. @ °F. 210	100	-40	V.I.	ASTM Slope*	Melting Pt., °F.	Specific Gravity/ 20°C.	Flash Pt., °F.	Fire Pt., °F.
(9)	2-Methylbutyl succinate (Rohm & Haas)	1.42	4.12	226	--	0.86	<-100	--	320	--
(9)	Sec-Amyl " "	--	3.65	281	--	0.93	-45	--	295	315
(9)	Capyl " "	--	7.55	965	--	0.81	-20	--	340	395
(9)	2-Ethylhexyl " "	2.10	7.00	1059	107	0.82	-70	--	325	--
(10)	Leuna Alcohol (284-320) succinate	1.94	6.66	--	--	0.83	<-98**	0.941	338	--
(10)	" " (356-482) "	4.07	22.9	--	73	0.79	-62**	0.944	383	--
(9)	Butyl maleate (Carbide & Carbon)	1.26	3.58	157	--	0.87	<-55	--	290	305
(9)	2-Ethylhexyl maleate (Carbide & Carbon)	2.24	9.26	2930	37	0.85	<-100	--	365	405

* Slope for widest temperature interval for which viscosities are reported.

** Pour point.

TABLE 12

MONO-ESTERS

Ref.	Acid	Alcohol	Viscosity/°F., cs. 210	100	-40	V.I.	ASTM Slope, 210-100°F.	Pour Point °F.	Flash Pt., °F. C.O.C.	Almen Wts. Carried Grad. Loading
(5)	Butyric	OPE 5 (octylphenoxytetraethoxyethanol)	7.23	55.05	--	98	0.738	-20	460	4
(5)	Butyric	n-Octadecylphenol	8.64	118.1	--	14	0.842	-5	400	2
(5)	2-Ethylhexanoic	C_8 Oxo (Esso)	1.16	3.12	102.4	--	0.91	<-75	275	--
(5)	2-Ethylhexanoic	Butyl Cellosolve	1.01	2.53	60.6	--	0.93	<-75	275	--
(5)	2-Ethylhexanoic	Dowanol 53A (Isopropanol + 2m propylene oxide)	1.25	3.54	178.8	--	0.91	<-75	255	--
(5)	2-Ethylhexanoic	Butyl Carbitol	1.30	3.61	156.6	--	0.88	<-75	290	--
(5)	C_8 Oxo (Esso)	C_8 Oxo (Esso)	1.28	3.31	91.4	--	0.84	<-75	280	--
(5)	C_9 Oxo (Esso)	C_8 Oxo (Esso)	1.39	3.72	103.1	--	0.83	<-75	285	--
(5)	Pelargonic (C_9)	Hexyl Cellosolve	1.43	3.76	--	--	0.80	-25	280	--
(5)	Lauric	Butyl Carbitol	2.07	6.25	--	140	0.743	0	--	8
(5)	Oxidized C_{13}-C_{14} Oxo Alcohols	n-Decyl	4.02	17.76	--	146	0.709	+45	370	--
(5)	Oxidized C_{16}-C_{19} Oxo Alcohols	C_{13}-C_{19} Oxo (Esso)	8.67	57.35	--	127	0.661	+45	380	6
(5)	Oleic	C_8 Oxo (Esso)	2.82	9.01	--	175	0.672	-10	430	--
(5)	"	C_9 Oxo (Esso)	3.26	10.87	--	186	0.652	-15	410	9
(5)	"	C_{10} Oxo (Esso)	3.26	11.34	--	175	0.670	-15	430	13
(5)	"	Oxo Bottoms (C_9+)	3.28	12.52	--	150	0.707	-35	360	5
(5)	"	ICI (C_8-C_9)	2.88	9.66	--	165	0.688	-20	405	6
(5)	"	n-Dodecyl	3.98	14.06	--	202	0.627	+40	460	5
(5)	"	Dowanol 36A (Isopropanol + 1m propylene oxide)	2.55	7.97	--	165	0.694	-20	380	10
(5)	"	Dowanol 53A (Isopropanol + 2m propylene oxide)	3.18	10.79	--	177	0.666	-20	410	6
(5)	"	Dowanol 65A (Isopropanol + 3m propylene oxide)	3.99	15.30	--	183	0.658	-10	435	6
(5)	"	Butyl Carbitol	3.31	10.31	--	205	0.619	-10	415	9
(5)	"	OPE-5 (octylphenoxytetraethoxyethanol)	8.78	52.35	--	138	0.629	-25	520	7
(5)	"	Hydroabietyl	12.44	130.2	--	94	0.706	+20	435	4
(5)	Stearic	Dowanol 53A	3.36	11.20	--	168	0.680	+55	525	14
(5)	"	Butyl Carbitol	3.34	11.24	--	187	0.650	+60	410	10
(5)	"	D.I.P. (Diisooctyl phenol)	7.44	48.46	--	122	0.690	+50	455	4

TABLE 13

MONO-ESTERS

Ref.	Acid	Alcohol	Vis. cs. @ °F. 210	100	V.I.	ASTM Slope 210-100°F.	Pour Pt., °F.	Specific Gravity/ 20°C.	Flash Pt., °F.
(10)	n-Hexanoic	n-Butanol	0.75	1.28	--	0.69	<-98	--	190
(10)	Isohexanoic	n-Butanol +2m. C_2H_4O	1.79	4.82	--	0.73	<-108	0.942	334
(9)	Isobutyric	Lauryl Cellosolve	1.81	4.86	--	0.72	+10	--	--
(10)	n-Octanoic	2,2,4 - Trimethylpentanone-3-ol-1	2.46	8.95	109	0.78	<-98	0.910	363
(11)	2-Ethylhexanoic	2-Ethylhexanol +4m. C_3H_6O	3.02	12.0	121	0.70	--	--	--
(10)	Leuna Acid (320-356)	C_9 Oxo (diisobutylene)	1.66	4.66	--	0.78	<-98	0.870	288
(10)	Leuna Acid (392-482)	n-Butanol +9m. C_2H_4O	5.32	23.7	163	0.65	+9	1.012	487
(10)	" " "	" +16m. C_2H_4O	10.2	62.2	138	0.61	+48	1.045	518
(10)	" " "	" +16m. C_2H_4O +4m. C_3H_6O	7.09	33.6	158	0.61	-67	1.009	464
(10)	" " "	Cyclohexanol	1.54	5.30	--	0.93	<-105	0.917	302
(10)	" " "	Leuna Alcohol (284-320) +11m. C_2H_4O	9.16	45.5	154	0.57	+18	1.029	496
(10)	" " "	" " (356-482)	2.86	12.0	92	0.79	-85	0.891	347
(10)	" " "	" " " +6m. C_2H_4O	3.68	15.9	136	0.72	-81	0.957	469
(10)	" " "	" " " +10m. C_2H_4O	8.49	43.0	152	0.59	+41	1.020	478
(10)	" " "	" " " +20m. "	12.0	69.0	145	0.57	+68	1.044	487
(10)	" " "	" " " +30m. "	22.7	127.5	145	0.48	+73	--	550
(10)	Lauric Acid	" " " +6m. "	4.60	20.6	158	0.68	48	0.946	421
(10)	Leuna Acid (392-482)	C_9 Oxo (Diisobutylene)	1.71	5.34	--	0.89	<-98	0.866	311
(10)	" "	" +10m. C_2H_4O	5.69	29.1	144	0.68	-3	0.993	491
(10)	" "	" +16m. "	7.47	36.0	155	0.60	+17	1.006	491
(10)	" "	" +28m. "	14.0	76.2	148	0.53	+80	--	536
(10)	" "	" +14m. " +3m. C_3H_6O	7.41	35.5	156	0.60	-58	0.996	482
(10)	" "	C_9-C_{12} Oxo (Duftschmid)	1.84	5.84	--	0.81	<-94	0.866	345
(10)	" "	C_{13} Oxo (Triisobutylene)	3.16	14.4	87	0.79	-78	0.874	345
(10)	" "	C_{17} Oxo (Tetroisobutylene)	3.50	17.9	69	0.80	-36	0.879	338
(12)	Stearic	Butyl	2.3	6.7	169	0.69	+65	--	--
(12)	Oleic	Butyl	2.3	6.2	191	0.65	-25	--	--
(10)	Oleic	2-Ethylhexanol	2.75	9.03	163	0.69	-89	0.867	432
(12)	Ricinoleic	2-Ethylhexanol	5.43	24.7	160	0.65	--	--	--
(12)	"	Undecyl	6.26	35.3	133	0.68	--	--	--
(9)	Acetyl Ricinoleic	Methoxyethyl	3.96	17.6	143	0.71	<-100	--	425
(11)	2-Ethylbutyryl ricinoleic	2-Ethylhexanol	3.85	15.3	168	0.69	--	--	--

TABLE 14

DIESTERS FROM GLYCOLS

Ref.	Acid	Glycol	Viscosity/°F., cs. 210	100	-40	V.I.	ASTM Slope, 210-100°F.	Freezing Pt., °F.	Pour Pt., °F.	Sp. Gr. d 25/4	Flash Pt., °F. C.O.C.	Almen Wts. Carried Grad. Loading
(4)	n-Octanoic	Ethylene glycol	1.76	5.36	--	--	0.796	+64	--	0.934	--	--
(5)	"	" "	1.90	5.88	--	--	0.786	--	+40	--	370	--
(5)	2-Ethylhexanoic	" "	1.49	5.00	5629	--	0.936	--	<-75	--	270	--
(5)	2-Ethylhexamoic	" "	5.86	25.52	--	167	0.617	--	+40	--	510	5
(5)	n-Octanoic	Propanediol-1,2	1.82	5.64	--	--	0.802	--	-65	--	330	--
(5)	Oleic	Isopropyl propanediol-1,3	6.97	33.66	--	156	0.615	--	-15	--	535	3
(5)	n-Octanoic	3,3-Dimethylol butanone-2	3.13	13.18	--	110	0.761	--	-55	--	375	--
(4)	n-Octanoic	2,2-Dimethyl propanediol-1,3	2.36	8.10	--	121	0.763	-67	--	0.920	--	--
(5)	n-Octanoic	" "	2.23	7.70	--	107	0.784	--	<-90	--	340	--
(4)	2-Ethylhexanoic	" "	2.16	8.77	--	35	0.873	<-98	--	0.920	--	--
(4)	Leuna Carboxylic acid (392-482°F.)	" "	3.21	15.40	--	71	0.805	<-74	--	0.930	--	--
(5)	Propionic	Butanediol-1,3	0.88	2.5	--	--	0.971	--	<-60	--	205	--
(5)	Butyric	" "	1.07	2.77	--	--	0.924	--	<-65	--	285	--
(5)	Crotonic	" "	2.03	8.44	--	7	0.910	--	<-55	--	260	--
(5)	Valeric	" "	1.13	2.85	--	--	0.878	--	<-60	--	210	--
(5)	n-Caproic	" "	1.41	3.95	--	--	0.851	--	<-65	--	270	--
(5)	i-Caproic	" "	1.54	4.91	--	--	0.891	--	<-60	--	275	--
(5)	Diethyl acetic	" "	1.42	4.36	--	--	0.905	--	<-75	--	250	--
(5)	n-Heptoic	" "	1.62	4.59	--	--	0.800	--	<-65	--	310	--
(5)	n-Octanoic	" "	2.06	6.60	--	118	0.775	--	-60	--	340	--
(5)	"	" "	2.07	6.59	--	121	0.771	--	<-75	--	320	--
(5)	2-Ethylhexanoic	" "	1.74	5.55	--	--	0.837	--	<-60	--	290	--
(5)	"	" "	1.48	4.40	332.3	--	0.868	--	<-75	--	195	--
(5)	C_8 Oxo	" "	2.05	7.42	--	70	0.838	--	<-60	--	295	--
(5)	Pelargonic	" "	2.30	7.59	--	129	0.753	--	-35	--	340	--
(5)	n-Capric	" "	2.69	9.39	--	140	0.728	--	5	--	400	--
(5)	Undecylenic	" "	2.75	9.74	--	141	0.726	--	-20	--	400	--
(5)	Lauric	" "	3.51	12.99	--	171	0.677	--	+20	--	405	--
(5)	Myristic	" "	4.27	17.96	--	167	0.676	--	+7	--	445	--
(5)	Oleic	" "	5.58	24.79	--	180	0.634	--	+5	--	485	--
(5)	Oleic	" "	5.27	22.09	--	172	0.627	--	-10	--	425	--
(5)	1m C_8 Oxo + 1m Oleic	" "	3.87	18.08	--	123	0.740	--	-5	--	350	--
(5)	1m n-Octanoic + 1m Oleic	" "	3.75	13.73	--	186	0.656	--	-25	--	410	--
(5)	Ethoxyacetic	" "	1.50	5.05	--	--	0.934	--	<-45	--	--	--
(5)	Chloroacetic	" "	1.66	6.47	--	--	0.964	--	-45	--	320	--
(5)	Dichloroacetic	" "	1.90	7.58	--	--	0.916	--	-55	--	320	--
(5)	Trichloroacetic	" "	2.24	9.64	--	19	0.885	--	-45	--	335	--
(5)	B-Chloropropionic	" "	2.30	8.31	--	95	0.797	--	<-45	--	465	--
(5)	Levulinic	" "	2.81	13.39	--	38	0.845	--	-45	--	380	--
(4)	n-Octanoic	Butanediol-1,4	2.29	6.85	--	160	0.705	+55	--	0.919	--	--
(4)	2-Ethylhexanoic	" "	1.98	6.89	--	--	0.831	<-98	--	0.936	--	--
(4)	Leuna carboxylic acids(392-482°F.)	" "	2.94	11.80	--	113	0.761	<-98	--	0.930	--	--
(5)	Heptoic	2-Methypentanediol-2.4	1.93	6.30	--	--	0.809	--	<-70	--	340	--
(5)	n-Octanoic	" "	2.04	6.62	--	112	0.786	--	-80	--	285	--
(5)	Caproic (C_6)	2-Ethylhexanediol-1,3	1.63	5.15	--	--	0.859	--	<-70	--	290	--
(5)	n-Octanoic	" "	2.14	7.30	--	103	0.793	--	-70	--	310	--
(4)	n-Octanoic	Hexanediol-1,6	2.62	8.40	--	162	0.697	46	--	0.920	--	--
(4)	2-Ethylhexanoic	" "	2.37	8.68	--	99	0.792	<-98	--	0.920	--	--
(1)	2-Ethylhexanoic	" "	2.35	8.64	1090	96	0.797	--	<-80	0.908	--	--
(4)	Leuna carboxylic acids (392-482°F.)	" "	3.20	12.20	--	146	0.714	-98	--	0.926	--	--
(4)	n-Octanoic	2-Methylhexanediol-1,6	2.71	8.88	--	161	0.697	-20	--	0.916	--	--
(4)	2-Ethylhexanoic	" "	2.48	9.20	--	104	0.783	<-98	--	0.915	--	--
(4)	Leuna carboxylic acids (392-482°F.)	" "	3.40	14.80	--	117	0.750	<-98	--	0.922	--	--
(1)	2-Ethylhexanoic	Decanediol 1,10	3.26	13.0	1850	136	0.727	--	<-80	0.900	--	--
(5)	2-Ethylhexanoic	Diethylene Glycol	1.90	6.62	1074	--	0.849	--	<-75	--	350	--
(5)	2-Ethylbutyric	Triethylene Glycol	1.67	5.15	--	--	0.835	--	<-35	--	300	3
(5)	2-Ethylhexanoic	" "	2.42	9.14	--	92	0.799	--	<-35	--	365	4
(5)	"	" "	2.24	8.24	1847	85	0.814	--	<-75	--	380	4
(1)	"	" "	2.41	8.91	1890	99	0.792	--	-60	0.960	--	--
(5)	Coconut oil acids	" "	3.82	14.62	--	176	0.669	--	+65	--	410	6
(5)	Oleic	" "	6.32	26.95	--	169	0.594	--	+15	--	520	15
(5)	$C_2H_5OCH_2CH_2COOH$	" "	2.67	10.58	--	96	0.786	--	<-35	--	400	5
(5)	2-Ethylhexanoic	Tetraethylene Glycol	2.45	9.28	2463	94	0.795	--	<-75	--	360	--
(1)	2-Ethylhexanoic	Polyethylene Glycol	3.07	12.3	3840	122	0.747	--	<-80	0.977	--	--
(5)	Oleic	Polyethylene Glycol 400	9.61	44.90	--	158	0.548	--	+30	--	535	7
(5)	Oleic	Polypropylene Glycol 400	8.22	39.73	--	156	0.583	--	-20	--	535	7
(5)	Acetic	Polypropylene Glycol 750	6.15	32.86	--	140	0.672	--	<-35	--	420	5
(5)	Oleic	" "	9.05	50.55	--	144	0.607	--	-35	--	460	15
(5)	Acetic	Polypropylene Glycol 1200	9.46	53.55	--	144	0.603	--	<-35	--	415	--

TABLE 15

DIESTERS FROM GLYCOLS

Ref.	Acid	Glycol	Vis., cs. @ °F. 210	100	V.I.	ASTM Slope 210-100°F.	Pour Point, °F.	Specific Gravity/ 20°C.	Flash Point, °F.
(10)	C_5-C_7 Forerun Fatty Acids	Ethylene Glycol	1.47	3.81	--	0.785	-58	0.957	295
(10)	C_5-C_9 Forerun Fatty Acids	"	1.78	4.95	--	0.752	-24	0.959	342
(10)	C_7-C_{11} Forerun Fatty Acids	"	1.79	5.08	--	0.760	-24	0.945	313
(10)	Leuna Acids (284+)	"	1.54	4.29	--	0.811	-101	0.946	286
(10)	" " (C_6-C_7)(~390-440)	"	1.58	4.56	--	0.821	<-98	0.940	323
(10)	" " (392-482)	"	1.87	5.95	--	0.807	-107	0.938	320
(10)	" " (392-482)	" +10m. C_2H_4O	8.84	43.2	155	0.573	+30	1.036	536
(10)	" " (392-482)	" +10m. C_2H_4O +1m. C_3H_6O	8.01	38.9	155	0.589	-33	1.027	518
(10)	" " (284-482)(50%) + (392-482)(50%)	"	1.99	6.38	--	0.788	-105	0.944	298
(10)	" " (392-482)(90%) + Soap Fatty Acid (10%)	"	2.90	11.7	108	0.766	-29	0.937	352
(10)	n-Octanoic	"	1.79	5.36	--	0.796	+64	0.934	370
(10)	2-Ethylhexanoic	"	1.65	5.51	--	0.884	<-94	0.932	331
(12)	"	"	1.68	5.63	--	0.878	<-70		
(10)	C_5-C_9 Forerun Fatty Acids	Butanediol - 1,4	1.78	4.83	--	0.738	-51	0.950	325
(10)	C_5-C_9 Forerun Fatty Acids	"	2.00	5.79	148	0.731	-22	0.938	336
(10)	Leuna Acids (C_6-C_7)	"	1.79	4.98	--	0.750	<-98	0.935	320
(10)	" " (284-482)(44%)	"	2.46	8.19	139	0.735	<-98	0.931	356
(10)	" " (392-482)(56%)								
(10)	" " (392-482)	"	2.94	11.8	113	0.761	-94	0.930	406
(10)	" " (392-482)	" +10m. C_2H_4O	8.56	43.9	151	0.593	-47	1.024	527
		" +15m. C_2H_4O	10.25	56.6	146	0.583	+3	1.042	527
		" +10m. C_2H_4O +2m. C_3H_6O	10.73	56.5	150	0.563	-49	1.024	518
(10)	Leuna Acids (284-482) + Oleic Acid (5%)	Butanediol - 1,4							
(10)	" " (284-482) + Oleic Acid (10%)	"	2.28	7.02	150	0.721	-83	0.933	324
(10)	" " (356-482) + Forerun Fatty Acids C8-C11 (5%)	"	2.32	7.18	152	0.717	-96	0.934	363
(10)	2-Ethylhexanoic	"	2.80	10.4	128	0.740	-96	0.932	349
(10)	n-Octanoic	"	1.98	6.89	--	0.831	<-98	0.936	392
		"	2.29	6.85	160	0.705	+55	0.919	365
(10)	n-Octanoic	"							
(10)	Butoxy Acetic Acid	"	1.67	4.54	--	0.762	-27	0.947	356
(10)	Oleic Acid	"	2.30	7.81	120	0.767	+14	1.020	--
(10)	Naphthenic Acid	"	6.85	41.7	128	0.686	+19	0.936	531
(10)	C_{10}-C_{16} Fatty Acids	"	8.21	74.1	84	0.755	-40	1.003	655
		" +10m. C_2H_4O	15.1	86.2	146	0.532	+28	0.991	545
(10)	" " "								
(10)	Leuna Acids (C_6-C_7)	" +10m. C_2H_4O +2m C_3H_6O	19.05	124.0	139	0.531	+30	0.994	529
(10)	" " (392-482)	Hexanediol-1,6 (Adipol)	2.14	6.50	144	0.736	<-94	0.923	356
(10)	2-Ethylhexanoic	" "	3.20	12.20	146	0.714	<-94	0.926	403
		" "	2.37	8.68	99	0.792	<-98	0.920	396
(10)	n-Octanoic	Hexanediol-1,6							
(10)	Leuna Acid (392-482)	" +15m. C_2H_4O	2.62	8.40	162	0.697	+46	0.920	378
(10)	" "	" +12m. C_2H_4O +3m C_3H_6O	11.9	72.2	141	0.583	+25	1.043	518
			9.20	48.8	145	0.590	-72	1.014	522
(10)	Leuna Acids (392-482)	Methylhexanediol-1,6							
(10)	" "	" +8m. C_2H_4O	3.40	14.80	117	0.750	-94	0.922	414
(10)	" "	" +14m. C_2H_4O	9.47	49.7	150	0.582	-65	1.005	531
(10)	" "	" +13m. C_2H_4O +1m. C_3H_6O	13.9	81.0	145	0.548	+14	1.044	536
		" +11m. C_2H_4O +3m. C_3H_6O	11.0	66.2	140	0.595	-44	1.035	536
(10)	" "		11.4	66.1	144	0.580	-60	1.027	504
(10)	" "	" +9m. C_2H_4O +5m. C_3H_6O	9.91	57.3	143	0.601	-62	1.014	518
(10)	Leuna Acids (C_6-C_7)	" +7m. C_2H_4O +7m. C_3H_6O	10.9	66.7	139	0.702	-58	1.006	525
(10)	n-Octanoic	Methylhexanediol-1,6 (Methyladipol)	2.25	7.15	138	0.740	<-94	0.923	369
(10)	2-Ethylhexanoic	" "	2.71	8.88	161	0.697	-20	0.916	410
		" "	2.48	9.20	104	0.783	<-94	0.915	396

TABLE 16

DIESTERS FROM GLYCOLS

Ref.	Acid	Alcohol	Vis. cs. @ 7. 210	Vis. cs. @ 7. 100	V.I.	ASTM Slope 210/100°F.	Pour Point, °F.	Specific Gravity/ 20°C.	Flash Point, °F.
(10)	n-Octanoic	2,2-Dimethylpropanediol-1,3	2.36	8.10	121	0.763	-67	0.920	338
(10)	2-Ethylhexanoic	" "	2.16	8.77	35	0.873	<-98	0.920	414
(13)	Leuna Acids (C_6-C_7)	" "	1.89	6.35	--	0.832	-92	0.928	345
(13)	lm. Leuna Acids (C_6-C_7)	lm. 2,2-Dimethylpropanediol-1,3	2.01	7.59	47	0.866	-80	0.934	315
(13)	Leuna Acids (392-482)	2,2-Dimethylpropanediol-1,3	3.21	15.4	71	0.805	-74	0.930	388
(13)	lm. Leuna Acids (392-482)	lm. 2,2-Dimethylpropanediol-1,3	2.90	14.8	18	0.862	-69	0.922	356
(13)	Leuna Acids (392-482)	2,2-Dimethylpropanediol-1,3 +8m. C_2H_4O	10.2	63.3	138	0.616	-53	1.017	550
(13)	" " "	" " +10m. C_2H_4O	8.40	44.7	148	0.608	-47	1.019	532
(13)	" " "	" " +11m. "	9.90	59.7	139	0.613	-62	1.030	527
(13)	" " "	" " +12m. "	8.19	43.5	147	0.612	-62	1.012	509
(13)	" " "	" " +13m. "	7.99	41.2	150	0.607	-63	1.012	536
(13)	" " "	" " +14m. "	12.2	72.2	143	0.573	-8	1.050	518
(13)	" " "	" " +15m. "	12.0	74.0	141	0.586	+19	1.045	514
(13)	" " "	" " +19m. "	10.1	61.7	139	0.612	+27	1.031	482
(13)	" " "	2,2-Dimethylpropanediol-1,3 +8m. C_2H_4O + 4m. C_3H_6O	8.07	43.1	147	0.616	-63	1.001	500
(13)	" " "	" " +9m. C_2H_4O + 2m. C_3H_6O	9.71	53.4	146	0.590	-2	1.022	507
(13)	" " "	" " +10m. C_2H_4O + 2m. C_3H_6O	9.77	55.0	145	0.597	-42	1.026	518
(10)	" " "	" " **+9.5m. C_3H_6O**	6.50	38.2	129	0.688	-62	0.959	504
(10)	Soap Fatty Acids	" "	8.14	49.5	134	0.651	+50	--	522
(10)	Soap Fatty Acids (C_{10}-C_{16})	" " +10m. C_2H_4O	16.2	103.0	137	0.547	+30	0.998	514
(10)	"	" " +9m. C_2H_4O +2m. C_3H_6O	15.8	104.9	138	0.562	+37	0.992	525
(10)	"	" " +10m. C_2H_4O +2m. C_3H_6O	15.4	938	144	0.532	+30	0.990	534
(10)	"	" " +9.5m. C_3H_6O	11.6	73.6	147	0.600	+28	0.943	502
(10)	Leuna Acids (284-482)	Dimethylolpentane	2.31	8.83	77	0.821	-85	0.929	333
(10)	" (356-392)	"	2.72	12.2	54	0.832	-85	0.925	325
(10)	" (392-482)	"	3.78	19.9	78	0.789	-74	0.921	388
(10)	" **(320-356)(50%) + (392-482)(50%)**	"	2.71	11.2	84	0.798	-87	0.920	388
(10)	" (284-482) + C_5-C_6Acids (20%)	"	2.36	8.90	87	0.807	-92	0.928	304
(10)	" (392-482) + Soap Acids (5%)	"	4.36	22.7	113	0.745	+1	0.918	370
(10)	" (392-482)	" +14m. C_2H_4O	9.12	57.4	134	0.638	-18	1.033	514
(13)	Leuna Acids (356-482)	Dimethylolhexane	2.85	12.4	77	0.803	-87	0.922	325
(10)	" (284-482) + C_5-C_6 Forerun Acids (20%)	"	2.30	8.57	86	0.812	-99	0.928	313
(13)	" (C_6-C_7)	Dimethylolpentane +11m. C_2H_4O + Dimethylolhexane	7.00	34.6	153	0.621	-62	1.019	500
(13)	" (392-482)	Dimethylolhexane	3.47	15.9	105	0.764	-67	0.919	347
(13)	" " + Soap Fatty Acids (15%)	"	4.16	21.7	104	0.759	+5	0.913	349
(13)	" " " (20%)	"	4.33	22.1	118	0.740	+16	0.917	354
(13)	" " " (25%)	"	4.46	23.0	120	0.736	+25	0.914	385
(13)	" "	Dimethylolhexane +3m. C_2H_4O	4.62	23.5	129	0.722	-62	0.961	446
(13)	" "	" +4.5m. C_2H_4O	5.20	26.0	143	0.689	-72	0.973	464
(13)	" "	" +7m. C_2H_4O	6.25	30.7	152	0.643	-65	0.980	500
(13)	" "	" +10m. C_2H_4O	8.26	45.8	144	0.623	-54	1.010	536
(13)	" "	" +11m. "	9.79	53.3	147	0.587	-38	1.020	527
(13)	" "	" +12.5m. C_2H_4O	10.3	58.1	144	0.588	-40	1.021	541
(13)	" "	" +14m. "	11.2	70.1	137	0.602	+10	1.036	530
(13)	" "	" +16m. "	9.53	52.2	147	0.593	-36	1.017	527
(13)	" "	" +20m. "	10.7	59.9	146	0.580	-20	1.021	504
(13)	" "	" +8m. C_2H_4O +4m. C_3H_6O	8.84	52.4	139	0.627	-63	1.001	477
(13)	" "	" +4m. C_3H_6O	5.17	31.5	103	0.753	-65	0.940	457
(13)	" "	" +6m. "	5.82	34.6	121	0.717	-56	0.951	468
(13)	" "	" +7m. "	6.37	39.3	121	0.707	-62	0.959	486
(13)	" "	" +11m. "	7.44	46.8	127	0.690	-58	0.963	491
(12)	2-Ethylhexanoic	1,10-Decanediol	3.24	13.0	133	0.732	<-70MP.	--	--
(10)	Leuna Acids (C_6-C_7)	C_{14} Glycol	2.17	8.45	54	0.852	-85	0.883	333
(12)	Acetic	Diethylene Glycol	1.3	3.6	--	0.879	+60MP.	--	--
(11)	Propionic	" "	1.12	2.95	--	0.928	-10	--	--
(11)	Isobutyric	" "	1.30	3.32	--	0.817	--	--	--
(11)	Isobutyric	Triethylene Glycol	1.54	4.17	--	0.79	--	--	--
(9)	2-Ethylhexanoic	" "	2.37	8.70	98	0.78	<-100MP.	--	--
(12)	Acetic	Tetraethylene Glycol	2.1	7.9	60	0.849	+20FP.	--	--
(9,12)	2-Ethylhexanoic	" "	2.92	11.7	112	0.763	<-70FP.	--	--

TABLE 17

ESTERS FROM POLYHYDRIC ALCOHOLS

Ref.	Acid	Alcohol	Viscosity/°F., cs. 210	100	V.I.	ASTM Slope 210-100°F.	Freezing Point °F.	Pour Point °F.	Specific Gravity 20°C.	Flash Point °F. C.O.C.	Almen Wts. Carried Gradual Loading
(4)	n-Octanoic	Glycerol	3.20	12.97	128	0.739	-11	--	0.940	--	--
(4)	2-Ethylhexanoic	"	3.21	17.39	23	0.850	-87	--	0.952	--	--
(4)	Leuna Carboxylic Acids (392-482°F.)	"	4.93	34.0	61	0.803	-76	--	0.954	--	--
(5)	Butyric	Trimethylolethane (Crude)	2.39	9.98	49	0.848	--	<-70	--	370	--
(3)	Mixed C7 Monocarboxylic Acids	Trimethylolethane	3.86	16.0	157	0.696	--	-94	--	465	--
(4)	n-Octanoic	"	3.86	17.75	127	0.735	+18	--	0.944	--	--
(5)	"	"	3.57	16.2	114	0.752	--	-70	--	--	--
(5)	"	" (Crude)	4.01	20.34	105	0.759	--	<-70	--	350	--
(4)	**2-Ethylhexanoic**	Trimethylolethane	3.84	20.90	70	0.796	-81	--	0.948	--	--
(4)	**3 m Leuna Carboxylic Acids**	"	5.57	42.50	64	0.802	-54	--	0.949	--	--
(4)	2 m " " "	"	6.57	59.50	53	0.807	-47	--	**0.962**	--	--
(4)	1 m " " "	"	7.80	105.0	0	0.864	-27	--	0.982	--	--
(4)	3 m C_{13} Oxo Acids	"	7.27	49.90	114	0.709	-17	--	0.925	--	--
(4)	2 m C_{13} Oxo Acids	"	7.11	42.13	133	0.672	-18	--	0.917	--	--
(5)	Butyric	Trimethylolpropane	2.43	9.84	66	0.829	--	<-70	--	365	--
(4)	n-Octanoic	"	3.96	18.00	135	0.724	-92	--	0.948	--	--
(5)	n-Octanoic	"	4.01	19.00	125	0.735	--	-75	--	445	--
(4)	2-Ethylhexanoic	"	4.17	26.28	39	0.821	-72	--	0.948	--	--
(4)	Leuna Carboxylic Acids	"	6.30	50.20	75	0.782	-56	--	0.958	--	--
(5)	1 m Oleic + 1 m 2-Ethylhexanoic + 1 m Butyric	"	5.70	27.84	151	0.661	--	-5	--	405	--
(5)	2 m Oleic + 1 m Butyric	"	7.21	46.15	123	0.692	--	0	--	--	--
(5)	3 m Oleic	"	9.40	--	--	--	--	0	--	--	--
(5)	n-Octanoic	Pentaerythritol	5.19	26.90	136	0.701	--	-5	--	510	--
(4)	"	"	4.73	23.80	134	0.713	+45	--	0.959	--	--
(4)	2-Ethylhexanoic	"	6.37	52.01	71	0.786	-49	--	0.966	--	--
(4)	Leuna Carboxylic Acids	"	10.46	117.2	73	0.755	-24	--	0.961	--	--
(5)	2 m Oleic + 2 m Acetic	"	11.09	72.06	135	0.614	--	-15	--	465	8
(5)	2 m Oleic + 1 m Acetic + 1 m Butyric	"	8.09	53.67	124	0.676	--	-35	--	445	10
(4)	4 m C_{13} Oxo Acids	"	10.0	71.10	126	0.654	-18	--	0.929	--	--
(4)	3 m C_{13} Oxo Acids	"	10.48	81.20	118	0.667	-17	--	0.934	--	--
(4)	2 m C_{13} Oxo Acids	"	11.70	114.9	97	0.703	-15	--	0.951	--	--

TABLE 18

ESTERS FROM POLYHYDRIC ALCOHOLS

Ref.	Acid	Alcohol	Viscosity, Cs. @ °F. 210	100	V.I.	ASTM Slope 210/100°F.	Pour Point, °F.	Specific Grav./20°C.	Flash Point, °F.
(10)	Formic	Trimethylolethane	2.52	10.0	83	0.807	-72	1.224	342
(10)	Acetic	"	2.26	12.4	-10	0.986	-49	1.112	324
(10)	Forerun (C_5)	"	2.72	10.8	100	0.780	-98	0.990	401
(10)	" (C_7)	"	3.69	15.9	137	0.734	-94	0.958	366
(10)	" (C_5-C_6) (40%) + Forerun (C_7-C_9) (60%)	"	3.61	16.2	121	0.744	-89	0.968	363
(10)	" (C_5-C_7) (40%) + Forerun (C_7-C_9) (60%)	"	3.84	16.5	146	0.711	-80	0.965	441
(10)	" (C_9)	"	4.78	23.5	140	0.702	-51	0.950	403
(10)	" (C_9-C_{11})	"	5.51	31.3	124	0.716	-9	0.917	401
(10)	Soap Acids (C_{10}-C_{16})	"	14.9	110.6	130	0.596	+43	0.948	572
(10)	1m. Soap Acids (C_{10}-C_{16})	"	15.3	191.7	86	0.808	+52	0.924	437
(10)	Soap Acids (50%) + Oleic Acid (50%)	"	12.2	84.2	132	0.611	+16	0.924	554
(10)	Oleic Acid	"	9.90	52.4	149	0.577	-60	0.915	588
(10)	Leuna Acids (C_6)	"	3.21	14.8	85	0.790	-87	0.978	352
(10)	2m. Leuna Acids (C_6)	"	3.82	23.4	23	0.838	-57	0.991	388
(10)	Leuna Acids (C_6-C_7)	"	3.37	16.2	82	0.790	-74	0.960	401
(10)	2m. Leuna Acids (C_6-C_7)	"	4.52	29.1	56	0.806	-58	0.972	370
(10)	1m. " " (C_6-C_7)	"	4.44	37.8	-60	0.896	-47	0.990	381
(10)	Leuna Acids (284-356)	"	3.53	17.9	74	0.796	-76	0.964	399
(10)	" " (284-482)	"	4.38	27.8	51	0.811	-56	0.965	374
(10)	" " (320-356)	"	3.86	17.8	126	0.736	+18	0.944	493
(10)	" " (329-482)	"	4.90	33.1	65	0.799	-54	0.960	390
(10)	" " " " + Soap Fatty Acids (5%)	"	5.16	35.0	77	0.787	-31	0.968	374
(10)	" " " " " " " (7.5%)	"	5.07	30.4	103	0.754	-54	0.952	455
(10)	" " " " " " " (10%)	"	5.41	37.0	84	0.777	-20	0.953	383
(10)	" " " " Lauric Acid (25%)	"	5.30	36.4	79	0.784	-63	0.954	378
(10)	" " " " Lauric Acid (50%)	"	5.47	35.2	99	0.756	-9	0.946	378
(10)	Leuna Acids (356-392)	"	4.54	31.2	35	0.825	-65	0.960	388
(10)	" " (356-482)	"	5.37	39.0	68	0.798	-56	0.954	419
(10)	" " (392-482)	"	5.57	42.5	64	0.802	-54	0.949	408
(10)	2m. Leuna Acids (392-482)	"	6.57	59.5	53	0.807	-47	0.962	406
(10)	1m. " " (" ")	"	7.80	10.5	0	0.864	-27	0.982	388
(10)	Leuna Acids (392-482)	Trimethylolethane + 4m. C_2H_4O	6.26	38.7	119	0.711	-54	0.997	520
(10)	" " " "	" + 10m. C_2H_4O	8.85	53.2	137	0.631	-54	1.020	545
(10)	" " " "	" + 12m. "	10.9	68.5	137	0.607	-47	1.039	536
(10)	" " " "	" + 13m. "	10.9	64.1	145	0.590	-56	1.025	523
(10)	" " " "	" + 14m. "	11.5	74.3	136	0.605	-51	1.034	527
(10)	" " " "	" + 15m. "	12.6	78.0	140	0.579	-49	1.038	518
(10)	" " " "	" + 16m. "	12.3	80.9	136	0.598	-49	1.039	500
(10)	" " " "	" + 17m. "	14.2	84.9	144	0.552	-51	1.035	518
(10)	" " " "	" + 20m. "	16.0	99.4	142	0.544	-22	1.043	536
(10)	" " " "	" + 13m. C_2H_4O + 1m. C_3H_6O	11.9	72.8	141	0.585	-51	1.049	509
(10)	" " " "	" + 12m. C_2H_4O + 2m. C_3H_6O	11.6	75.3	136	0.606	-58	1.026	516
(10)	" " " "	" + 11m. " + 3m. "	10.7	68.7	135	0.616	-53	1.025	518
(10)	" " " "	" + 10m. " + 3m. "	11.6	77.2	134	0.612	-60	1.019	518
(10)	" " " "	" + 10m. " + 4m. "	10.8	74.1	130	0.632	-51	1.018	523
(10)	" " " "	" + 9m. " + 5m. "	11.3	81.4	127	0.625	-47	1.018	518
(10)	" " " "	" + 8m. " + 7m. "	10.8	70.1	134	0.617	-54	0.999	536
(10)	" " " "	" + 8m. " + 6m. "	11.1	78.6	128	0.634	-62	1.013	527
(10)	" " " "	" + 7m. " + 7m. "	12.6	90.2	130	0.615	-51	1.013	509
(10)	" " " " + Soap Fatty Acids (5%)	"	6.54	50.4	85	0.763	-49	0.947	480
(10)	" " " " + " " " (7.5%)	"	6.56	47.0	99	0.744	-54	0.946	482
(10)	" " " " + " " " (10%)	"	6.71	49.0	98	0.743	-54	0.947	477
(10)	" " " " + " " " (15%)	"	6.84	56.7	77	0.774	+19	0.946	365
(10)	" " " " + " " " (50%)	"	9.06	67.1	117	0.683	+10	0.940	538
(10)	" " " " + " " " (80%)	"	12.6	81.7	137	0.590	+25	0.930	58[illegible]
(10)	" " " " + " " " (90%)	"	12.5	89.6	130	0.617	+39	0.932	561
(10)	" " " " + " " " (95%)	"	11.9	76.4	137	0.597	+39	0.930	558
(10)	n-Octanoic Acid	"	3.86	17.8	127	0.735	+18	0.944	475
(10)	2-Ethylhexanoic Acid	"	3.84	20.9	70	0.796	-81	0.948	410
(10)	" + Oleic Acid (67%)	"	9.31	53.7	142	0.611	-74	0.924	572
(10)	Acids from C_{11}-C_{14} Oxo Alcohol (Ruhrchemie)	"	6.56	37.1	135	0.675	-11	0.919	531
(10)	C_{13} Acid from Oxo Alcohol	"	7.11	42.1	133	0.672	-18	0.917	549
(10)	2m. " " " "	"	7.27	49.9	114	0.709	-17	0.925	504
(10)	Leuna Acids (392-482) + C_{13} Oxo Acids (20%)	"	6.36	44.9	98	0.747	-58	0.941	491
(10)	" " " + C_{13} Oxo Acids (30%)	"	6.12	41.7	101	0.745	-62	0.937	487
(10)	" " " + C_{14} Oxo Acids (Ruhrchemie) (7.5%)	"	5.92	44.0	80	0.779	-51	0.944	423
(10)	" " " + " " " (10%)	"	6.26	46.3	88	0.764	-54	0.944	464
(10)	" " " + " " " (15%)	"	6.17	45.8	86	0.769	-54	0.943	459
(10)	" " "	1/6m. i-Butanol + 19m. C_2H_4O + Trimethylolethane	12.8	73.5	145	0.559	-47	1.035	536
(10)	" " "	1/2m. i-Butanol + 21m. C_2H_4O + Trimethylolethane	11.0	64.1	143	0.586	-58	1.026	514
(10)	" " "	1/2m. i-Butanol + 25m. C_2H_4O + Trimethylolethane	13.1	79.7	150	0.568	-22	1.035	484

TABLE 19

ESTERS FROM POLYHYDRIC ALCOHOLS

Ref.	Acid	Alcohol	Viscosity, Cs. @ °F. 210	100	V.I.	ASTM Slope 210/100°F.	Pour Point, °F.	Specific Grav./20°C.	Flash Point, °F.
(10)	Leuna Acids C6-C7	Trimethylolpropane	3.52	19.1	48	0.822	-72	0.962	426
(10)	" " (392-482)	"	6.30	50.2	75	0.782	-56	0.958	446
(10)	n-Octanoic	"	3.96	18.0	135	0.724	-92	0.948	478
(10)	2-Ethylhexanoic	"	4.18	26.3	39	0.821	-72	0.948	412
(12)	Butyl	Glycerol	1.9	6.9	--	0.970	< -70 MP	--	--
(12)	Isobutyl	"	1.71	5.69	--	0.866	< -70 MP	--	--
(10)	C5-C6 Forerun Fatty Acids	"	2.44	8.90	106	0.780	-105	0.985	387
(10)	C5-C7 (50%), C7-C11 (50%) Forerun Fatty Acid	"	2.84	11.5	102	0.774	-96	0.979	378
(10)	C9-C11 Forerun Fatty Acid	"	4.96	24.3	144	0.692	--	0.941	383
(10)	Leuna Acids (C6)	"	2.44	9.66	76	0.816	--	0.978	369
(10)	" " (C7)	"	2.65	10.8	84	0.800	--	0.962	396
(10)	" " (C8)	"	3.50	17.9	69	0.802	--	0.956	--
(10)	" " (C9)	"	3.62	20.8	33	0.832	--	0.954	419
(10)	" " (284-482)	"	3.11	14.7	68	0.810	-71	0.970	390
(10)	" " (392-482)	"	4.93	34.0	61	0.803	-76	0.954	405
(10)	" " " "	Glycerol + 15m. C_2H_4O	8.17	49.4	135	0.648	-69	1.034	536
(10)	n-Octanoic Acid	Glycerol	3.20	13.0	128	0.739	-11	0.940	471
(10)	2-Ethylhexanoic Acid	"	3.21	17.4	23	0.850	-87	0.952	419
(12)	"	"	3.13	14.5	77	0.800	< -70 MP	--	--
(10)	Stearic Acid	"	7.23	--	--	--	--	--	432
(10)	Oleic Acid	"	8.80	42.7	158	0.572	+3	0.923	554
(10)	Leuna Acid C6-C7	Pentaerythritol	5.45	37.5	84	0.777	-62	0.989	455
(10)	3m. Leuna Acid C6-C7	"	6.61	61.1	49	0.811	-45	1.000	442
(10)	2m. " " "	"	9.22	116.4	40	0.809	-31	1.020	428
(10)	C7 Forerun Fatty Acids	"	4.30	44.0	--	0.960	-81	0.995	491
(10)	n-Octanoic	"	4.73	23.8	134	0.713	+45	0.959	500
(10)	2-Ethylhexanoic	"	6.32	49.0	80	0.774	+14	0.962	486
(10)	3m. "	"	7.05	69.8	47	0.814	-56	0.979	457
(10)	Leuna Acids (392-482)	"	10.5	117.2	74	0.753	-24	0.961	543
(10)	" " "	Pentaerythritol + 14m. C_2H_4O	13.5	91.7	135	0.591	-44	1.036	536
(10)	" " "	" + 16m. "	13.9	96.9	134	0.592	-49	1.036	527
(10)	" " " + Soap Fatty Acids (7.5%)	Pentaerythritol	10.7	111.0	85	0.733	-44	0.958	545
(10)	" " " + " " " (15%)	"	10.4	113.2	76	0.750	-29	0.971	509
(10)	Soap Fatty Acids	"	20.7	198.2	120	0.604	+54	--	482
(10)	4m. C_{13} Oxo Acid (From Alcohol)	"	10.0	71.1	126	0.654	-18	0.929	581
(10)	3m. " " " " "	"	10.5	81.2	118	0.667	-17	0.934	631
(10)	2m. " " " " "	"	11.7	114.9	97	0.703	-15	0.951	507
(10)	Leuna Acids (C6-C7)	Hexanetriol	3.23	17.0	36	0.838	-71	0.960	378
(10)	Leuna Acids (392-482)	"	9.28	37.6	167	0.511	-44	0.953	446
(10)	Leuna Acids (284+)	Laurintriol	5.26	34.4	89	0.771	-58	--	392

TABLE 20

ESTERS FROM DIBASIC ACIDS CONTAINING ETHER-OXYGEN ATOMS

Ref.	Acid	Alcohol	Viscosity °F., cs. 210	Viscosity °F., cs. 100	V.I.	ASTM Slope 210-100°F.	Pour Point, °F.	Flash Pt., °F. C.O.C.	Almen Wts. Carried Grad. Loading
(5)	Diglycolic $O(CH_2COOH)_2$	n-Decyl	3.70	16.36	130	0.731	+80	410	--
(5)	"	C_{11} Oxo	4.08	21.84	91	0.773	< -35	390	6
(5)	"	C_8 Oxo	3.08	14.68	64	0.816	-60	395	--
(5)	$(CH_2OCH_2COOH)_2$	C_{10} Oxo	3.99	19.23	120	0.743	< -35	445	5
(5)	$O(CH_2CH_2COOH)_2$	n-Decyl	5.30	25.54	150	0.673	< -35	--	10
(5)	$O(CH_2CH_2COOH)_2$	C_{13} Oxo	25.16	226.9	126	0.565	-20	415	11
(5)	$(CH_2OCH_2CH_2COOH)_2$	C_{12}-C_{13} Oxo	4.97	22.97	155	0.672	0	410	10
(5)	$(CH_2OCH_2CH_2OCH_2CH_2COOH)_2$	C_8 Oxo	3.49	13.70	154	0.702	< -35	355	4
(5)	$S(CH_2CH_2OCH_2CH_2COOH)_2$	C_8 Oxo	4.78	22.84	146	0.692	< -35	415	8
(5)	$O(CH_2CH_2OCH_2CH_2OCH_2CH_2COOH)_2$	C_8 Oxo	6.58	32.61	152	0.634	< -35	425	8
(5)	$(CH_2OCH_2COOH)_2$	Butyl Carbitol	4.59	23.95	121	0.732	< -35	440	4
(5)	$(CH_2OCH_2CH_2COOH)_2$	Butyl Carbitol	3.96	16.60	158	0.694	< -35	--	15

TABLE 21

ESTERS CONTAINING RING STRUCTURES

Ref.	Name	Viscosity/°F., cs. 210	100	V.I.	ASTM Slope 210-100°F.	Pour Point, °F.	Flash Point °F. C.O.C.	Almen Wts. Carried Gradual Loading
(1)	Diethyl phthalate	1.73	6.26	--	.907	-27*	--	--
(1)	Methyl phthalyl ethyl glycolate	3.36	34.1	-125	1.044	<-31*	--	--
(1)	Dibutyl phthalate	2.33	9.72	43	.857	-31*	--	--
(1)	Ethyl phthalyl ethyl glycolate	3.51	26.6	-106	.936	+68*	--	--
(1)	Butyl phthalyl butyl glycolate	3.75	23.8	29	.856	<-31*	--	--
(1)	Di-(2-ethylhexyl) phthalate	4.36	30.0	20	.838	<-67*	--	--
(5)	Di C_9 Oxo Phthalate	5.38	39.49	66	.799	-30	--	8
(5)	" " " Tetrahydrophthalate	4.90	33.27	63	.800	-30	--	4
(5)	" " " Hexahydrophthalate	4.78	31.99	61	.802	<-35	--	7
(5)	Di n-Decyl 4-Methyl-tetrahydrophthalate	4.55	25.40	101	.757	<-35	--	--
(5)	C_9 Oxo Isophthalate	6.38	50.85	76	.781	<-35	--	7
(5)	α,α^1-Dicarboxy-m-xylene + n-Decyl Alcohol	5.03	25.51	136	.700	+30	--	12
(5)	α,α^1-Dicarboxy-p-xylene + n-Decyl Alcohol	5.78	27.70	153	.651	+35	--	15
(5)	Hexachlorotetrahydrophthalic Acid + n-Decyl Alcohol	9.61	98.0	79	.750	-20	--	15
(5)	C_8 Oxo Terephthalate	5.65	38.40	92	.765	<-35	--	--
(5)	1 m 5-Amylsalicylic + 1 m Stearic + 1 m n-Octyl Alcohol	3.31	12.15	163	.689	+70	395	7
(5)	1 m t-Amylsalicylic Acid + 1 m Lauric + 1 m C_{10} Oxo Alcohol	2.67	9.54	131	.741	<-35	385	3
(5)	Mixed Aromatic (coal oxidation) + Lorol B Alcohol	25.04	285.6	113	.613	+50	565	10
(5)	Dilinoleic Acid + C_8 Oxo Alcohol	13.36	101.90	126	.620	-10	460	6
(5)	" " + n-Dodecyl Alcohol	15.75	112.1	133	.578	+55	525	3
(5)	" " + n-Amyl Alcohol	10.16	68.86	136	.619	+20	460	8
(5)	" " + C_{10} Oxo Alcohol	11.11	73.77	133	.619	+20	520	12
(5)	" " + Butyl Cellosolve	13.6	102.5	127	.614	0	475	10
(5)	" " + Butyl Carbitol	12.43	81.60	136	.596	+5	490	8
(5)	Tall Oil (W. Va. P. & P. Co.) + 1 m Oxo Bottoms	7.28	48.53	118	.701	0	385	15
(5)	Tall Oil (W. Va. P. & P. Co.) + C_8 Oxo Alcohol	6.86	37.51	141	.555	+15	390	15
(5)	Tall Oil (W. Va. P. & P. Co.) + 2 Ethylhexanol	5.59	27.18	150	.763	-15	400	8
(5)	Tall Oil (Unitol R) + 2 Ethylhexanol	180.3	13130.	--	.660	+60	360	11
(5)	Tall Oil (Unitol R) + C_8 Oxo Alcohol	88.1	3694.0	--	.667	+40	400	5
(5)	Tall Oil (Unitol R) + n-Butyl Alcohol	7.51	58.15	99	.734	+10	385	6
(5)	Benzoic + Butanediol-1, 3	3.49	23.30	-44	.896	-15	385	--
(5)	Phenylacetic + Butanediol-1, 3	2.95	13.52	66	.814	-40	390	--
(5)	Hydrocinnamic + Butanediol-1, 3 (a)	11.57	482.0	-276	1.000	+25	465	--
(5)	Diphenyl Acetic + Butanediol-1, 3 (a)	2.91	12.82	78	.802	-45	220	--
(5)	Cyclohexylacetic + Butanediol-1, 3	3.55	17.19	92	.777	<-45	370	--
(5)	Cyclohexylpropionic + Butanediol-1, 3	4.04	19.46	122	.739	<-45	420	--
(5)	Cyclohexylbutyric + Butanediol-1, 3	4.50	23.34	120	.735	<-45	435	--
(5)	Cyclohexylvaleric + Butanediol-1, 3	5.06	27.32	126	.720	<-45	425	--
(5)	Cyclohexylcaproic + Butanediol-1, 3	5.08	28.01	121	.728	-50	400	--
(5)	Naphthenic + Butanediol-1, 3	5.05	36.00	58	.807	-40	370	--
(5)	C_9 Naphthenic + Butanediol-1, 3	3.32	17.24	49	.824	<-60	345	--
(5)	C_{10} Naphthenic + Butanediol-1, 3	3.87	22.31	51	.813	-50	330	--
(5)	C_{11} Naphthenic + Butanediol-1, 3	5.43	44.26	41	0.828	-30	370	--

* Freezing point

(a) Data on these two compounds appear to be reversed

TABLE 22

ESTERS CONTAINING RING STRUCTURES

Ref.	Compound	Viscosity, Cs. @ °F. 210	100	-40	V.I.	ASTM Slope*	Melting Pt., °F.	Specific Gravity/ 20°C.	Flash Pt., °F.	Fire Pt., °F.
(9)	Methyl Phthalate (Carbide and Carbon)	1.68	6.90	--	-44	0.98	--	--	315	335
(12)	Ethyl Phthalate	1.73	6.3	121(0°)	--	0.914	-30	--	340	360
(9)	Allyl Phthalate (Ohio-Apex)	1.71	5.94	995	44	0.89	0	--	340	360
(9)	Butyl Phthalate (B.F.Goodrich)	2.24	0.13	2250	43	0.85	<-100	--	240	370
(12)	Butyl Phthalate	2.31	9.71	202(0°)	37	0.84	-31	--	--	--
(9)	Amyl Phthalate (Commercial Solvents)	--	14.5	574(0°)	--	0.86	<-100	--	--	--
(9)	n-Hexyl Phthalate (Carbide and Carbon)	2.92	13.5	--	60	0.80	-30	--	275	370
(9)	Hexyl Phthalate (Hardesty)	3.24	20.9	--	-54	0.89	+5	--	275	370
(9)	Capryl Phthalate	4.12	26.8	31800	22	0.78	-65	--	310	455
(12)	Capryl Phthalate	4.2	27.1	--	32	0.827	--	--	--	--
(9)	Capryl, butyl Phthalate (Rohm and Haas)	4.02	25.9	--	19	0.82	-65	--	390	440
(9)	2-Ethylhexyl Phthalate (Ohio-Apex)	4.26	29.7	2160(0°)	7	0.83	<-100	--	385	465
(10)	2-Ethylhexyl Phthalate (Ohio-Apex)	5.04	38.8	--	35	0.830	-54**	0.990	352	--
(12)	Octyl Phthalate	4.30	29.3	2800(0°)	19	0.846	<-65	--	--	--
(9)	Methoxyethyl Phthalate (Ohio-Apex)	3.04	17.1	--	-11	0.87	--	--	380	415
(12)	Methoxyethyl Phthalate	2.8	14.9	--	-11	0.889	--	--	--	--
(11)	Ethoxyethyl Phthalate	2.99	16.6	--	-3	0.833	--	--	--	--
(9)	Butoxyethyl Phthalate	3.21	16.4	--	-46	0.84	--	--	365	470
(12)	Butyl, Diisobutylphenoxyethyl phthalate	5.60	63.3	30000(0°)	-49	0.912	-15	--	--	--
(10)	Leuna Alcohol (280-329)	3.92	27.6	--	-28	0.896	-67**	1.007	387	--
(10)	Leuna Alcohol (329-482)	7.08	77.7	--	25	0.839	-36**	0.988	383	--
(0)	Leuna Alcohol (392-482)	7.34	89.2	--	9	0.856	--	0.977	--	--
(9)	Butyl Isophthalate (Genesee Research)	2.51	11.1	--	38	0.85	-10	--	--	--
(9)	2-Ethylhexyl Isophthalate (Genesee Research)	4.80	35.2	--	33	0.82	<-65	--	--	--
(9)	Butyl Terephthalate (Genesee Research)	2.43	9.86	--	65	0.81	+60	--	--	--
(9)	2-Ethylhexyl Terephthalate (Genesee Research)	4.97	33.9	--	66	0.79	-65	--	--	--
(9)	2-Ethylhexyl Tetrahydrophthalate	3.37	18.6	--	29	0.83	<-100	--	--	--
(12)	Butoxyethyl Tetrahydrophthalate	2.80	12.8	6850	54	0.828	<-70	--	--	--
(9)	Tributyl glycerol triphthalate (B.F.Goodrich)	4.84	36.0	--	32	0.82	-50	--	365	390
(9)	Butyl phthalyl butyl glycolate	3.72	23.9	1800(0°)	2	0.863	<-35	--	--	--
(12)	2-Butoxyethyl Carbate(a)	3.52	18.6	25000	52	0.812	-55	--	--	--

* Slope for widest temperature range for which viscosities are reported.

** Pour Point.

(a) Bicyclo (2.2.1)-2-heptene-5, 6-decarboxylate (from maleic anhydride + cyclopentadiene).

TABLE 23

ESTERS FROM HYDROXY-ACIDS

Ref.	Acid	Alcohol	Mols Ethylene Oxide	Viscosity/ °F., cs. 210	100	V.I.	ASTM Slope 210-100°F.	Pour Point °F.	Flash Pt., °F. (C.O.C.)	Almen Wts. Carried Gradual Loading
(5)	1m Hydroxystearic	1m C_8 Oxo	1	6.88	40.92	131	0.679	+20	340	7
(5)	"	"	5	9.25	51.14	146	0.600	+20	355	15
(5)	1m Lactic + 1m Oleic	1m n-Butanol	3	4.09	16.00	180	0.659	-5	400	15
(5)	" "	"	5	5.22	21.18	177	0.617	-5	370	6
(5)	" "	"	2.8 C_3	4.93	21.47	163	0.653	-30	400	13
(5)	" "	"	2.2 C_3	3.77	14.87	166	0.683	-10	365	9

TABLE 24

ESTERS FROM ALKENYLSUCCINIC ACIDS

Ref.	Alkenyl Group	Alcohol	Viscosity/ °F., cs. 210	100	V.I.	ASTM Slope, 210-100°F.	Pour Point, °F.	Flash Pt., °F. C.O.C.	Almen Wts. Carried Grad. Loading
(5)	C_4(IsoButylene)	n-Decyl	3.49	15.57	115	0.752	<-35	390	5
(5)	C_6(2-Ethyl-1-butene)	n-Decyl	5.67	33.98	117	0.727	<-35	380	10
(5)	"	Butyl Carbitol	5.57	34.72	108	0.742	<-35	--	15
(5)	C_{10} Diamylene	n-Decyl	16.82	180.5	106	0.659	-20	450	8
(5)	C_{10} 1-Decene	Ethyl	2.19	6.99	131	0.751	<-35	--	7
(5)	C_{10}-C_{12} (Solvay)	n-Amyl	4.11	26.91	19	0.838	<-35	390	6
(5)	"	C8 Oxo	6.16	53.95	51	0.813	-20	395	3
(5)	"	Butyl Carbitol	5.63	38.66	89	0.769	<-35	410	4
(5)	"	Butyl Cellosolve	4.70	31.35	57	0.805	<-35	395	4
(5)	"	n-Decyl	5.75	37.80	99	0.750	<-35	425	6
(5)	"	Methyl + n-Decyl	5.15	35.42	73	0.791	<-35	365	2
(5)	"	Methyl + C_{11}-C_{12} Oxo	6.80	59.75	65	0.791	+30(?)	435	4
(5)	C_{12}-C_{14} (Solvay)	n-Amyl	4.50	29.11	53	0.809	<-35	370	5
(5)	"	n-Decyl	6.24	40.73	110	0.728	<-35	400	5
(5)	"	Butyl Cellosolve	5.00	33.56	72	0.791	<-35	410	5
(5)	"	Butyl Carbitol	5.68	35.54	109	0.739	<-35	430	14
(5)	C_{14}(1-Tetradecene)	Ethyl	3.17	13.72	106	0.767	-25	--	11
(5)	C_{14}-C_{18} (Solvay)	n-Amyl	5.26	28.97	126	0.718	<-35	460	5
(5)	"	n-Decyl	6.25	35.53	132	0.687	-10	490	9
(5)	"	Methyl + n-Decyl	5.70	33.62	120	0.720	-25	395	4
(5)	"	Ethyl + n-Decyl	5.13	28.26	123	0.723	-25	435	6
(5)	"	Isobutyl + n-Tetradecyl	6.47	38.77	126	0.695	+35	460	7
(5)	C_{16}-C_{18} (Fischer olefins)	n-Decyl	21.61	235.7	112	0.625	-15	415	6
(5)	C_{10}-C_{18} (polypropylene)	n-Decyl	14.01	152.1	96	0.692	-20	420	5
(5)	C_{18} (1-octadecene)	n-Decyl	6.56	37.27	134	0.676	+25	460	4
(5)	C_{24} (wax)	n-Decyl	11.08	76.36	130	0.628	+65	480	9
(5)	"	Methyl + n-Decyl	11.25	84.40	123	0.645	+65	435	11
(5)	C_{24} (Polypropylene)	n-Decyl	19.96	271.1	93	0.680	-10	395	8
(5)	"	Methyl + n-Decyl	15.44	230.5	65	0.741	-5	455	5
(5)	C_{24}	C8 Oxo	10.28	75.96	122	0.660	+65	435	3

TABLE 25

COMPOUNDS CONTAINING SULFUR

Ref.	Acid or Other Reactant	Alcohol or Mercaptan	Viscosity/°F., cs. 210	Viscosity/°F., cs. 100	V.I.	ASTM Slope 210-100°F.	Pour Point °F.	Flash Point °F., C.O.C.	Almen Wts. Carried Gradual Loading
I.	**THIO-ETHER LINKAGE**								
	A. Mono Esters								
(5)	$n\text{-}C_{12}H_{25}\text{-}S\text{-}(CH_2)_{10}\text{-}COOH$	Iso-amyl	4.36	16.75	189	0.637	+75	425	11
(5)	$C_2H_5\text{-}S\text{-}COOH$	n-Octadecyl	3.19	10.94	175	0.670	+80	440	15
	B. Di Basic Acid Esters								
(5)	$S\text{-}(CH_2CH_2COOH)_2$	Butyl Carbitol	4.01	17.18	155	0.698	< -35	--	15
(5)	"	2-Ethyl hexyl	2.91	11.60	113	0.760	< -35	410	6
(5)	"	C8 Oxo	3.48	13.89	148	0.710	< -35	395	9
(5)	"	C9 Oxo	4.13	18.41	148	0.705	< -35	--	15
(5)	"	C10 Oxo	4.39	19.88	152	0.695	< -35	--	--
(5)	$(CH_2SCH_2CH_2COOH)_2$	Butyl Carbitol	5.45	26.58	149	0.670	< -35	485	15
(5)	2 m Thioglycolic + 1 m Isoprene	n-Decyl	5.97	32.21	138	0.681	< -35	--	15
(5)	" + 1 m Cyclopentadiene	"	4.31	19.66	148	0.703	< -35	--	15
(5)	" + 1 m Vinyl Cyclohexane	"	4.68	21.41	154	0.683	< -35	--	9
(5)	1 m " + 1 m Undecylenic	Iso-Amyl	3.64	13.99	167	0.683	-10	415	15
(5)	" + "	Butyl Cellosolve	4.06	16.55	169	0.677	+5	--	15
(5)	" + "	Butyl Carbitol	4.72	20.66	164	0.666	-35	--	12
(5)	" + 1 m Oleic	C8 Oxo	5.99	30.61	146	0.664	< -15	455	9
(5)	" "	Butyl Carbitol	6.48	31.79	153	0.634	-10	460	15
(5)	1 m SCl_2 + 2 m Oleic + 2 m t-octyl mercaptan	n-Dodecyl	18.27	146.6	128	0.584	+5	405	7
(5)	" " "	Isopropyl	15.30	149.0	110	0.654	-15	295	15
(5)	O-di-$(CH_2SCH_2CH_2COOH)$ Benzene	C11-C12 Oxo	5.20	27.66	131	0.709	-40	--	15
(5)	Dithiodiglycolic	C8 Oxo	3.19	13.47	116	0.756	-65	435	15
(5)	$S\text{-}(CH_2CH_2COOH)_2$	B-tert.-Octylmercapto-ethanol	9.89	74.06	119	0.670	< -35	--	6
(5)	Trimethyl Adipic	tert.-$C_8H_{17}S\text{-}CH_2CH_2OH$	41.94	616.9	111	0.595	0	--	--
	C. Glycol Esters (Sulfur in Acid)								
(5)	tert.-$C_8H_{17}S\ CH_2CH_2COOH$	Trimethylene Glycol	6.51	43.59	110	0.725	< -35	--	6
(5)	"	Hexamethylene Glycol	8.01	54.05	122	0.682	< -35	--	15
(5)	"	Triethylene Glycol	7.10	47.47	131	0.707	< -35	--	15
(5)	"	Tetramethylene Glycol	7.76	50.75	124	0.680	< -35	--	15
(5)	"	Thiodiglycol	15.85	145.6	116	0.635	-5	--	4
(5)	$C_2H_5\text{-}S\text{-}CH_2COOH$	Propylene Glycol 400	7.87	43.97	142	0.634	-40	480	15
(5)	tert.-$C_{12}H_{25}S\text{-}CH_2CH_2COOH$	Trimethylene Glycol	12.21	163.6	60	0.764	-10	--	--
	D. Glycol Esters (Sulfur in Glycol)								
(5)	Caprylic	Thiodiglycol	3.50	12.86	172	0.674	+65	--	15
(5)	C9 Oxo Acid	"	3.87	17.40	134	0.725	-65	430	--
(5)	Coconut Oil Acid	"	5.36	--	--	--	+95	--	15
	E. Esters of Thio Alkyl Succinic Acid								
(5)	1 m Maleic + 1 m n-C_{12} mercaptan	2 m Butanol	3.33	13.39	138	0.725	+10	425	11
(5)	" "	2 m C8 Oxo Alcohol	4.74	23.97	133	0.714	+25	460	11
(5)	" "	2 m n-Decanol	5.16	24.76	150	0.676	+30	475	15
(5)	" "	2 m Dowanol 69A (Tripropylene glycol mono isopropyl ether)	8.31	57.91	120	0.683	+5	355	15
(5)	" + 1 m tert. C_{12} mercaptan	2 m Dowanol 69A	29.22	623.9	72	0.706	+20	355	7
(5)	" + 2 m n-C_{12} "	1 m n-Decanol	5.24	24.85	153	0.669	+25	445	15
(5)	" + " " "	1 m C11-C12 Oxo Alcohol	5.75	29.11	145	0.671	+30	375	10
(5)	1 m Itaconic + 1 m n-C_{12} mercaptan	2 m C8 Oxo Alcohol	5.88	32.91	131	0.697	+10	440	15
(5)	" " "	2 m Butyl Carbitol	9.82	55.95	144	0.599	+50	415	15
(5)	1 m Itaconic + 1 m tert. C_{12} mercaptan	2 m Dowanol 69A	11.32	134.9	71	0.734	-5	360	--
(5)	" " "	2 m C11-C12 Oxo Alcohol	7.63	50.84	120	0.689	< -35	395	11
(5)	" 2 m " " "	1 m " " "	10.18	120.0	63	0.773	-10	--	7
	F. Ethers								
(5)	Dichloroethylether	2 m Lorol mercaptan	4.60	19.95	165	0.669	+60	430	11
(5)	"	2 m tert.-C_{12} mercaptan	5.32	35.40	87	0.774	-35	335	15
(5)	"	2 m tert.-C_{16} mercaptan	7.82	79.80	57	0.796	-15	330	15
II.	**THIO-ESTER LINKAGE**								
	A. Mono Esters								
(5)	Oleic	tert.-C8 mercaptan	3.96	16.35	162	0.688	-35	365	8
(5)	"	tert.-C_{12} mercaptan	4.87	22.71	152	0.680	-15	365	10
(5)	Stearic	tert.-C8 "	4.09	17.31	160	0.689	-40	425	6
(5)	"	n-C_{12} mercaptan		Solid					
(5)	"	tert.-C_{12} mercaptan		Solid					
	B. Di Basic Acid Esters								
(5)	Adipic	tert.-C8 mercaptan	5.99	42.91	89	0.764	< -35	405	--
(5)	"	tert.-C_{12} mercaptan	9.44	105.07	64	0.775	-10	360	15
(5)	"	1 m tert.-C8 mercaptan + 1 m Lorol mercaptan	4.14	17.61	161	0.688	+25	360	15
(5)	Sebacic	tert.-C8 mercaptan	18.36	188.2	112	0.636	-35	410	15
(5)	Sebacic	tert.-C_{12} mercaptan		Solid					
(5)	$C_{10}\text{-}C_{12}$ Alkenyl Succinic	1 m Lorol mercaptan + 1 m n-Decanol	5.72	34.21	118	0.724	-5	425	11
III.	**XANTHATES**								
(5)	C8 Oxo Xanthate	Ocenyl Chloromcetate	3.93	16.57	155	0.698	+35	380	15
(5)	I.C.I. "	I.C.I. Chloromcetate	3.66	18.96	75	0.793	-50	--	15
(5)	C16 Thioxanthate	C11-C12 Oxo Chloroscetate	4.82	34.79	40	0.824	-35	--	15
(5)	2-Ethylhexyl Xanthate	Triethylene Glycol Chloromcetate	7.28	61.66	82	0.765	-15	370	15
(5)	Decyl "	" " "	10.88	101.8	99	0.704	0	400	15
IV.	**THIO-PHOSPHATES**								
(5)	1 m Dibutyl Dithiophosphoric Acid	1 m Ethyl Oleate	3.48	13.60	155	0.701	+10	--	15
(5)	2 m Na Dibutyl Dithiophosphate	2 m Butyl Oleate + 1 m SCl_2	13.16	98.17	127	0.617	+10	370	15

TABLE 26

COMPOUNDS CONTAINING PHOSPHORUS

Ref.	Acid	Alcohol	Viscosity/°F., cs. 210	Viscosity/°F., cs. 100	V.I.	ASTM Slope 210-100°F.	Pour Point °F.	Flash Pt., °F. (C.O.C.)	Almen Wts. Carried Gradual Loading
(5)	1 m $POCl_3$	3 m C_8 Oxo	4.48	20.06	156	0.687	<-35	--	15
(5)	1 m $POCl_3$	3 m C_9 Oxo	3.77	15.99	146	0.711	<-35	--	12
(5)	1 m $POCl_3$	3 m n-Dodecyl	5.24	23.31	163	0.648	+100	--	--
(5)	1 m $POCl_3$	3 m C_{11} Oxo	6.95	38.70	140	0.658	<-35	360	15
(5)	1 m $POCl_3$	3 m C_{12}-C_{13} Oxo	7.32	40.23	142	0.643	<-35	420	15
(5)	1 m $POCl_3$	3 m C_{14} Oxo	14.22	110.2	126	0.613	<-35	350	15
(5)	1 m $POCl_3$	3 m Oxo Bottoms	4.72	28.31	90	0.772	-55	300	15
(5)	1 m $POCl_3$	3 m Butyl Carbitol	3.39	13.03	154	0.701	<-35	--	15
(5)	1 m $POCl_3$	2 m Butyl Carbitol + 1 m Methyl Cellosolve	7.32	36.66	152	0.617	-60	330	15
(5)	1 m $POCl_3$	1 m 2-Ethylhexanol + 1.1 m Ethylene Oxide	12.91	86.70	134	0.595	<-35	--	15
(5)	1 m $POCl_3$	3 m tert.-C_8H_{17}-SCH_2CH_2OH	146.9	3589.0	--	0.544	--	--	15
(5)	2 m $POCl_3$	4 m Butyl Cellosolve + 1 m Ethylene Glycol	4.50	18.25	178	0.650	-75	380	13
(5)	2 m $POCl_3$	4 m 2-Ethyl Hexanol + 1 m Ethylene Glycol	8.91	63.59	120	0.677	-55	350	14
(5)	2 m $POCl_3$	4 m 2-Ethyl Hexanol + 1 m Triethylene Glycol	15.02	128.2	120	0.627	-40	350	15
(5)	2 m $POCl_3$	4 m C_8 Oxo + 1 m Triethylene Glycol	56.78	702.7	121	0.527	-15	375	15
(5)	2 m $POCl_3$	4 m Butyl Carbitol + 1 m Triethylene Glycol	19.26	143.1	133	0.559	-35	360	12
(5)	2 m $POCl_3$	4 m C_8 Oxo + 1 m Thiodiglycol	30.79	284.9	127	0.545	-30	395	13
(5)	1 m Di-isopropyl-di-thio Phosphoric Acid + 1 m Dicylopentadiene		3.95	25.15	18	0.841	-30	345	--

TABLE 27

OTHER PHOSPHATES AND BORATES

Ref.	Ester	Viscosity, cs. @ °F. 210	100	-40	VI	ASTM Slope**	Freezing Pt., °F.	Specific Grav./20°C.	Flash Pt., °F.	Fire Pt., °F.	Wt. % Hydrolyzed 24 Hrs., 212°F.
(12)	Trimethyl Phosphate	0.65	1.35	11.8	--	0.930	-70*	--	--	--	--
(9)	Tri-n-butyl Phosphate	1.06	2.66	46.9	--	0.839	<-50	0.974	340	380	0.0
(11, 12)	Tributyl "	1.19	2.73	47.0	--	0.795	<-70*	--	--	--	--
(9)	Tri-n-amyl "	1.36	3.79	114.	--	0.819	<-50	0.953	355	380	--
(9)	Tri-(2-ethylbutyl)"	1.68	4.79	240	--	0.793	<-50	0.950	--	--	--
(9)	Tri-n-hexyl "	1.76	4.75	153	--	0.742	<-50	0.941	410	445	0.0
(9)	Tri-(2-ethylhexyl)"	2.29	8.27	847	96	0.776	<-50	0.920	400	460	--
(9)	Tri-n-octyl "	2.49	8.45	232(-25°)	135	0.712	-30	0.920	440	515	--
(12)	Tri-n-octyl	2.27	8.21	787	94	--	--	--	--	--	--
(9)	Tri-methoxyethyl "	1.47	4.39	283	--	0.820	<-70	1.157	420	455	5.5
(9)	Tri-butoxyetnyl "	2.03	6.72	616	103	0.973	<-65	1.009	420	490	0.5
(11)	Triisononyl "	3.51	14.7	--	136	0.726	--	--	--	-	--
(11)	Tricresyl "	4.04	29.2	--	-24	0.872	--	--	--	--	--
(12)	Tricresyl "	4.1	29.3	15030(0°)	-14	0.773	-10	--	--	--	--
(9)	Tri-(2-ethylhexyl) Borate	1.94	6.28	433	--	0.79	<-40*	--	345	365	--
(9)	Tricapryl Borate	1.90	6.62	Solid	--	0.82	0*	--	310	355	--

* Melting Point
** Slope for widest temperature range for which viscosities are reported.

TABLE 28

CARBONATES AND UREA DERIVATIVES

Ref.	Compound	Viscosity, cs. @ °F. 210	100	-40	VI	ASTM Slope*	Melting Pt., °F.	Specific Grav/20°C.	Flash Pt., °F.	Fire Pt., °F.	Wt. % Hydrolyzed 48 Hrs. at 212°F.
(9)	Di-ethyl Carbonate	0.402	0.676	2.61	--	0.96	-45 F.P.	0.975	115	115	35.5
(9)	Di-n-Butyl "	0.723	1.52	13.1	--	0.87	<-70 F.P.	0.924	190	195	41.7
(9)	Di-n-Amyl "	0.918	2.09	27.6	--	0.85	<-70 F.P.	0.910	195	235	--
(9)	Di-n-hexyl "	1.17	2.93	59.1	--	0.82	<-70	0.900	275	295	28.3
(9)	Di-n-octyl "	1.79	5.28	--	--	0.76	+24	0.887	330	360	21.3
(9)	Propylene "	0.792	1.71	20.6	--	0.88	<-70	1.19	290	295	44.5
(9)	n-Butylene-2 "	0.777	1.68	--	--	0.91	+64	1.11	250	270	62.6
(9)	n-Amylene-2 "	0.955	2.38	78.9	--	0.94	<-50	1.07	290	295	--
(9)	2-Methylpentanediol Carbonate	--	--	--	--	--	+207	--	300	340	--
(9)	Dicyclopentyl "	1.63	4.97	157	--	0.74	<-50	1.04	240	275	--
(9)	Butyl Diglycol "	2.87	12.3	1450(-25°)	85	0.96	<-25	1.07	370	400	<0.5
(11)	Butyl Diglycol "	2.73	11.6	--	77	0.757	--	--	--	--	--
(12)	Butyl Diglycol "	2.77	11.8	--	79	0.804	-70	--	--	--	--
(12)	Butoxyethyl Diglycol "	3.65	18.3	--	86	0.782	-40	--	--	--	--
(9)	Butoxyethyl Diglycol "	3.31	15.7	3140(-25°)	82	0.97	<-25	1.08	380	410	<0.5
(11)	Butoxyethyl Diglycol "	3.57	17.7	--	84	0.789	--	--	--	--	--
(9)	Phenyl Diglycol "	--	--	--	--	--	+103	1.23	460	520	<0.5
(12)	Cresyl Diglycol "	8.65	219.3	--	-170	0.975	+5	--	--	--	--
(9)	Di-amyl Urea	11.1	95.7	--	109	0.68	--	--	--	--	0.0
(9)	Propylene Urea	--	--	--	--	--	--	--	300	340	0.0
(9)	Di(3.3 Diethylaminopropyl) Urea	16.3	177	--	103	0.67	--	0.934	400	415	0.0

* Slope for widest temperature interval for which viscosities are reported.

TABLE 29

OTHER COMPOUNDS CONTAINING NITROGEN

Ref.	Component A	Amine or Alcohol	Viscosity/ °F., cs. 210	100	V.I.	ASTM Slope, 210-100°F.	Pour Point, °F.	Flash Pt.,°F. C.O.C.	Almen Wts. Carried Grad. Loading
(5)	Sebaconitrile	--	2.13	7.14	108	0.787	+15	325	4
(5)	$(CH_2OCH_2CH_2CN)_2$	--	2.41	9.35	81	0.814	<-35	330	--
(5)	$(CH_2OCH_2CH_2OCH_2CH_2CN)_2$	--	3.35	17.23	55	0.817	<-35	370	5
(5)	$S(CH_2CH_2OCH_2CH_2CN)_2$	--	4.58	25.95	99	0.761	<-35	425	9
(5)	$O(CH_2CH_2OCH_2CH_2OCH_2CH_2CN)_2$	--	4.55	27.44	79	0.782	-30	435	11
(5)	Omega-Cyanopelargonic (C_{10})	Tetraethylene Glycol	6.80	40.19	131	0.680	-50	460	3
(5)	"	Thiodiglycol	7.79	47.30	133	0.660	+20	460	15
(5)	"	Triethylene Glycol	8.04	48.83	133	0.653	-25	465	5
(5)	Adduct: 2m acrylonitrile	1m Polypropylene Glycol 400	8.08	52.55	126	0.670	-40	425	7
(5)	Oleic	Dimethylethylenediamine	12.03	86.60	128	0.624	+35	510	1
(5)	Sebacic	Di-2-ethylhexylamine	17.37	261.8	73	0.723	-10	365	4
(5)	Oleic	Methyldiethanolamine	4.66	18.26	185	0.629	+10	420	5
(5)	Adipic	Di-2-ethylhexylaminoethanol	4.96	29.47	101	0.756	-55	385	4
(5)	Capric	2-Methyl-2-nitro-1,3-propanediol	3.97	20.29	100	0.765	0	375	3
(5)	Coconut Oil Acids	"	5.23	27.42	134	0.703	+40	410	8
(5)	4-Methyl-4-nitropimelic	C_{10} Oxo	4.75	26.25	112	0.743	<-35	350	4

TABLE 30

COMPLEX ESTERS - ACID CENTER

Ref.	Dibasic Acid	Glycol	Acid	Viscosity cs. @ °F. 210	100	VI	ASTM Slope 210/100°F	Pour Pt., °F.	Flash Pt., °F.	Almen, Wts. Carried Grad. Loading
(5)	Adipic	Ethylene glycol	Acetic	14.0	116.3	121	0.631	-15	396	3
(5)	"	"	Acetic	16.1	137.3	122	0.617	0	450	4
(5)	"	"	Oleic-Acetic	10.3	62.8	139	0.610	+50	465	4
(5)	"	"	Oleic	--	72.0	--	--	+35	490	6
(5)	"	"	Caprylic	--	--	--	--	+45	--	--
(10)	"	"	Leuna C_{11}	10.49	120.3	70	0.761	-35	340	--
(5)	"	1, 3 Propane diol	Butyric	9.42	54.7	142	0.611	-25	405	4
(5)	"	1, 3 Butane diol	Acetic	9.33	69.7	118	0.680	-40	455	--
(5)	"	"	Propionic	4.05	17.24	158	0.693	-70	275	--
(5)	"	"	Crotonic	4.85	30.6	81	0.781	-40	330	--
(5)	"	"	Butyric	3.32	13.28	139	0.723	<-85	295	--
(5)	"	"	Butyric	3.89	15.96	161	0.690	<-55	285	--
(5)	"	"	Caprylic	4.08	17.00	165	0.684	-85	375	--
(5)	"	"	C_8 Oxo	5.54	29.6	136	0.696	-55	380	--
(5)	"	"	Butyric-Oleic	5.02	20.7	175	0.631	-20	285	--
(5)	"	"	Oleic	6.72	32.4	156	0.622	-10	335	--
(5)	"	Pentaglycol	Caprylic	5.01	24.7	144	0.681	<-70	355	--
(5)	"	Triethylene glycol	Butyric	8.24	43.6	148	0.609	<-35	385	3
(5)	"	"	Valeric	6.35	30.0	157	0.628	<-35	395	3
(5)	"	"	Caprylic	7.49	37.2	152	0.610	<-35	470	7
(5)	"	Tetraethylene glycol	Butyric	8.29	42.7	150	0.590	<-35	425	6
(5)	"	"	Butyric	8.68	45.3	148	0.596	<-35	425	6
(5)	"	"	Valeric	8.49	42.5	153	0.588	<-35	435	4
(5)	"	"	Caproic	8.85	44.5	153	0.582	<-35	460	6
(5)	"	"	Caprylic	8.68	43.3	153	0.583	<-35	475	5
(5)	"	Polyethylene glycol 300	Butyric	11.48	62.2	148	0.560	-35	435	5
(5)	"	" 400	Butyric	11.24	60.4	149	0.561	-10	450	15
(5)	"	Polypropylene glycol 400	Butyric	8.49	42.5	153	0.588	<-35	435	4
(5)	"	Thiodiglycol	Butyric	6.92	36.15	147	0.640	<-35	--	8
(5)	Adipic-Sebacic	Tetraethylene glycol	Butyric	7.49	37.8	151	0.614	-45	375	15
(5)	Sebacic	1, 3 - Butane diol	Caprylic	5.75	26.1	161	0.635	<-75	385	--
(5)	"	Triethylene glycol	Butyric	9.74	49.7	152	0.570	+15	400	5
(5)	"	"	Valeric	8.89	41.8	158	0.562	+15	410	7
(5)	"	Tetraethylene glycol	Acetic	13.4	82.2	141	0.567	<-35	440	7
(5)	"	"	Acetic	13.1	80.2	141	0.569	<-35	400	5
(5)	"	"	Propionic	9.92	51.8	150	0.573	<-35	415	7
(5)	"	"	Butyric	10.60	54.6	152	0.559	<-35	435	5
(5)	"	"	Valeric	11.58	58.8	152	0.542	<-35	445	5
(5)	"	"	Caproic	11.00	56.1	152	0.551	<-35	465	7
(5)	Oxalic	Ethylene glycol	Oleic	4.70	18.9	180	0.637	+10	435	5
(5)	Oxalic	Polyethylene glycol 400	Acetic	6.30	38.0	124	0.703	<-35	395	6
(5)	Diglycolic	1, 3 - Butane diol	Butyric	5.61	37.5	94	0.761	-40	280	--
(5)	"	"	Caprylic	4.18	21.7	105	0.776	-70	370	--
(5)	Dilinoleic	"	Caprylic	11.98	71.1	142	0.676	-65	390	--
(5)	Thio-dipropionic	Tetraethylene glycol	Butyric	7.73	42.5	144	0.633	-40	390	15
(5)	Thio-dipropionic	Thio-diglycol	Butyric	7.11	37.3	150	0.636	<-35	375	15
(10)	Adipic	Trimethylolethane	C_6-C_7 Leuna	5.34	33.0	104	0.751	-65	420	--

TABLE 31

COMPLEX ESTERS - GLYCOL CENTER

(Glycol has no Ether Oxygen Atoms)

Ref.	Glycol	Acid	Alcohol	Viscosity, cs., @ °F. 210	100	V.I.	ASTM Slope 210/100°F.	Pour Pt., °F.	Flash Pt., °F.	Sp. Gr./ 20°C.
(5)	Ethylene glycol	Adipic	C_8 Oxo	5.06	23.7	153	0.673	-30	415	
(5)	"	Adipic	ICI Nonyl	4.89	23.7	145	0.691	0	405	
(10)	"	Adipic	Leuna (284-356)	4.30	20.1	141	0.712	-80	425	0.992
(5)	"	Adipic	2-Ethylhexyl	4.92	23.5	148	0.686	-30	420	
(5)	"	Adipic-Sebacic	"	7.44	40.1	143	0.634	-15	425	
(5)	"	Adipic	Butyl Carbitol	6.83	34.4	151	0.632	-40	435	
(6)	"	Oxalic	2-Ethylhexyl	2.74	11.56	79	0.803	--	--	
(5)	Trimethylene glycol	Adipic	n-Butyl	7.70	38.7	152	0.605	-10	390	
(5)	" "	Thio-dipropionic	n-Butyl	5.29	24.7	155	0.663	<-35	385	
(10)	Dimethylol propane	Adipic	Leuna C_6-C_7	8.48	54.4	130	0.657	-45	430	1.002
(10)	" "	β-Methyladipic	C_{11}-C_{14} Oxo	11.7	81.9	130	0.622	-25	420	0.963
(10)	" "	Adipic	Leuna (284-356)	5.30	27.9	135	0.702	-70	400	0.982
(10)	Dimethylol pentane	Adipic	" "	6.94	40.3	134	0.670	-65	420	0.989
(10)	" "	Adipic	2-Ethylhexyl	5.90	32.3	135	0.689	-80	465	0.973
(10)	1, 4 Butane diol	Adipic	Leuna (C_6-C_7)	7.18	39.7	141	0.650	+25	390	1.005
(10)	" "	Adipic	Leuna (284-356)	5.38	26.8	145	0.680	-30	420	0.993
(10)	" "	Adipic	2-Ethylhexyl	5.26	24.7	155	0.655	-15	448	0.978
(5)	1, 5 Pentane diol	Oxalic	C_{10} Oxo	6.26	36.6	128	0.695	<-35	385	
(6)	" " "	Sebacic	2-Ethylhexyl	10.77	59.3	147	0.574	+20	--	
(5)	1, 6 Hexane diol	Adipic	C_8 Oxo	8.40	43.0	151	0.596	+55	425	
(5)	" " "	Sebacic	"	10.68	56.3	150	0.564	+75	490	
(10)	" " "	Adipic	2-Ethylhexyl	5.86	29.3	145	0.662	-5	415	0.975
(10)	" " "	Adipic	Leuna	6.14	29.5	154	0.639	-5	400	0.983
(10)	" " "	Adipic	2-Ethylhexyl	2.92	11.6	115	0.758	-80	445	0.982
(6)	2-Ethylhexane diol-1,6	Sebacic	2-Ethylhexyl	26.12	153.1	142	0.470	+25	--	
(5)	Thio-diglycol	Adipic	n-Butyl	6.55	30.8	158	0.619	+25	345	
(5)	"	Adipic	Ethyl Cellosolve	5.34	25.0	155	0.662	<-35	385	
(10)	1, 6 Methylhexane diol	Adipic	Leuna (284-356)	7.23	40.2	141	0.649	-75	425	0.995
(10)	Trimethylolpropane	Adipic	Leuna (C_6-C_7)	12.6	95.2	125	0.627	-65	400	1.016
(10)	"	β-Methyladipic	"	19.8	210.7	112	0.632	-45	430	1.018
(10)	Pentaerythritol	Adipic	Leuna (284-356)	32.3	310.0	125	0.547	-40	400	1.035
(6)	"	Sebacic	2-Ethylhexanol	53.7	318.8	135	0.405	-25	--	--

TABLE 32

COMPLEX ESTERS - GLYCOL CENTER

(Glycol Contains Ether-Oxygen Atoms)

Ref.	Glycol	Acid	Alcohol	Viscosity, Cs. @ °F. 210	100	-40	V.I.	ASTM Slope 210/100°F.	Pour Pt., °F.	Flash Pt., °F.
(5)	Diethylene glycol	Adipic	n-Butyl	9.15	50.7	--	145	0.603	-50	460
(5)	" "	"	2-Ethylhexyl	6.70	34.6	16,126	144	0.643	-55	410
(5)	" "	Adipic-Sebacic	"	9.07	49.5	--	147	0.601	-60	450
(5)	" "	Sebacic	"	Solid at Room Temperature						
(6)	" "	"	Methyl Carbitol	"	"	"	"			
(5)	Triethylene glycol	Adipic	n-Butyl	10.40	58.2	--	146	0.585	<-35	405
(6)	" "	"	2-Ethylhexyl	9.14	51.8	--	143	0.609	-45	--
(6)	" "	"	"	6.44	32.6	12,420	143	0.645	<-60	--
(5)	" "	"	"	7.84	41.3	32,488	147	0.617	-55	430
(5)	" "	"	C8 Oxo	5.28	24.5	10,052	156	0.662	-60	385
(5)	" "	"	C8 Oxo	7.27	36.5	--	151	0.619	<-35	425
(6)	" "	"	Caprył	8.68	48.0	--	144	0.608	-40	--
(6)	" "	"	C9 Oxo	12.68	85.2	--	134	0.599	-30	--
(6)	" "	"	ICI Nonyl	9.05	52.6	--	141	0.618	-50	--
(5)	" "	"	" "	7.94	42.8	--	145	0.622	-50	380
(6)	" "	"	Carbitol	13.2	83.2	--	139	0.576	-30	--
(6)	" "	Mixed Methyl Adipic	2-Ethylhexyl	5.28	29.0	--	127	0.717	-55	--
(5)	" "	Adipic-Sebacic	"	9.56	50.7	33,976	149	0.583	-55	455
(6)	" "	" "	"	8.47	44.9	--	148	0.605	<-60	--
(6)	" "	Sebacic	2-Methylpropyl	10.77	58.3	--	148	0.569	+15	--
(6)	" "	"	Amyl	5.5	23.9	--	167	0.630	-20	--
(6)	" "	"	2-Ethylbutyl	10.44	56.5	--	148	0.575	-5	--
(6)	" "	"	2-Methylamyl	15.25	93.1	--	142	0.554	0	--
(6)	" "	"	2-Ethylhexyl	11.17	60.6	--	148	0.564	-10	--
(6)	" "	"	"	7.76	39.3	17,908	151	0.608	-50	--
(5)	" "	"	2-Ethylhexyl	11.86	64.7	--	143	0.557	-15	470
(6)	" "	"	Caprył	11.31	61.4	--	148	0.563	+10	--
(5)	" "	"	C8 Oxo	7.55	37.3	Solid	153	0.606	-45	460
(5)	" "	"	" "	9.54	48.8	--	152	0.574	-10	455
(6)	" "	"	C9 Oxo	12.29	67.9	--	147	0.554	+5	--
(5)	" "	"	ICI Nonyl	19.08	123.4	--	140	0.530	+10	410
(5)	" "	"	" "	9.05	50.3	--	145	0.606	--	--
(5)	" "	"	" "	10.93	62.3	--	145	0.581	-10	--
(5)	" "	"	" "	16.1	94.4	--	144	0.529	+15	480
(6)	" "	"	Cellosolve	7.09	34.5	--	155	0.614	-5	--
(6)	" "	"	Carbitol	14.2	84.2	--	144	0.550	+30	--
(5)	" "	C14-C18 Alkenylsuccinic	Methyl	20.65	245.3	--	105	0.648	-10	485
(5)	Tetraethylene glycol	Oxalic	C8 Oxo	6.41	37.2	--	130	0.688	<-35	420
(5)	" "	"	n-Decyl	5.45	27.9	--	131	0.685	+65	425
(5)	" "	Adipic	2-Ethylhexyl	8.34	44.3	Solid	147	0.608	-40	430
(5)	" "	"	C8 Oxo	8.73	46.0	--	149	0.598	<-35	435
(5)	" "	"	ICI Nonyl	9.20	53.0	--	142	0.612	<-35	380
(5)	" "	"	C10 Oxo	8.99	48.9	--	146	0.602	<-35	455
(5)	" "	"	Dowanol 53A	11.12	66.66	--	141	0.592	-35	435
(5)	" "	Adipic-Sebacic	2-Ethylhexyl	10.34	56.1	37,295	148	0.577	-50	460
(5)	" "	Sebacic	n-Octyl	9.55	47.1	--	154	0.546	+50	500
(5)	" "	"	n-Octyl	10.36	51.8	--	153	0.509	+40	480
(5)	" "	"	2-Ethylhexyl	12.34	74.4	--	142	0.577	-40	465
(5)	" "	"	C8 Oxo	12.38	66.9	--	148	0.547	<-35	480
(6)	Polyglycol 200	Oxalic	2-Ethylhexyl	8.53	61.8	--	116	0.688	-20	--
(6)	" "	"	"	6.74	42.0	--	122	0.697	-20	--
(6)	" "	Adipic	2-Ethylhexyl	11.09	65.0	--	144	0.587	-60	--
(6)	" "	"	Caprył	13.41	78.1	--	144	0.554	-45	--
(6)	" "	"	C8 Oxo	10.04	56.4	35,708	145	0.590	<-60	--
(6)	" "	"	ICI Nonyl	12.52	77.3	--	140	0.580	-45	--
(6)	" "	"	Carbitol	22.7	168.9	--	134	0.599	-25	--
(6)	" "	Adipic-Sebacic	2-Ethylhexyl	9.60	51.5	18,223	148	0.580	--	--
(6)	" "	Sebacic	n-Octyl	13.47	54.2	--	162	0.457	+50	--
(6)	" "	"	Caprył	8.43	44.4	--	149	0.604	-50	--
(6)	" "	"	2-Ethylhexyl	11.41	61.7	--	148	0.560	-55	--
(6)	" "	"	"	9.05	47.0	--	150	0.587	-40	--
(6)	" "	"	2-Ethylhexyl	11.05	57.6	17,694	150	0.553	<-60	--
(6)	" "	"	"	10.63	56.8	--	149	0.568	-40	--
(6)	" "	"	"	8.58	43.6	--	152	0.590	-40	--
(6)	" "	"	C8 Oxo	12.16	65.6	20,344	149	0.550	-40	--
(6)	" "	"	" "	14.10	76.5	29,872	148	0.529	-50	--
(6)	" "	"	C9 Oxo	13.63	77.1	--	146	0.544	-60	--
(6)	" "	"	5-Ethylnonanol-2	20.03	130.3	--	139	0.526	0	490
(6)	" "	"	7-Ethylundecanol-2	--	--	--	--	--	+50	--
(6)	" "	"	3, 9-Diethyltridecenol-6	29.74	250.0	--	130	0.530	+20	--
(6)	" "	"	Butyl Cellosolve	10.57	53.0	--	153	0.552	+10	--
(6)	" "	"	2-Ethyl butyl Cellosolve	11.48	59.6	--	151	0.548	-50	--
(6)	" "	"	Methyl Carbitol	20.23	116.9	--	144	0.496	+45	--
(6)	" "	"	Butyl Carbitol	12.32	64.4	--	151	0.539	+15	--
(6)	" "	"	Propylene glycol monoethyl ether	17.45	106.8	--	142	0.529	+35	--
(6)	" "	"	Propylene glycol monoisopropyl ether	21.37	140.2	--	139	0.518	+35	--
(6)	Polyethylene glycol 300	Adipic	Methyl Carbitol	20.51	133.7	--	140	0.523	-25	430
(6)	" " "	Sebacic	ICI Nonyl	10.77	58.4	--	148	0.569	-20	--
(6)	" " "	"	Methyl Carbitol	26.20	159.0	--	141	0.478	+20	--
(6)	Polyethylene glycol 400	"	2-Ethylhexyl	9.29	47.9	--	151	0.581	+25	--
(6)	" " "	"	C9 Oxo	12.98	72.3	--	147	0.548	+10	--
(6)	Polyethylene glycol 600	"	2-Ethylhexyl	26.57	162.7	--	141	0.477	+20	--

TABLE 33

COMPLEX ESTERS FROM HYDROXY ACIDS

Alcohol - Hydroxy Acid - Dibasic Acid - Hydroxy Acid-Alcohol

Ref.	Dibasic Acid	Hydroxy-Acid	Alcohol	Mols. of Ethylene Oxide	Viscosity, Cs. @ °F. 210	100	V.I.	ASTM Slope 210/100°F.	Pour Pt., °F.	Flash Pt., °F.	Almen Wts. Carried Grad. Load
(5)	Adipic	Lactic	n-Butyl	6	7.13	38.7	143	0.645	-40	425	15
(5)	Sebacic	"	"	6	7.70	39.3	150	0.612	-35	365	5
(5)	Adipic	"	"	10	8.71	46.2	148	0.600	-40	365	6
(5)	Sebacic	"	"	10	9.52	48.8	148	0.575	-45	--	7
(5)	Adipic	"	"	5.6 C_3	7.98	46.0	139	0.640	-40	365	4
(5)	Sebacic	"	"	5.6 C_3	9.65	59.1	137	0.620	-40	430	6
(5)	Adipic	"	"	4.4 C_3	5.47	30.6	126	0.714	-45	--	--
(5)	Sebacic	"	"	2	5.54	27.0	150	0.666	-35	450	3

TABLE 34

COMPLEX ESTERS FROM HYDROXY ACIDS

Acid - Hydroxy Acid - Glycol - Hydroxy Acid - Acid

Ref.	Glycol	Hydroxy-Acid	Acid	Mols. of Ethylene Oxide	Viscosity, Cs. @ °F. 210	100	V.I.	ASTM Slope 210/100°F.	Pour Pt., °F.	Flash Pt., °F.	Almen Wts. Carried Grad. Load
(5)	Ethylene glycol	Hydroxy stearic	Acetic	2	16.78	106.7	140	0.542	+20	480	3
(5)	" "	" "	Butyric	2	12.18	82.9	133	0.608	+20	495	--
(5)	Triethylene glycol	" "	Acetic	2	--	115.4	--	--	+30	480	6
(5)	" "	" "	Butyric	2	12.67	69.26	148	0.547	+20	460	--
(5)	" "	" "	--	2	--	Solid	--	--	>70	--	--
(5)	Tetraethylene glycol	Lactic	--	2	6.62	54.3	75	0.778	-25	--	0
(5)	" "	"	Acetic	2	4.28	29.9	7(?)	0.848(?)	-15	375	9
(5)	" "	"	Butyric	2	3.26	14.16	109	0.761	-55	385	2
(5)	" "	"	Butyric (Half ester)	2	4.03	21.9	83	0.781	-40	400	9
(5)	" "	"	--	6	--	Solid	--	--	>70	--	--
(5)	" "	"	Acetic	6	5.40	38.4	74	0.789	-15	400	15
(5)	" "	"	Butyric	6	4.18	20.0	130	0.728	-45	415	7
(5)	" "	"	Butyric (Half ester)	6	4.81	25.2	126	0.723	-45	400	15

TABLE 35

COMPLEX ESTERS

Three Ester Groups Per Molecule

Ref.	Acid	Glycol	DiAcid	Alcohol	Viscosity, Cs. @ °F. 210	100	V.I.	ASTM Slope 210/100°F.	Pour Pt., °F.	Flash Pt., °F.
(5)	2-Ethylhexanoic	Ethylene glycol	Adipic	2-Ethylhexanol	5.88	31.6	138	0.684	-25	400
(5)	"	Diethylene glycol	"	"	5.18	27.8	129	0.712	-55	370
(5)	"	Tri " "	"	"	6.47	33.5	146	0.651	-55	420
(5)	"	Tetra " "	"	"	6.37	33.0	146	0.655	-55	385
(5)	Caproic	Trimethylene glycol	Adipic	"	7.55	48.8	124	0.684	<-35	410
(5)	"	Triethylene glycol	"	"	7.24	38.6	143	0.638	<-35	400
(5)	"	Thiodiglycol	"	"	6.95	45.7	117	0.707	+50	355
(5)	Caprylic	Triethylene glycol	Sebacic	C_8 Oxo	7.47	35.1	158	0.593	+10	445
(5)	"	Tetraethylene glycol	"	C_9 Oxo	10.33	54.4	150	0.508	-15	370
(5)	"	" "	"	C_{10} Oxo	7.96	38.6	155	0.591	-25	400
(5)	"	" "	"	C_{15}-C_{19} Oxo	5.65	25.5	162	0.637	-15	360
(5)	"	Pentamethylene glycol	C_{14}-C_{18} Alkenylsuccinic	Methyl	10.49	74.7	126	0.647	<-35	470
(5)	"	Triethylene glycol	"	"	9.05	62.2	125	0.644	<-35	515

APPENDIX II A TABLES

RESULTS OF ESTER EVALUATION
CARRIED OUT UNDER CONTRACT AF 33(038)-14593

TABLE 36

PROPERTIES OF MONO-ESTERS

Compound	Source	Neut. No. mg. KOH/gm.	Viscosity, cs. @ °F. 210	100	0	-40	-65	ASTM Slope, 210/100°F.	ASTM Slope, 210/-40°F.	V.I.	Hardiman & Nissan V.I.	Flash Pt., °F.	Fire Pt., °F.	Pour Pt., °F.	Melting Pt., °F.
2-Ethylhexyl-2-ethylhexanoate	Lab. prep.	0.32	1.092	2.855	19.51	92.0	362	0.922	0.902	-	-	270	300	<-75	-85
C_8 Oxo-2-ethylhexanoate	Lab. prep.	-	1.16	3.12	-	102.4	(410)	0.911	0.884	-	-	275	-	<-75	-
C_8 Oxo-C_8 Oxoate	Lab. prep.	-	1.28	3.31	-	91.4	370	0.839	0.830	-	-	280	-	<-75	-
C_8 Oxo - pelargonate	Lab. prep.	0.68	1.374	3.549	20.67	78.8	259	0.810	0.786	-	-	305	330	<-75	WNC(1)
C_8 Oxo - C_9 Oxoate	Lab. prep.	-	1.39	3.72	-	103.1	410	0.827	0.806	-	-	285	-	<-75	-
C_8 Oxo-decanoate	Lab. prep.	0.05	1.592	4.316	28.75	117.6	395	0.781	0.764	-	-	330	365	-65	-
C_{13} Oxo - 3,5,5-trimethylhexanoate	Lab. prep.	0.39	2.460	9.059	144	1411	Viscous	0.782	0.781	82	139	350	390	<-75	WNC(1)
Tetrahydrofurfuryl oleate	Emery	2.54	3.004	10.45	118.4	Solid	--	0.692	-	161	157	390	440	-10	-

(1) Would not crystallize after 15 hrs. @ -94°F.

TABLE 37

PROPERTIES OF DIBASIC ACID ESTERS

Compound	Source	Neut. No., mg. KOH/gm.	Viscosity, cs. @ °F. 210	100	0	-40	-65	ASTM Slope, 210/100°F.	ASTM Slope, 210/-40°F.	V.I.	Hardiman & Nissan V.I.	Flash Pt., °F.	Fire Pt., °F.	Pour Pt., °F.	Melting Pt., °F.
Adipates															
Di-isobutyl	Cabot	1.03	1.475	4.153	31.97	Cryst.	--	0.835	0.822(1)	--	--	285	340	-25	--
Di-butyl Cellosolve	Lab. Prep.	0.17	2.244	7.312	86.3	634	Solid	0.753	0.772	129	156	390	430	-40	(-8)
Mono-C8 Oxo-mono-n-hexyl	Lab. Prep.	0.45	2.336	7.513	97.6	456	Cryst.	0.735	0.737	141	160	400	430	-60	--
Di-2-ethylhexyl	Hardesty	0.05	2.354	8.166	108.3	818	4810	0.769	0.772	116	143	360	435	< -75	WNC(2)
Di-2-ethylhexyl (Flexol A-26)	Carbide	0.02	2.362	8.216	108.8	833	4920	0.770	0.774	116	147	395	450	< -75	--
Di-capryl (Octanol-2)	Hardesty	0.11	2.416	8.668	121.2	Cryst.	--	0.777	0.774(1)	110	143	370	430	-60	+41
Di-C8 Oxo	Hardesty	0.23	2.700	9.421	121.1	913	5450	0.725	0.738	141	153	380	450	< -75	WNC
Di-C8 Oxo	Cabot	0.21	2.702	9.441	121.4	906	5277	0.727	0.738	141	153	385	455	< -75	--
Di-C8 Oxo (Plexol 244)	Rohm & Haas	0.28	2.794	9.952	135.6	1037	6460	0.724	0.735	141	152	385	455	< -75	WNC
Di-C8 Oxo (PX-208)	Pittsburgh	0.33	2.807	9.842	131.3	1025	6220	0.716	0.733	148	153	400	450	< -75	--
Di-3,5,5-trimethylhexyl (PX-209)	Pittsburgh	0.12	3.424	12.89	202	1974	16,350	0.689	0.717	161	152	395	465	< -75	--
Di-3,5,5-trimethylhexyl (Hylene B)	duPont	0.02	3.447	12.82	207	1955	16,660	0.683	0.715	167	153	380	455	< -75	+43
Di-3,5,5-trimethylhexyl	Hardesty	0.07	3.458	13.13	213	2119	17,990	0.691	0.719	162	150	400	465	< -75	--
Di-n-decyl (Hylene D)	duPont	0.08	3.592	13.00	Solid	--	--	0.662	--	180	157	440	520	+80	--
Di-C10 Oxo	Lab. Prep.	0.04	3.598	14.43	282	2954	22,980	0.702	0.727	153	146	450	485	< -75	WNC
Di-C13 Oxo	Lab. Prep.	0.61	5.611	30.93	1259	21,710	Viscous	0.703	0.719	131	124	470	540	-70	WNC
Azelates															
Di-2-ethylbutyl (Plastolein 9050)	Emery	0.05	2.412	7.764	79.2	467	2160	0.726	0.728	146	159	365	435	< -75	-39
Di-2-ethylhexyl (Plastolein 9058)	Emery	0.99	2.944	10.78	154.3	1132	6260	0.721	0.726	142	149	400	470	< -75	-38
Di-2-ethylhexyl	Lab. Prep.	0.36	3.000	11.08	162.8	1202	6688	0.719	0.725	144	149	420	480	< -70	--
Di-C8 Oxo	Lab. Prep.	0.52	3.378	12.53	177.0	1281	7026	0.687	0.697	166	153	425	495	< -70	--
Di-3,5,5-trimethylhexyl	Lab. Prep.	0.74	4.241	17.25	309	2907	Viscous	0.665	0.686	174	149	400	500	< -75	WNC
Di-C10 Oxo	Lab. Prep.	0.05	4.345	18.59	376	3643	25,330	0.678	0.692	164	144	470	520	< -75	WNC
Sebacates															
Di-Sec. Amyl (Plexol 202)	Rohm & Haas	0.08	2.271	7.483	81.5	528	2970	0.756	0.755	127	156	375	415	< -75	WNC
Di-hexyl (Mixed sec. hexanols)	Hardesty	0.71	2.676	9.400	140.8	1294	9680	0.732	0.761	137	152	360	420	< -75	+10
Di-butoxyethyl	Deecy	9.10	3.187	11.46	Solid	--	--	0.690	--	163	155	425	505	+5	--
Di-2-ethylhexyl (Plexol 201W)	Rohm & Haas	0.10	3.285	12.46	183.4	1386	7690	0.704	0.708	152	149	420	550	< -75	-47
Di-2-ethylhexyl (Plexol 201)	Rohm & Haas	0.07	3.390	12.80	188.6	1482	8384	0.693	0.705	159	150	430	500	< -75	-45
Di-capryl	Hardesty	0.12	3.320	12.96	201	Cryst.	--	0.714	0.714(1)	146	145	420	480	-70	+36
Di-C8 Oxo	Hardesty	0.45	3.772	14.60	231	1848	Cryst.	0.676	0.689	171	151	415	505	-60	-46
Di-C8 Oxo (PX-408)	Pittsburgh	0.40	3.792	14.67	225	1769	10,080	0.675	0.685	171	152	425	510	-60	--
Di-3,5,5-trimethylhexyl	Hardesty	0.10	4.458	19.46	402	Cryst.	--	0.678	0.688(1)	162	142	420	500	< -75	-20
Di-C10 Oxo	Lab. Prep.	0.06	4.702	20.83	431	4191	28,860	0.671	0.682	161	142	465	545	< -75	--

(1) ASTM slope 210/0°F.
(2) Would not crystallize after 15 hrs. @ -94°F.

TABLE 38

PROPERTIES OF OTHER MONO-, DI-, AND TRIBASIC ACID ESTERS

Compound	Neut. No., mg. KOH/gm.	Viscosity, Cs. at °F. 210	100	0	-40	-65	ASTM Slope 210/ 100°F.	-40°F.	-65°F.	V. I.	H&N V. I.	Flash Pt., °F.	Fire Pt., °F.	Pour Pt., °F.	Melting Pt., °F.	Vapor Pressure, mm. at 400°F.
Monoesters																
C_8 Oxo n-octanoate	0.09	1.342	3.446	19.62	71.8	231	0.815	0.786	0.785	--	--	285	320	<-75	-85(?)	70
Isopropoxyethoxyethyl n-octanoate	1.46	1.363	3.567	33.51	104.1	--	0.821	0.815	--	--	--	315	340	-55	-9	50
2-Ethylbutoxyethoxyethyl caproate	0.18	1.367	3.609	24.45	113.9	501	0.826	0.822	0.828	--	--	330	360	<-75	WNC	35
n-Hexyl C_{13} Oxoate	1.86*	1.740	5.330	52.10	307.0	1480	0.814	0.808	0.805	--	157	315	350	<-75	WNC	--
C_{13} Oxo C_{13} Oxoate	0.17	3.380	15.65	478.4	7228	76500	0.775	0.788	0.784	96	115	405	445	<-75	WNC	3.0
Adipates																
Di-sec.-hexyl (Hardesty)	0.13	1.807	5.792	75.3	solid	6317	0.824	--	0.860	--	149	305	350	<-75	+50	26
Mono-C_8 Oxo mono-2-ethylbutyl	0.11	2.275	7.402	81.40	531.9	2833	0.748	0.754	0.755	132	157	390	430	<-75	WNC	6.0
Mono-C_{10} Oxo mono-n-butyl	0.10	2.291	7.448	80.20	459	2515	0.747	0.743	0.748	133	158	365	405	<-75	--	7.4
Diisopropoxyethoxyethyl	2.20*	2.948	10.86	192.1	2212	26500	0.723	0.764	0.779	142	149	420	470	<-75	+18	1.4
Di-2-ethylbutoxyethoxyethyl	0.36	3.686	14.14	283.6	3522	40310	0.679	0.730	0.743	170	151	440	495	<-75	WNC	0.20
Diheptoxyethoxyethyl	0.22	4.128	17.34	435.0	5641	61130	0.683	0.725	0.733	164	145	440	495	<-75	WNC	0.15
Dicapryloxyethoxyethyl	0.15	4.70	19.90	447.3	5337	57870	0.655	0.693	0.704	170	147	415	480	<-75	--	--
Dinonoxyethoxyethyl	0.52	5.764	29.72	1612	54400	--	0.677	0.751	--	143	156	440	520	-50	--	--
Succinate																
Di-C_8 Oxo	0.29	2.329	8.226	131.2	1278	10220	0.781	0.804	0.806	108	143	350	405	<-75	WNC	5.6
Triesters																
Tri-n-butyl aconitate	0.19	2.438	9.922	177.8	1509	10450	0.829	0.799	0.794	65	116	370	410	<-75	WNC	7.0
Tri-n-hexyl ester of Evanacid 3CS**	0.42	3.320	15.47	375	4118	35250	0.784	0.765	0.762	89	116	460	520	<-75	WNC	0.7

* Not treated for acidity reduction--small sample.

** Evanacid 3CS is HOOCCC(COOH)SCCOOH.

WNC: Would not crystallize after 15 hours at -94°F.

TABLE 39

PROPERTIES OF POLYHYDRIC ALCOHOL ESTERS

Compound	Source	Neut. No., mg. KOH/gm.	Viscosity, cs. @ °F. 210	100	0	-40	-65	ASTM Slope, 210/100°F.	ASTM Slope, 210/-40°F.	V.I.	Hardiman & Nissan V.I.	Flash Pt., °F.	Fire Pt., °F.	Pour Pt., °F.	Melting Pt., °F.
Diethylene glycol di-2-ethylhexanoate	Lab. Prep.	0.47	1.969	6.980	116.4	1152	8579	0.843	0.852	--	129	360	410	<-75	WNC(1)
Triethylene glycol di-2-ethylbutyrate	Carbide	0.13	1.975	6.376	84.7	801	6640	0.795	0.827	--	153	355	415	<-75	WNC
Pentanediol-1,5 di-2-ethylhexanoate	Lab. Prep.	0.97	2.115	7.694	118.8	958	5452	0.829	0.817	81	129	390	425	<-75	WNC
Tripropylene glycol di-caproate	Lab. Prep.	0.13	2.134	7.000	82.4	591	3572	0.775	0.784	116	153	395	420	<-75	--
Dipropylene glycol di-2-ethylhexanoate	Lab. Prep.	0.54	2.208	8.708	197	2522	Viscous	0.851	0.858	54	111	355	410	<-75	WNC
Triethylene glycol di-2-ethylhexanoate	Carbide	0.23	2.350	8.678	164.3	1832	16,260	0.799	0.820	94	135	385	450	<-75	WNC
Dipropylene glycol di-n-octanoate	Lab. Prep.	0.08	2.367	8.075	77.3	647	3405	0.759	0.756	124	152	400	430	<-75	--
Tripropylene glycol di-2-ethylhexanoate	Lab. Prep.	0.28	2.641	10.76	271	3840	42,670	0.801	0.826	84	122	405	445	<-75	WNC
Tripropylene glycol di-n-octanoate	Lab. Prep.	0.40	2.756	9.741	135.2	1040	7000	0.725	0.740	141	152	415	450	<-75	--
Polyethylene glycol di-2-ethylhexanoate	Carbide (400)	0.05	2.810	10.90	233	2977	30,980	0.759	0.792	115	138	400	465	<-75	WNC
Diethylene glycol dipelargonate	Emery	0.61	2.897	10.17	Solid	--	--	0.707	--	152	155	405	440	0	+11
2-Ethoxymethyl-2,4-dimethyl-pentanediol-1,5-di-2-ethylhexanoate	Lab. Prep.	0.11	3.297	16.67	636	10,950	Viscous	0.815	0.813	56	98	380	455	-65	--
Trimethylolpropane tri-n-octanoate	Lab. Prep.	0.04	4.046	18.39	369	3276	22,180	0.717	0.703	140	133	485	550	<-75	+18
Pentaerythritol tetra-n-caproate	Lab. Prep.	0.05	4.133	19.97	447	4656	38,635	0.734	0.717	125	125	470	550	<-75	+21
Hercoflex 600	Hercules	0.16	4.529	22.63	530	5919	Cryst.	0.721	0.706	130	127	470	555	<-75	+19

(1) Would not crystallize after 15 hrs. @ -94°F.

TABLE 40

PROPERTIES OF OTHER POLYHYDRIC ALCOHOL ESTERS

Compound	Neut. No., mg. KOH/gm.	Viscosity, Cs. @ °F. 210	100	0	-40	-65	ASTM Slope 210/ 100°F.	-40°F.	-65°F.	V.I.	H&N V.I.	Flash Pt.,°F.	Fire Pt.,°F.	Pour Pt.,°F.	Melting Pt.,°F.	Vapor Pressure, mm. @ 400°F.
Diesters																
2-Ethoxymethyl-2,4-dimethylpentanediol-1,5 dicaproate	0.12	2.490	9.230	138.2	1140	7800	0.781	0.776	0.776	105	138	395	440	< -75	WNC	3.8
Tetraethylene glycol dicaproate	0.44	2.552	8.607	118.2	1055	--	0.729	0.764	--	142	156	415	445	-60	+1	1.7
Polyglycol 200 di-n-butyrate	0.10	2.566	8.788	135.1	1423	Solid	0.735	0.780	--	138	154	390	425	-60	-38	12
Tripropylene glycol dipelargonate	0.29	2.900	10.63	155.3	1178	Solid	0.725	0.732	--	140	149	420	480	< -75	--	1.3
Polyglycol 200 mono-2-ethylbutyrate monocaproate	0.09	2.918	10.38	172.7	1851	18860	0.711	0.757	0.769	150	153	420	450	< -75	WNC	3.5
Polyglycol 200 dicaproate	0.17	2.920	10.27	158.3	1532	--	0.706	0.747	--	153	157	420	460	-65	--	2.9
Triesters																
Trimethylolpropane mono-2-ethylbutyrate dicaproate	0.46	3.163	14.03	300.7	2959	24500	0.780	0.761	0.759	95	121	415	465	<-75	WNC	2.2
Triethanolamine tri-2-ethylhexanoate	0.53	3.962	21.85	870.0	13834	100000+	0.793	0.778	0.758+	73	98	445	500	-70	WNC	0.54
Tetraester																
Pentaerythritol di-2-ethylbutyrate dicaproate	0.16	4.660	27.08	1020	16400	--	0.764	0.746	--	95	106	470	520	-65	WNC	0.60
Complex Ester																
Ester C**	0.18	7.78	40.37	Cryst	Solid	--	0.618	--	--	148	139	460	490	-35	0	2.4

**Ester C: C_8 Oxo alcohol-adipic acid-thiodiglycol-adipic acid-C_8 Oxo alcohol

WNC: Would not crystallize after 15 hours at -94°F.

TABLE 41

PROPERTIES OF MISCELLANEOUS SYNTHETIC LUBRICANT MATERIALS

Compound	Source	Neut. No., mg. KOH/gm.	Viscosity, cs. @ °F. 210	100	0	-40	-65	ASTM Slope, 210/100°F.	ASTM Slope, 210/-40°F.	V.I.	Hardiman & Nissan V.I.	Flash Pt., °F.	Fire Pt., °F.	Pour Pt., °F.	Melting Pt., °F.
Polyalkylene Glycols															
UCON DLB-50BX	Carbide	0.04	2.361	8.015	102.2	816	-- --	0.758	0.771	124	152	285	340	< -75	--
UCON DLB-50B	"	0.09	2.430	7.865	93.1	714	-- --	0.725	0.754	146	160	300	340	< -75	--
UCON LB-65	"	0.05	2.504	10.35	226	2891	-- --	0.826	0.825	65	113	270	310	< -75	--
UCON LB-70X	"	0.03	2.553	10.97	266	3820	-- --	0.836	0.835	55	106	280	310	< -75	--
Esters With Ring Structures															
Di-n-butyl phthalate	Carbide	0.05	2.286	9.591	215	2650	-- --	0.867	0.851	36	95	335	385	< -75	--
Di-2-ethylhexyl phthalate	"	0.11	4.305	30.17	2303	Viscous	-- --	0.847	0.832(1)	9	56	400	465	-55	--
Di-methyl dimerate	Emery	4.62	8.818	62.26	2749	"	-- --	0.666	0.663(1)	121	118	475	530	-45	--
Di-n-butyl dimerate	"	7.81	9.019	57.65	1837	"	-- --	0.639	0.631(1)	132	129	495	565	-45	WNC(2)
Di-2-ethylhexyl dimerate	"	9.03	13.44	108.1	5663	"	-- --	0.631	0.622(1)	122	117	530	590	-55	--
Complex and Poly-esters															
Complex Ester B(3)	Lab. Prep.	1.06	7.402	38.64	1398	24,620	-- --	0.627	0.669	147	140	430	480	-65	--
Complex Ester A(4)	Lab. Prep.	0.10	10.35	53.46	--	23,700	-- --	0.564	0.609	151	150	465	540	< -60	WNC
Paraplex AP-52	Rohm&Haas	--	9.842	58.85	2127	28,460	-- --	0.611	0.624	140	137	470	535	--	WNC
Acryloid HF-825-(P) (50% Solids in Plexol 201)	Rohm&Haas	--	209	1616	75,390	Solid	-- --	0.358	0.390(1)	--	160	360	425	--	--
Other Materials															
Di-3,5,5-trimethylhexyl diglycolate	duPont	0.91	3.695	18.03	810	26,390	-- --	0.769	0.822	98	116	370	440	-60	WNC
Triethanolamine tri-2-ethylhexanoate	Lab. Prep.	0.53	3.962	21.85	870	13,830	-- --	0.793	0.778	73	98	445	500	-70	WNC
Tri-2-ethylhexyl ester of Evanacid 3CS(5)	Lab. Prep.	0.44	4.509	28.07	1510	30,970	--	0.796	0.782	66	89	460	535	-60	WNC

(1) ASTM Slope 210/0°F.
(2) Would not crystallize after 15 hrs. @ -94°F.
(3) C8 Oxo alcohol-adipic acid-tripropylene glycol-adipic acid-C8 Oxo alcohol.
(4) 2-ethylhexanol-sebacic acid-Polyglycol 200-sebacic acid-2-ethylhexanol.
(5) Carboxymethyl mercapto succinic acid purchased from Evans Chemetics, Inc.

TABLE 42

LOW TEMPERATURE PROPERTIES OF ESTERS

Compound	Source	Melting Point, °F.	Pour Point, °F.	Cloud Point, °F.	ASTM Slope 210/100°F.	ASTM Slope 210/-40°F.	Difference
Di-C8 Oxo adipate (Plexol 244)	Rohm & Haas	WNC(1)	< -75	<-80	0.724	0.736	0.012
" " " (Stripped)	Lab. Prep.	WNC	< -75	-42	0.722	0.736	0.014
" " " (Distilled)	Lab. Prep.	WNC	< -75	<-70	0.723	0.739	0.016
" " " (Distilled, charcoal treat.)	Lab. Prep.	WNC	< -75	-34	0.720	0.735	0.015
Di-butyl Cellosolve adipate	Lab. Prep.	-3	-40	--	0.753	0.772	0.019
Mono-C8 Oxo-mono-n-hexyl adipate	Lab. Prep.	-44	-60	-60	0.735	0.737	0.002
Di-2-ethylhexyl adipate (Flexol A-26)	Carbide	-90(2)	< -75	-68	0.770	0.774	0.004
Di-C_9 Oxo adipate (Hylene B)	duPont	+43	< -75	-20	0.683	0.715	0.032
Di-sec. hexyl adipate	Hardesty	+50	< -75	-16	0.823	0.859	0.036
Mono-C8 Oxo-mono-2-ethylbutyl adipate	Lab. Prep.	WNC	< -75	<-80	0.748	0.754	0.006
Di-2-ethylbutyl azelate (Plastolein 9050)	Emery	-39	<-75	-22	0.726	0.728	0.002
Di-2-ethylhexyl azelate (Plastolein 9058)	Emery	-38	<-75	--	0.721	0.726	0.005
Di-sec. amyl sebacate (Plexol 202)	Rohm & Haas	-108(2)	<-75	<-70	0.756	0.755	-0.001
Di-sec. hexyl sebacate	Hardesty	+10	<-75	-66	0.732	0.761	0.029
Di-2-ethylhexyl sebacate (Plexol 201)	Rohm & Haas	-45	<-75	-74	0.693	0.705	0.012
Di-2-ethylhexyl sebacate, distilled (Plexol 201W)	Rohm & Haas	-47	<-75	-44	0.704	0.708	0.004
Di-C8 Oxo sebacate	Hardesty	-46	-60	--	0.676	0.689	0.013
Di-C8 Oxo sebacate (PX 408)	Pittsburgh	-40	-60	-44	0.675	0.685	0.010
Di-C_9 Oxo sebacate	Hardesty	-20	<-75	--	0.678	0.692	0.014
Dipropylene glycol di-n-octanoate	Lab. Prep.	-100	<-75	< -80	0.759	0.756	-0.003
Tripropylene glycol di-n-octanoate	Lab. Prep.	+7	<-75	--	0.725	0.740	0.015
Tetraethylene glycol di-caproate	Lab. Prep.	+1	-60	--	0.729	0.764	0.035
Trimethylolpropane tri-n-octanoate	Lab. Prep.	+18	<-75	--	0.717	0.703	-0.014
Pentaerythritol tetra-caproate	Lab. Prep.	+21	<-75	<-75	0.734	0.717	-0.017

(1) Would not crystallize after 15 hrs. @ -94°F.

(2) Data obtained from literature , Section I of Appendix.

TABLE 43

VISCOSITY-VOLATILITY PROPERTIES OF MONO-, DI-, AND TRIBASIC ACID ESTERS

Material	Viscosity, Cs. @ °F. 210	100	-40	-65	Flash Pt., °F.	Vapor Pressure, mm. @ 400°F.	Boiling Point, °F. at mm. Hg. 0.5	1.0	2.0	3.0	Temp. @ 10000 Cs. Viscosity, °F.	Viscosity-Volatility Index*
Monoesters												
2-Ethylhexyl 2-ethylhexanoate	1.092	2.855	92.0	362.1	270	120	190	212	232	245	-102	334
C_8 Oxo n-octanoate	1.342	3.446	71.8	231.0	285	70	216	237	259	272	-116	354
Isopropoxyethoxyethyl n-octanoate	1.363	3.567	104.1	Solid	315	50	230	252	276	286	(-122)	(398)
2-Ethylbutoxyethoxyethyl caproate	1.367	3.609	113.9	501.0	330	35	240	262	285	300	-97	382
C_8 Oxo pelargonate	1.374	3.549	78.8	258.9	305	60	217	239	261	274	-112	373
C_8 Oxo decanoate	1.592	4.316	117.6	395.1	330	27	245	267	290	306	-107	397
n-Hexyl C_{13} Oxoate	1.740	5.330	307.0	1480	315	--	--	--	--	--	-88	--
C_{13} Oxo 3,5,5-trimethylhexanoate	2.460	9.059	1411	Too viscous	350	24	278	297	317	330	-66	383
C_{13} Oxo C_{13} Oxoate	3.380	15.65	7228	76500	405	3.0	333	358	384	400	-68	452
Dibasic Acid Diesters												
Di-C_8 Oxo succinate	2.329	8.226	1278	10220	350	5.6	298	323	350	370	-64	414
Di-sec.-hexyl adipate	1.807	5.792	Solid	6320	305	26	248	271	294	308	-59	353
Dibutoxyethyl adipate	2.244	7.312	634	Solid	390	3.5	322	348	376	394	-60	436
Mono-C_8 Oxo mono-2-ethylbutyl adipate	2.275	7.402	531.9	2833	390	6.0	300	325	350	369	-80	430
Mono-C_{10} Oxo mono-n-butyl adipate	2.291	7.448	459	2515	365	7.4	288	314	342	358	-82	424
Mono-C_8 Oxo n-hexyl adipate	2.336	7.513	456	Cryst.	400	4.2	310	336	364	382	(-92)	456
Di-2-ethylhexyl adipate (Flexol A-26)	2.362	8.216	833	4920	395	3.3	342	355	383	398	-74	457
Di-C_8 Oxo adipate (Plexol 244)	2.794	9.952	1037	6460	385	2.6	330	358	390	398	-74	464
Di-C_8 Oxo adipate (PX-208)	2.807	9.842	1025	6220	400	2.9	326	354	384	404	-73	457
Diisopropoxyethoxyethyl adipate	2.948	10.86	2212	26500	420	1.4	372	394	414	428	-57	471
Di-C_{10} Oxo adipate	3.598	14.43	2954	22980	450	0.85	385	405	427	440	-56	483
Di-2-ethylbutoxyethoxyethyl adipate	3.686	14.14	3522	40310	440	0.20	432	454	474	490	-52	526
Diheptoxyethoxyethyl adipate	4.128	17.34	5641	61130	440	0.15	436	455	470	(482)	-47	517
Dicaproxyethoxyethyl adipate	4.700	19.90	5337	57870	415	--	--	--	--	--	-48	--
Di-C_{13} Oxo adipate	5.611	30.93	21710	Viscous	470	0.13	448	472	500	520	-31	531
Dinonoxyethoxyethyl adipate	5.764	29.72	54400	--	440	--	--	--	--	--	-23	--
Di-2-ethylbutyl azelate (Emery)	2.412	7.764	467.0	2160	365	(4.3)	314	338	368	385	-85	453
Di-2-ethylhexyl azelate (Emery)	2.944	10.78	1132	6260	400	1.5	362	385	410	424	-71	481
Di-2-ethylhexyl azelate	3.000	11.09	1202	6688	415	1.2	367	390	419	430	-69	488
Di-C_8 Oxo azelate (Emery)	3.378	12.52	1281	7026	425	1.1	367	394	425	440	-60	485
Di-3,5,5-trimethylhexyl azelate	4.241	17.25	2907	Viscous	400	0.88	385	405	433	447	-52	435
Di-C_{10} Oxo azelate	4.345	18.59	3643	25330	470	0.46	405	432	466	488	-54	420
Di-sec.-amyl sebacate	2.271	7.483	528.0	2970	375	6.4	304	326	353	367	-78	431
Dicapryl sebacate	3.320	12.96	Cryst.	--	420	0.90	376	405	432	449	(-65)	497
Di-2-ethylhexyl sebacate (Plexol 210W)	3.285	12.46	1386	7690	420	0.78	380	408	441	462	-69	510
Di-C_8 Oxo sebacate (Hardesty)	3.772	14.60	1848	Cryst.	415	0.80	382	408	440	452	-65	505
Di-C_8 Oxo sebacate (PX-408)	3.792	14.67	1769	10080	425	0.66	388	416	445	464	-65	510
Di-C_{10} Oxo sebacate	4.702	20.83	4191	28860	465	0.31	418	440	(460)	(480)	-53	513
Di-n-butyl-phthalate	2.286	9.591	2650	--	340	14	270	294	319	335	-52	371
Di-2-ethylhexyl phthalate	4.305	30.17	Viscous	Solid	400	1.6	354	382	408	426	-20	428
Tribasic Acid Triesters												
Tri-n-butyl aconitate	2.438	9.922	1509	10450	370	7.0	301	327	350	365	-65	415
Tri-n-hexyl ester of Evanacid 3CS.	3.320	15.47	4118	35250	460	0.7	387	414	444	(462)	-52	496
Polyesters												
Complex Ester B	7.402	38.64	24620	--	430	3.1	324	350	382	398	-29	411
Complex Ester C	7.780	40.87	Solid	Solid	460	2.4	344	362	392	408	(-40)	432
Paraplex AP-52	9.842	58.85	28460	--	470	0.53	398	420	(435)	(445)	-26	461
Complex Ester A	10.35	53.46	23700	--	465	0.45	404	425	450	462	-30	480

Complex Ester B: C_8 Oxo alcohol-adipic acid-tripropylene glycol-adipic acid-C_8 Oxo alcohol
Complex Ester C: C_8 Oxo alcohol-adipic acid-thiodiglycol-adipic acid-C_8 Oxo alcohol
Complex Ester A: 2-Ethylhexyl alcohol-sebacic acid-polyglycol 200-sebacic acid-2-ethylhexyl alcohol
* Boiling point, °F. @ 2 mm. Hg. minus temperature @ 10000 Cs. viscosity = viscosity-volatility index.
Data in parentheses signify decomposition is occurring or solid state exists.

TABLE 44

VISCOSITY - VOLATILITY PROPERTIES OF POLYHYDRIC ALCOHOL ESTERS

Material	Viscosity, Cs. @ °F. 210	100	-40	-65	Flash Pt., °F.	Vapor Pressure, mm. @ 400 °F.	Boiling Point, °F. @ mm. Hg. 0.5	1.0	2.0	3.0	Temp. @ 10000 Cs. Viscosity, °F.	Viscosity-Volatility Index
Glycol Diesters												
Diethylene glycol di-2-ethylhexanoate	1.969	6.980	1152	8579	360	(8)	286	310	339	(356)	-67	406
Triethylene glycol di-2-ethylbutyrate (3GH)	1.975	6.376	801	6640	355	7.4	300	322	347	362	-74	421
Pentanediol-1,5 di-2-ethylhexanoate	2.115	7.694	958	5452	390	8.6	283	307	336	350	-72	408
Tripropylene glycol dicaproate	2.134	7.000	591.4	3572	395	6.3	307	330	355	370	-77	432
Dipropylene glycol di-2-ethylhexanoate	2.204	8.708	2522	Viscous	355	(12)	292	314	335	346	-58	390
Triethylene glycol di-2-ethylhexanoate (3GO)	2.350	8.678	1832	16260	385	2.3	344	368	394	408	-66	460
Dipropylene glycol di-n-octanoate	2.367	8.075	647	3405	400	3.8	323	346	372	390	-79	451
2-Ethoxymethyl-2,4-dimethylpentanediol-1,5 dicaproate	2.490	9.230	1140	7800	395	3.8	315	342	370	390	-68	438
Tetraethylene glycol dicaproate	2.552	8.607	1055	--	415	1.7	354	382	407	423	-68	475
Polyethylene glycol 200 di-n-butyrate	2.566	8.788	1423	Solid	390	12	283	306	332	(346)	-62	394
Tripropylene glycol di-2-ethylhexanoate	2.641	10.76	3840	42670	405	3.1	328	355	382	398	-52	434
Tripropylene glycol di-n-octanoate	2.756	9.741	1040	7000	415	1.8	362	382	405	416	-69	474
Polyethylene glycol di-2-ethylhexanoate (4GO)	2.810	10.90	2977	30985	400	1.3	363	390	416	425	-63	479
Tripropylene glycol dipelargonate	2.900	10.63	1178	Solid	420	1.3	366	392	416	(425)	-68	484
Polyethylene glycol 200 mono-2-ethylbutyrate monocaproate	2.918	10.38	1851	18860	420	3.5	332	354	380	394	-59	439
Polyethylene glycol 200 dicaproate	2.920	10.27	1532	--	420	2.9	338	362	386	402	-63	449
Trihydric Alcohol Triesters												
Trimethylolpropane mono-2-ethylbutyrate dicaproate	3.163	14.03	2959	24500	415	2.2	338	367	395	414	-57	452
Triethanol amine tri-2-ethylhexanoate	3.962	21.85	13830	100000+	445	0.54	396	429	465	(486)	-37	502
Trimethylolpropane tri-n-octanoate	4.046	18.39	3276	22180	485	0.21	432	458	484	502	-55	539
Tetrahydric Alcohol Tetraesters												
Pentaerythritol di-2-ethylbutyrate dicaproate	4.660	27.08	16400	--	470	0.60	396	419	440	456	-34	478
Pentaerythritol tetracaproate	4.133	19.97	4656	38635	470	0.25	422	448	475	490	-49	524
Hercoflex 600 (Hercules)	4.529	22.63	5919	Cryst.	470	0.26	423	445	478	490	-46	524
Other Materials												
UCON DLB-50BX	2.361	8.015	816	--	285	33	246	267	288	302	-74	362
UCON LB-65	2.504	10.35	2891	--	270	71	218	238	260	273	-55	315
UCON LB-70X	2.553	10.97	3820	--	280	65	224	244	263	277	-51	314
MIL-O-6081, Grade 1010 Mineral Oil	2.54	10.4	2500	--	290	--	216	236	255	268	-56	311

Data in parentheses signify decomposition is occurring.

TABLE 45

OXIDATION INHIBITORS IN DI-2-ETHYLHEXYL SEBACATE

(0.5 Wt. % Concentration)

Oxidation Inhibitor	--	None	Paranox 441	Zinc DIPS	Sharples 66-1	Calco MB	Aerolube 70	Goodrite SAR	p,p-Dioctyl-diphenylamine
Source	Specification MIL-O-6081		Enjay Co.	(Experimental)	Sharples	American Cyanamid	American Cyanamid	Goodrich	Goodrich
Corrosion/oxidation Stability (250°F.)									
Weight Change, mg./cm.^{2}									
Copper	± 0.2 (Max.)	0	-0.05	-0.06	-54.5	-0.02	+0.14	-0.03	-0.02
Steel	" "	+0.01	-0.02	-0.01	+0.02	0	+0.01	0	-0.01
Aluminum Alloy	" "	+0.01	0	0	+0.19	0	+0.01	-0.01	0
Magnesium Alloy	" "	-0.01	+0.02	-0.01	+0.19	0	+0.02	+0.02	+0.03
Cadmium-plated Steel	" "	+1.48	0	-0.38	-0.23	-0.02	0	+0.03	0
Visible Corrosion									
Copper	Sl. Discoloration	Magenta & brown	Magenta	Dark purple	Thick green coat	Gold	Black & purple	Magenta	Magenta
Steel	None	Grey	None	None	Grey	Slightly brassy	None	None	None
Aluminum Alloy	None	None	None	None	Grey	None	None	Slightly brown	None
Magnesium Alloy	None	Grey	None	None	Grey	None	None	None	None
Cadmium-plated Steel	None	Badly etched	Brassy	Grey	Black & Yellow	None	None	None	None
Oil Loss,%	--	5.6	0	0.5	0.1	0	0.8	0	0.12
Viscosity Change @ 100°F., %	-5 to +20	+87.5	+0.08	+0.11	0	+0.08	+0.06	+0.14	+0.11
Neutralization No. Increase	0.20 (Max.)	75.1	0.07	0.37	0.10	0.04	0.31	0.05	0.12
Separation and Gumming	None	None	None	None	Yes	None	Yes	None	None
Oxidation Rate - ml. O_2 absorbed in 4 successive 15 minute periods at 392°F.	--	250+ ---	4-86-57-26	0-0-0-0	0-0-0-0	0-0-2-2	250+ ---	0-0-0-7	0-0-1-4

TABLE 46

OXIDATION INHIBITORS IN DI-2-ETHYLHEXYL SEBACATE

(0.5 Wt. % Concentration)

Oxidation Inhibitor	6-Ethoxy-2,2,4-trimethyl-1,2-dihydro-quinoline	2,5-Di-tertiary-butyl-hydro-quinone	Phenyl-hydroquinone	Santowhite	p-Amino hydro-genated cardinol	N-acetyl-4-amino-3-pentadecyl phenol	2,4,6-Tritertiary butyl phenol	Antioxidant 2246	2-Mono-tertiary butyl hydro-quinone
Source	Monsanto	Eastman	Eastman(exp.)	Monsanto	Irvington Varnish	(Experimental)	(Experimental)	American Cyanamid	Eastman
Corrosion/oxidation Stability (250°F.)									
Weight Change, mg./cm.^{2}									
Copper	-0.05	-2.90	0	+0.08	0	-0.07	-0.03	-0.02	-0.05
Steel	-0.01	+0.03	0	-0.01	+0.02	0	0	0	0
Aluminum Alloy	0	+0.08	0	0	-0.01	-0.02	0	0	0
Magnesium Alloy	+0.02	+0.01	+0.02	+0.03	+0.01	+0.01	0	0	0
Cadmium-plated Steel	0	+0.02	0	+0.05	+0.03	+0.02	+0.04	+0.01	+0.01
Visible Corrosion									
Copper	Magenta, brown	Brown	Magenta	Black,green	Gold	Magenta	Magenta	Magenta	Magenta
Steel	Brown	Magenta	None	Slight brown	None	None	None	None	None
Aluminum Alloy	Grey	Magenta	None	None	None	None	None	None	None
Magnesium Alloy	Slight magenta	Grey	None	Grey	None	None	None	None	None
Cadmium-plated Steel	Grey	Magenta	None	Grey	Slight grey	Grey	None	Slight Brassy	None
Oil Loss, %	0	1.8	0.37	0.11	0	0	1.7	0.89	0.5
Viscosity change @ 100°F. %	+0.14	+6.57	-0.08	+0.13	+0.08	+0.10	+0.48	+1.4	-1.3
Neutralization No. Increase	0.07	42.8	0.07	0.19	0.09	0.03	0.17	0.02	0
Separation and Gumming	Yes	Yes	None	None	None	None	None	None	None
Oxidation Rate - ml. O_2 absorbed in 4 successive 15 minute periods at 392°F.	11-250+ --	250+ ---	0-0-0-1	0-0-0-1	0-1-1-1	0-0-0-0	250+ ---	250+ --- 0-0-0-0*	4-25-250+ - 0-250+ --*

* Oxidation rate results at 0.2 Wt. % concentration.

TABLE 47

OXIDATION INHIBITORS IN DI-2-ETHYLHEXYL SEBACATE

(0.5 Wt. % Concentration)

Oxidation Inhibitor	PSP 34	Bis-phenol A (2,2-di-p-hydroxy-phenyl propane)	N-butyryl p-amino phenol	Bis (5-methyl-2-hydroxy phenyl) sulfide	Phenothiazine	Tenamine (Sustane)	Santolube 394-C	Zinc dibutyl-dithio carbamate	Paranox 56
Source	DuPont	(Experimental)	(Experimental)	(Experimental)	Eastman	Eastman	Monsanto	Sharples	Enjay Co.
Corrosion/oxidation Stability (250°F.)									
Weight Change, mg./cm.^{2}									
Copper	0	0	0	-0.01	+0.06	-0.01	0	-1.47	-0.01
Steel	0	0	0	+0.04	0	0	+0.02	+0.05	+0.01
Aluminum Alloy	0	0	0	+0.04	0	+0.02	0	+0.02	0
Magnesium Alloy	0	+0.01	+0.01	+0.03	0	0	+0.01	+0.06	0
Cadmium-plated Steel	0	-0.02	0	+0.07	+0.06	-0.01	0	-0.01	0
Visible Corrosion									
Copper	Magenta	Magenta	Magenta	Purple, green	Dark purple	Purple,blue	Magenta, brown	Brown	Slight gold
Steel	Slight grey	Purple	Slight tan	Purple, brassy	Purple	None	Blue	Magenta	Slight grey
Aluminum Alloy	None	None	None	Purple, brassy	Purple	Slight tan	Slight blue	Brown	None
Magnesium Alloy	None	None	None	Magenta	Purple	Slight brassy	None	Brown	None
Cadmium-plated Steel	Slight brassy	Slight brassy	Brassy	Purple, brown	Green purple	Slight brassy	Slight magenta	Brown	None
Oil Loss, %	0.62	0.38	0	0.87	0.88	0.25	0.13	0.37	0
Viscosity change @ 100°F., %	+0.48	+0.94	+0.31	+1.4	+0.16	+1.1	+4.8	+1.67	+1.28
Neutralization No. Increase	0.05	0.08	0.02	0.10	0.02	0.10	0.78	0.62	0.18
Separation and Gumming	None	None	None	Yes	Slight separation	None	Yes	Yes	None
Oxidation Rate - ml. O_2 absorbed in 4 successive 15 minute periods at 392°F.	1-3-250+ -- 1-2-18-250*	3-2-8-10	0-0-0-0	0-0-0-0	0-0-0-0 0-0-0-0*	0-0-0-1	8-103-250+ --	2-0-0-0	3-3-0-0

* Oxidation Rate results at 0.2 Wt. % concentration.

TABLE 48

PERFORMANCE OF OXIDATION INHIBITORS AT 347°F. IN DI-2-ETHYLHEXYL SEBACATE

(Determined in MIL-L-6387 Corrosion/Oxidation Stability Test at 347°F., modified to allow periodic sampling and progressive determination of the neutralization number of the test oil.)

Base Stock: Plexol 201 W (distilled grade)

Inhibitors (Approx. order of effectiveness)	Concentration Wt. %	Stable Life, Hrs. (Based on Neut. No. increase)
Phenothiazine	0.5	170
Phenothiazine	0.3	80
Phenothiazine(1)	0.3(1)	55(1)
Phenothiazine	0.1	32
p-Amino hydrogenated cardinol	0.5	50
N-Acetyl-4-amino-3-pentadecyl phenol	0.5	40
N-Butyryl-p-amino phenol	0.5	30
Paranox 441	0.5	30
Santowhite	0.5	24
Phenyl hydroquinone	0.5	24
Antioxidant 2246	0.5	24
Zinc DIPS	0.5	<24
p,p-Dioctyl-diphenylamine	0.5	<24
Calco MB	0.5	<24
Tenamine (Sustane)	0.5	<24
Bis-phenol A	0.5	<24
Goodrite SAR	0.5	<24
Paranox 56	0.5	<24

(1) Base stock for this blend was plasticizer grade Plexol 201.

TABLE 49

OXIDATION STABILITY OF ESTERS AT 347°F. (175°C.)

MIL-L-6387 Corrosion and Oxidation Stability Test at 347°F. modified to allow removal of sample periodically for acidity determination.

Material (Inhibited with 0.3% Phenothiazine, Practical Grade)	Stable Life, Hours		
	Untreated, 0-100%	Stripped, 5-100%	Distilled, 5-95%
Di-C_8 Oxo adipate I (Plexol 244)	45;45	40;40	60
Di-C_8 Oxo adipate I, Thermally treated @ 392°F., 48 Hrs.	--	55	--
Di-C_8 Oxo adipate II (Plexol 244)	85;85	75	72
Di-C_8 Oxo adipate II, 5-95%, Charcoal Treated			80
Di-C_8 Oxo adipate (PX-208)	30;20	35;20	--
Di-2-ethylhexyl adipate (Flexol A-26)	140;160	115,140	--
Di-capryl adipate (Hardesty)	35	40,20	--
Di-2-ethylbutyl azelate (Plastolein 9050)	35;20	30;20	--
Di-sec-amyl sebacate (Plexol 202)	90	80,75	--
Di-C_8 Oxo sebacate (PX-408)	35	30;20	--
Di-2-ethylhexyl sebacate (Plexol 201)	55;75	70,80	--
Di-2-ethylhexyl sebacate (Plexol 201W)	80;110;70;95;75	--	--
Triethylene glycol di-2-ethylbutyrate (Flexol 3GH)	35	50	--
Triethylene glycol di-2-ethylhexanoate (Flexol 3GO)	70,55	70;60	--
Dipropylene glycol di-n-octanoate*	95	--	--
Tripropylene glycol dicaproate*	30	--	--
Tri-n-hexyl ester of Evanacid 3CS*	25	--	--
Tri-n-butyl aconitate	< 20	--	--

* Lab. Preps, initially purified by distillation and charcoal treatment.

TABLE 50

HYDROLYTIC STABILITY OF SYNTHETIC LUBRICANTS

(Determined in MIL-L-6387 Hydrolytic Stability Test - 75 gms. of sample and 25 gms. of water agitated in presence of copper strip for 48 hrs. at 200°F.)

Material	Initial Neutralization No. of Oil, mg. KOH/gm.	Neut. No. Increase	Neutralization No. of Water Layer, mg. KOH/gm.	Insolubles, % on Original	Wt. Loss of Copper Strip, mg./cm^2	Change in cs. Viscosity, % at 100°F.	% at -40°F.
MIL-L-6387 Requirements	--	1.0(max.)	1.0(max.)	0.5(max.)	0.2(max.)	..-5 to +15..	
Mono-esters							
C_8 Oxo pelargonate	0.42	0.17	0.07	0.001	0.22	-0.5	+0.1
Esters of Chain Dibasic Acids							
Di-2-ethylhexyl adipate (Flexol A-26)	0.05	0.13	0.01	0.13	+0.01	-0.6	+1.0
Di-C_8 Oxo adipate (Plexol 244)	0.28	0.47	0.0	0.008	0.08	+0.2	+2.4
Di-capryl adipate (Octanol-2)	0.13	0.41	0.01	0.015	0.18	-0.2	Solid
Di-2-ethylhexyl azelate	1.19	0.49	0.20	0.008	0.25	+0.2	+2.9
Di-2-ethylhexyl sebacate (Plexol 201)	0.07	0.06	0.01	0.13	0.0	-0.8	+0.9
Di-2-ethylhexyl sebacate (Plexol 201 W)	0.14	0.22	0.002	0.012	0.08	0.0	+0.9
Di-C_8 Oxo sebacate (PX 408)	0.42	0.66	0.20	0.035	0.39	+0.2	-0.5
Di-capryl sebacate (Octanol-2)	0.14	0.10	0.20	0.023	0.67	-0.3	Solid
Di-sec. amyl sebacate (Plexol 202)	0.10	0.26	0.0	0.003	0.13	-2.4	-5.1
Esters of Polyhydric Alcohols							
Pentanediol-1,5-di-2-ethylhexanoate	1.01	0.06	0.11	0.013	0.28	+0.1	+2.0
Triethyleneglycol di-2-ethylbutyrate (Flexol 3GH)	0.31	0.68	0.72	0.012	1.31	+0.2	+5.1
Triethyleneglycol di-2-ethylhexanoate (Flexol 3GO)	0.42	0.51	0.32	--	0.87	-0.9	+0.4
Polyethyleneglycol di-2-ethylhexanoate (Flexol 4GO)	0.18	0.41	0.46	0.007	0.74	-1.7	+6.9
Pentaerythritol-tetra-caproate (Hercoflex 600)	0.11	0.19	0.03	0.001	+0.034	-6.6	+1.3
Miscellaneous							
Di-2-ethylhexyl phthalate	0.05	0.06	0.0	0.02	0.03	+20.7	Solid
Paraplex AP-52 (Rohm & Haas)	0.21	0.97	0.09	0.013	0.32	-87.	-96.
Acryloid HF-825(P)[1]	0.10	0.15	0.05	0.017	0.0	+2.3	--
Complex ester A[2]	0.12	0.38	0.12	0.013	0.13	-2.8	--
UCON DLB-50B	0.26	0.12	0.40	0.003	0.73	+5.8	+31.5
UCON DLB-50BX	0.14	0.12	0.01	0.006	0.08	+6.0	+36
UCON LB-65	0.23	0.09	0.42	0.004	0.07	+16.5	--
UCON LB-70X	0.24	0.18	0.19	0.004	0.50	+17.3	+108

(1) 50% solids in di-2-ethylhexyl sebacate.
(2) Formulation given in Table XX-6.

TABLE 51

THERMAL STABILITY-STUDIES AT 392°F.

(20-50 ml. Sample Heated in Nitrogen Atmosphere for 48 Hours at 392°F.)

Material	Source	Initial Neut. No., mg. KOH/gm.	Neut. No. Increase, mg. KOH/gm.	Decomposition, % of Theoretical(1)
Monoesters				
C_8 Oxo n-octanoate	Lab. Prep.	0.09	1.56	0.71
" " "	" "	0.09	1.37	0.59
C_8 Oxo pelargonate	" "	0.68	0.92	0.44
C_8 Oxo decanoate	" "	0.05	0.96	0.49
Isopropoxyethoxyethyl n-octanoate	" "	1.46	1.03	0.50
2-Ethylbutoxyethoxyethyl caproate	" "	0.18	0.12	0.06
Dibasic Acid Diesters				
Adipates				
Di-C_8 Oxo, I (Plexol 244)	Rohm and Haas	0.35	0.17	0.06
" " " "	" "	0.35	0.24	0.08
" " " Stripped, 5-100%	Lab. Prep.	0.25	-0.05	--
" " " " 5-100%	" "	0.25	0.20	0.07
Di-C_8 Oxo, II	Rohm and Haas	0.14	0.09	0.03
" " " Stripped, 5-100%	Lab. Prep.	0.12	0.19	0.06
" " " Distilled, 5-95%	" "	0.02	0.15	0.05
" " " " 5-95%	" "	0.02	0.21	0.07
" " " " 5-95%.		0.02	0.27	0.09
and Charcoal Treated	" "	0.02	0.09	0.03
Di-C_8 Oxo (PX-208)	Pitt. Coke & Chem.	0.33	5.43	1.79
PX-208 Stripped, 5-100%	Lab. Prep.	0.93	1.35	0.44
Di-C_8 Oxo (Adipol 10-A)	Hardesty	0.23	1.43	0.47
Di-2-Ethylhexyl (Flexol A-26)	Carbide	0.05	0.14	0.05
Flexol A-26, Stripped, 5-100%	Lab. Prep.	0.06	0.04	0.01
Mono-C_8 Oxo-mono-n-hexyl	Lab. Prep.	0.45	2.21	0.68
" " " "	" "	0.45	0.99	0.30
Mono-C_8 Oxo-mono-n-2-ethylbutyl	Lab. Prep.	0.11	0.20	0.06
Mono-C_{10} Oxo-mono-n-butyl	Lab. Prep.	0.10	2.11	0.69
Dicapryl	Hardesty	0.17	42.0	13.9
" , Stripped, 5-100%	Lab. Prep.	0.80	40.9	13.5
Di-C_{10} Oxo, I	Lab. Prep.	0.04	1.07	0.41
" " " , II	" "	8.08	0.20	0.08
" " , III, Purified	" "	0.07	0.08	0.03
Di-n-butoxyethyl	Lab. Prep.	0.17	1.70	0.66
Diisopropoxyethoxyethyl	" "	2.20	0.33	0.12
Di-2-ethylbutoxyethoxyethyl	" "	0.36	0.37	0.16
Di-heptoxyethoxyethyl	" "	0.22	0.40	0.19
Dicaproxyethoxyethyl	" "	0.15	1.79	0.91
Dinonoxyethoxyethyl	" "	0.52	0.44	0.20
Sebacates				
Di-sec.-amyl (Plexol 202)	Rohm and Haas	0.06	2.38	0.73
Plexol 202, Stripped, 5-100%	Lab. Prep.	0.02	3.02	0.92
Di-sec.-hexyl	Hardesty	0.76	3.43	1.13
Di-2-ethylhexyl (Plexol 201)	Rohm and Haas	0.10	0.22	0.08
Plexol 201, Stripped, 5-100%	Lab. Prep.	0.15	0.04	0.02
Di-2-ethylhexyl (Plexol 201W)	Rohm and Haas	0.13	0.0	0.0
Di-C_8 Oxo (PX-408)	Pitt. Coke & Chem.	0.40	5.86	2.22
PX-408, Stripped, 7-100%	Lab. Prep.	1.04	1.02	0.39

(1) Decomposition theoretically possible is assumed to be complete breakdown to give the stoichiometric quantity of original acid.

TABLE 52

THERMAL STABILITY STUDIES AT 392°F.

Material	Source	Initial Neut. No., mg. KOH/gm.	Neut. No. Increase, mg. KOH/gm.	Decomposition, % of Theoretical(1)
Sebacates (Continued)				
Di-C_8 Oxo, I	Hardesty	0.70	1.07	0.41
" " , I, + 0.5% Phenothiazine	Lab. Prep.	0.61	1.04	0.40
Di-C_8 Oxo, II	Hardesty	0.19	4.69	1.78
Dicapryl	Hardesty	0.27	2.68	1.00
Di-C_{10} Oxo	Lab. Prep.	0.06	0.20	0.09
Azelates				
Di-2-ethylbutyl, I, (Plastolein 9050)	Emery	0.26	0.63	0.20
" " , I, " "	"	0.18	0.66	0.21
" " , I, Stripped, 5-100%	Lab. Prep.	0.14	0.35	0.11
Di-2-ethylhexyl Plastolein (9058)	Emery	1.17	0.66	0.24
Other Diesters				
Di-C_8 Oxo Succinate	Lab. Prep.	0.03	0.90	0.27
Di-2-ethylhexyl phthalate	Carbide	0.11	0.16	0.06
Glycol Diesters				
Pentanediol-1,5 di-2-ethylhexanoate	Lab. Prep.	0.97	0.19	0.07
2-Ethoxymethyl-2,4-dimethylpentanediol-1,5 dicaproate	Lab. Prep.	0.12	0.86	0.30
Triethyleneglycol di-2-ethylbutanoate (Flexol 3GH)	Carbide	0.65	0.31	0.10
Flexol 3 GH, Stripped, 5-100%	Lab. Prep.	0.20	-0.01	--
" " " , 5-100%	" "	0.20	0.10	0.03
Triethyleneglycol di-2-ethylhexanoate (Flexol 3GO)	Carbide	0.59	-0.10	--
" " " (Flexol 3GO)	"	0.59	-0.36	--
" " " (Flexol 3GO)	"	0.39	-0.22	--
Flexol 3GO, Stripped, 5-100%	Lab. Prep.	0.20	-0.02	--
Polyethylene Glycol di-2-ethylhexanoate (Flexol 4GO)	Carbide	0.27	0.27	0.0
Polyethylene Glycol 200 dibutyrate	Lab. Prep.	0.10	2.04	0.62
Polyethylene Glycol 200 dicaproate	" "	0.17	0.41	0.14
Polyethylene Glycol 200 mono-2-ethylbutyrate monocaproate	" "	0.09	0.16	0.06
Dipropylene glycol di-2-ethylhexanoate		0.54	2.42	0.83
" " "	" "	0.54	-0.07	--
Dipropylene glycol di-n-octanoate	" "	0.08	0.34	0.12
" " "	" "	0.08	0.27	0.09
Tripropylene glycol dicaproate	" "	0.13	0.23	0.08
" " "	" "	0.13	-0.02	--
" " "	" "	0.13	0.57	0.20
Tripropylene glycol di-n-octanoate	" "	0.40	-0.10	--
" " "	" "	0.40	-0.18	--
" " "	" "	0.40	-0.08	--
" " dipelargonate	" "	0.29	0.27	0.11
Tripropylene glycol di-2-ethylhexanoate	" "	0.28	1.57	0.62
" " "	" "	0.28	-0.01	--
" " "	" "	0.28	0.45	0.18
Other Esters				
Trimethylolpropane tri-n-octanoate	" "	0.04	0.09	0.03
Trimethylolpropane mono-2-ethylbutyrate dicaproate	" "	0.46	-0.17	--
Pentaerythritol tetracaproate	" "	0.05	0.05	0.01
Pentaerythritol di-2-ethylbutyrate dicaproate	" "	0.16	0.01	0.0
Tri-2-ethylhexyl ester of 3CS Acid(2)	" "	0.44	1.96	0.31
Tri-n-hexyl ester of 3CS. Acid(2)	" "	0.42	1.41	0.47
Complex ester C		0.18	2.69	1.45

(2) 3CS Acid is $HOOCCH_2CH(COOH)SCH_2COOH$

TABLE 53

THERMAL STABILITY OF ESTERS AT 455°F.

Material	Source	Initial Neut. No., mg. KOH/gm.	Neut. No. Increase, mg. KOH/gm.	Decomposition % of Theoretical(1)
Dicapryl adipate	Hardesty	0.17	--(2)	100
Di-C_{10} Oxo adipate	Lab. Prep.	0.06	2.36	1.01
Diisopropoxyethoxyethyl adipate	Lab. Prep.	2.20	0.84	0.31
Diheptoxyethoxyethyl adipate	" "	0.22	1.59	0.71
Dicaproxyethoxyethyl adipate	" "	0.15	2.90	1.47
Di-2-ethylbutoxyethoxyethyl adipate	" "	0.36	0.68	0.29
Dipropylene glycol di-n-octanoate	" "	0.08	1.52	0.52
Tripropylene glycol di-n-octanoate	" ""	0.40	5.79	2.34
Polyethylene glycol 200 dicaproate	" "	0.17	0.49	0.17
Polyethylene glycol 200 monocaproate mono-2-ethylbutyrate	" "	0.09	0.74	0.26
Polyethylene glycol di-2-ethylhexanoate (4GO)	Carbide	0.27	0.59	0.23
Tri-n-butyl aconitate	Am. Sugar Ref.	0.19	17.75	3.60

(1) Decomposition theoretically possible is assumed to be complete breakdown to give the stoichiometric quantity of original acid.

(2) No liquid sample remained at the end of the test. White crystals of adipic acid had sublimed to the cooler top of the thermal tube. A small amount of dark residue remained in the bottom of the tube. No actual determination of acidity was made.

TABLE 54

SAE-SOD TEST CONDUCTED IN SAE E.P. LUBRICANT TESTING MACHINE

Manual Step-Wise Loading at 50 Lbs. Each 10 Seconds After Run-In Period

1000 RPM; 3.4:1 Shaft Speed Ratio
Timken Test Cups No. T-48651
Room Temp. (75-80°F.) at Start of Test

Lubricant	Run-In Minutes @ Lbs. Load	Timken Test Cup Batch	Failure Load, Lbs. Individual Determinations	Average
EA0-100	2 @ 200	B & C	950; 1000	975
(Grade 1100	2 @ 50	"	975;(1) 1000	988
Mineral Oil)	2 @ 50	U	800; 800; 800	800
ET0-10	2 @ 200	B & C	<200;(2) <200;(2) 350	250
(Grade 1010	2 @ 100	"	<100;(2) <100;(2)	<100
Mineral Oil)	2 @ 50	"	300; 300; 325;(1) 350	318
	2 @ 50	U	<50;(2) <50(2)	<50
Syn. B-8	2 @ 200	B & C	750; 775(1)	762
	2 @ 50	U	500;* 650; 650; 650	650
Syn. B-15	1 @ 200	B & C	600; 700; 850	717
	2 @ 200	"	700; 700; 750; 775(1)	731
	2 @ 50	"	700	
	2 @ 50	U	550; 650; 650; 650; 700; 700	650
Syn. B-16	2 @ 50	B & C	650; 750; 750; 800; 850	760
	2 @ 50	U	550; 600; 600	583
Syn. B-17	2 @ 50	B & C	700; 700; 750; 750	725
	2 @ 50	U	500; 600; 600; 650; 650; 700; 775(1)	647
Syn. A-12	2 @ 200	B & C	450; 550; 550	517
Syn. A-20	2 @ 50	U	500; 550	525
Syn. C	2 @ 200	B & C	650	
	2 @ 50	U	400;* 600; 650	625
PRL-3161	2 @ 50	B & C	700; 700; 750; 800	738
	2 @ 50	U	450;* 550; 650; 700; 750	662

Lubricant	Run-In Minutes @ Lbs. Load	Timken Test Cup Batch	Failure Load, Lbs. Individual Determinations	Average
Syn. D	2 @ 200	B & C	600;* 750; 750; 800; 850; 850	800
	2 @ 50	B & C	750; 750	750
	2 @ 50	U	750; 750	750
Syn. E	2 @ 200	B & C	600?*; 750	750
Syn. F	2 @ 50	U	500;* 650; 650; 700	667
Syn. G	2 @ 200	B & C	950; 1000; 1100	1017
	2 @ 50	U	700; 750; 800; 800; 850; 850	792
TYPE 1 ESTERS				
Syn. 1-A	2 @ 200	B & C	500; 600; 650; 675(1)	606
Syn. 1-B	2 @ 200	B & C	575;(1) 625;(1) 650	617
	2 @ 50	U	450; 500; 550	500
Syn. 1-C	2 @ 200	B & C	700; 750	725
Syn. 1-D	2 @ 200	B & C	650; 700	675
TYPE 2 ESTERS				
Syn. 2-A	2 @ 150	B & C	<150;(2) <150(2)	<150
Syn. 2-B	2 @ 200	B & C	<200;(2) <200;(2) 400	<200-400
Syn. 2-C	2 @ 200	B & C	375;(1) 400; 400; 450; 450 450; 475;(1) 550	444
	2 @ 50	B & C	500; 500	500
	2 @ 50	U	200;* 300; 350	325
Syn. 2-D	2 @ 200	B & C	450; 475(1)	462
Syn. 2-E	2 @ 200	B & C	550; 550	550

(1) Failure occurred during 50 lb. load increase; value listed is average of old and new loads.
(2) Failed during run-in.
* Omitted from averages because not considered representative of performance.

TABLE 55

EFFECT OF OPERATING CONDITIONS OF FAILURE LOAD IN SAE MACHINE

Automatic Continuous Loading at 78 Lbs. per Second (4680 Lbs. per Minute After Run-In Period

Timken Test Cups No. T-48651, Batches "B" and "C"
Room Temp. (75-80°F.) at Start of Test

Shaft Speed Ratio	Speed RPM	Run-In Minutes @ Lbs. Load	Lubricant	Failure Load, Lbs. Individual Runs	Average
3.9	530	1 @ 200	EAO-100	3800; 3860; 3960; 4000	3905
			Syn. A-12	3200; 3350; 3450; 3550	3388
			PRL-3161	3300; 3400; 3460; 3540	3425
			Syn. C	3550	
3.9	750	1/2 @ 200	Syn. C	2070	
3.9	750	1 @ 200	EAO-100	2400; 2460	2430
			PRL-3161	2100; 2270	2185
3.9	750	5 @ 200	EAO-100	2450	
			Syn. C	1550; 1800	1675
			Syn. 1-B	2100; 2200	2150
3.9	750	1 @ 200 and 5 @ 500	EAO-100	1950	
			Syn. C	500	
			Syn. B-14	1200	
			Syn. 1-B	1000; 1300; 3300	1200
3.9	750	1 @ 200	Syn. C	600; 600	600
		2 @ 400 and 2 @ 600	Syn. B-14	600	
			Syn. 1-B	600; 600	600
3.9	750	5 @ 200 and 2 @ 400	EAO-100	1500; 1760	1630
			Syn. A-12	1050	
			Syn. C	1750	
			Syn. B-14	>1700 (Incipient Scuffing at 1700)	
			Syn. 1-B	>1200 (Incipient Scuffing at 1200)	
3.9	750	10 @ 200 and 2 @ 400	EAO-100	1920; 2150	2035
			Syn. 1-B	1520	
3.9	1000	1 @ 200	EAO-100	1500; 1570	1535
			Syn. A-12	800; 910; 950; 1000; 1000	932
			PRL-3161	1000; 1040	1020
			Syn. C	920; 1040	980
			Syn. B-14	1050; 1050; 1050; 1150	1075
3.9	1000	2 @ 200	Syn. A-12	800; 850; 850	833
3.4	1000	2 @ 50	EAO-100	1550	

TABLE 56

EFFECT OF OPERATING CONDITIONS ON FAILURE LOAD IN SAE MACHINE

Timken Test Cups No. T-48651, Batches "B" and "C"
Room Temp. (75-80°F.) at Start of Test

Shaft Speed Ratio	Speed RPM	Run-In Minutes @ Lbs. Load	Stepwise Manual Loading: Lbs. Increase at Intervals of	Stepwise Manual Loading: Average Rate Lbs./Min.	Lubricant	Failure Load* Lbs.
3.9	750	2 @ 200	50 ea. 2 min.	25	EAO-100	450
			100 ea. 2 min.	50	EAO-100	600
			100 ea. 1 min.	100	EAO-100	700
3.9	1000	1 @ 200	100 ea. 1 min.	100	EAO-100	600
			100 ea. 1 min.	100	Syn. B-14	600
3.9	1000	1 @ 200	100 ea. 30 sec.	200	EAO-100	700
3.9	1000	2 @ 200	50 ea. 30 sec.	100	Syn. B-15	500
3.9	1000	2 @ 200	100 ea. 30 sec.	200	Syn. B-15	700
			" " "	"	PRL-3161	700
			" " "	"	Syn. A-12	400
			" " "	"	Syn. 2-C	200
3.9	1000	5 @ 200	50 ea. 1 min.	50	Syn. B-15	400
			100 ea. 30 sec.	200	Syn. B-15	700
			50 ea. 10 sec.	300	Syn. B-15	550
			200 ea. 30 sec.	400	Syn. B-15	800
14.6	1000	2 @ 50	50 ea. 10 sec.	300	EAO-100	200

* Individual determinations.

TABLE 57

LUBRICATION STUDIES IN 4-BALL E.P. TESTER

(1800 RPM for 1 Minute at Room Temperature)

Material	Viscosity, Cs. @ °F. 210	100	Applied Load, Kg. No Delay Seizure	Weld
Refined Mineral Oil (distillate) (A)	1.2	3.1	30	90
" " " " (B)	3.1	15.3	35	90
" " " " (C)	5.7	44.3	30	90
" " " " (D)	9.8	112	35	90
" " " " (E)	14.1	195	35	95
C_8 Oxo-n-octanoate	1.34	3.45	45	100
Di-C_8 Oxo Adipate (Plexol 244)	2.83	10.1	45	95
Di-C_{10} Oxo Adipate	3.60	14.4	50	90
Di-C_{13} Oxo Adipate	5.61	30.9	50	100
Di-2-ethylhexyl Sebacate (Plexol 201)	3.36	10.8	55	100
Containing 2.5 wt. % Acryloid HF-825	4.55	17.7	55	110
" 5.0 wt. % " " "	6.11	23.9	55	114
" 7.5 wt. % " " "	7.94	31.7	55	110
" 10.0 wt. % " " "	10.10	41.0	55	110

TABLE 58

LUBRICATION STUDIES IN 4-BALL E.P. TESTER

(1800 RPM for 1 Minute at Room Temperature)

Material	Applied Load, Kg. No Delay Seizure	Weld
Di-2-ethylhexyl sebacate (Plexol 201)	55	100
Di-C_8 Oxo sebacate (PX-408)	55	100
Di-C_{10} Oxo adipate	50	90
Di-C_8 Oxo succinate	65	95
Di-2-ethylbutoxyethoxyethyl adipate	45	100
Tripropylene glycol di-caproate	45	95
Polyglycol 200-mono-2-ethylbutyrate-mono-caproate	45	100
UCON LB-70X	45	95
Tri-n-butyl aconitate	45	95
Hercoflex 600	60	100
Complex Ester A	75	140
Tri-2-ethylhexyl ester of Evanacid 3CS (1)	110	160
Tri-n-hexyl ester of Evanacid 3CS	110	160
5% " " " " " " , 95% Plexol 244	55	105
20% " " " " " " , 80% " "	65	125
50% " " " " " " , 50% " "	90	145

(1) Evanacid 3CS is $HOOC-CH_2-CH(COOH)S-CH_2-COOH$

TABLE 59

OXIDATION STABILITY OF ESTERS AT 347°F.

(Determined in MIL-L-6387 Corrosion/Oxidation Stability Test at 347°F., modified to allow periodic sampling and progressive determination of the neutralization number of the test oil).

All materials contain 0.3 wt. % phenothiazine (practical grade)

Material	Stable Life, Hrs. (Based on Neut. No. Increase)
Di-2-ethylhexyl sebacate (Plexol 201 - plasticizer)	55; 75
Di-2-ethylhexyl sebacate (Plexol 201W - distilled)	80; 110; 70
Di-C8 Oxo adipate (Batch I of Plexol 244 - plasticizer)	45; 45
Di-C8 Oxo adipate (Batch II of Plexol 244 - plasticizer)	85; 85
" " " " " - stripped	75
" " " " " - distilled	72
" " " " " - distilled & charcoal treated	80
Di-sec. amyl sebacate (Plexol 202)	90
Di-C8 Oxo sebacate (PX-408)	35
Di-capryl adipate (Hardesty)	<24
Triethylene glycol di-2-ethylbutyrate (Flexol 3GH)	35

TABLE 60

PROPERTIES OF DI-C8 OXO ADIPATE (PLEXOL 244)

Effect of Refinement

Treating Methods Employed on Plasticizer Grade di-C8 Oxo Adipate (Plexol 244)	None	5% Removed by Vacuum Stripping	5-95% Heart Cut From Vacuum Distillation	5-95% Heart Cut From Distillation Treated With Animal Charcoal
Properties				
Neutralization No., mg. KOH/gm.	0.14	0.12	0.02	0.02
Viscosity, cs. @ 210°F.	2.824	2.825	2.824	2.818
" " 100°F.	10.11	10.08	10.09	10.02
" " -40°F.	1075	1085	1131	1070
" " -65°F.	6725	6800	6750	6725
ASTM Slope, 210/100°F.	0.724	0.722	0.723	0.720
" " , 210/-40°F.	0.736	0.735	0.739	0.735
Viscosity Index	142	143	142	144
Hardiman & Nissan V.I.	151	151	151	152
Flash Point, °F.	380(1)	400	415	410(1)
Fire Point, °F.	450(1)	470	460	450
Vapor Pressure at 400°F., mm.	2.7(1)	2.9	3.0	2.6
Viscosity/Volatility Index	458	455	452	461
Pour Point, °F.	<-75	<-75	<-75	<-75
Melting Point, °F.	WNC(2)	WNC(2)	WNC(2)	WNC(2)
Cloud Point, °F.	<-80	-42	<-70	-34
Oxidation Stability at 347°F.				
Stable Life, Hrs.	85(1)	75	72	80
Neut. No. Increase After 48 Hrs.	0.86(1)	0.68	0.57	0.59
Thermal Stability at 392°F.				
Neut. No. Increase	0.13(1)	0.19	0.19(1)	0.18(1)
Decomposition, %	0.05(1)	0.06	0.06(1)	0.06(1)

(1) Average of more than one determination.

(2) Would not crystallize after 15 hrs. at -94°F.

APPENDIX II B FIGURES

FIGURE 1.

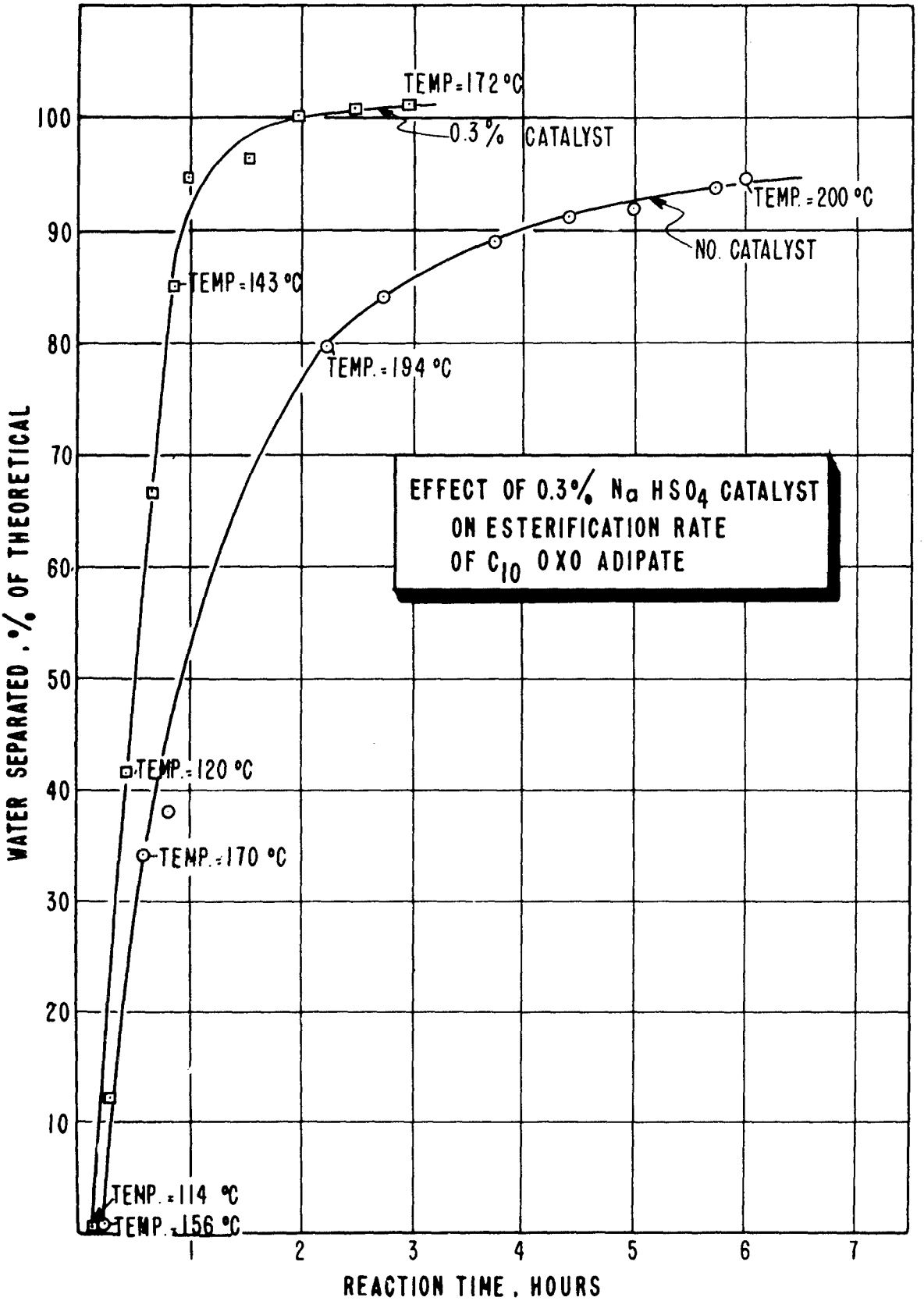

TEMP=172 °C
0.3 % CATALYST
TEMP.=200 °C
NO. CATALYST
TEMP.=143 °C
TEMP.=194 °C
EFFECT OF 0.3% Na HSO4 CATALYST
ON ESTERIFICATION RATE
OF C10 OXO ADIPATE
TEMP.=120 °C
TEMP.=170 °C
TEMP.=114 °C
TEMP.=156 °C
WATER SEPARATED, % OF THEORETICAL
REACTION TIME, HOURS
100
90
80
70
60
50
40
30
20
10
1
2
3
4
5
6
7

FIGURE 2.

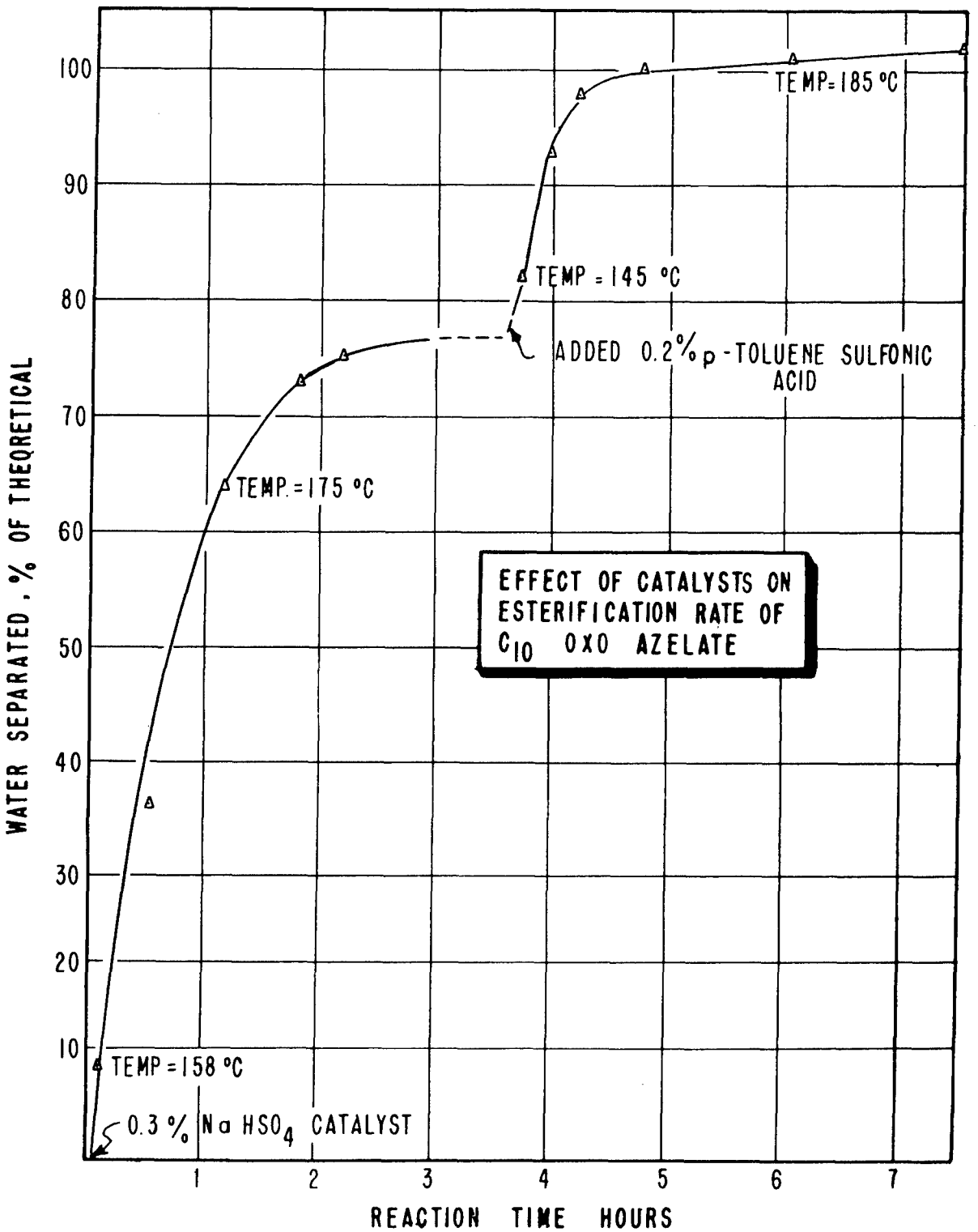

EFFECT OF CATALYSTS ON ESTERIFICATION RATE OF C_{10} OXO AZELATE
WATER SEPARATED, % OF THEORETICAL
REACTION TIME HOURS
TEMP = 158 °C
0.3 % Na HSO_4 CATALYST
TEMP. = 175 °C
TEMP = 145 °C
ADDED 0.2% p-TOLUENE SULFONIC ACID
TEMP = 185 °C

FIGURE 3

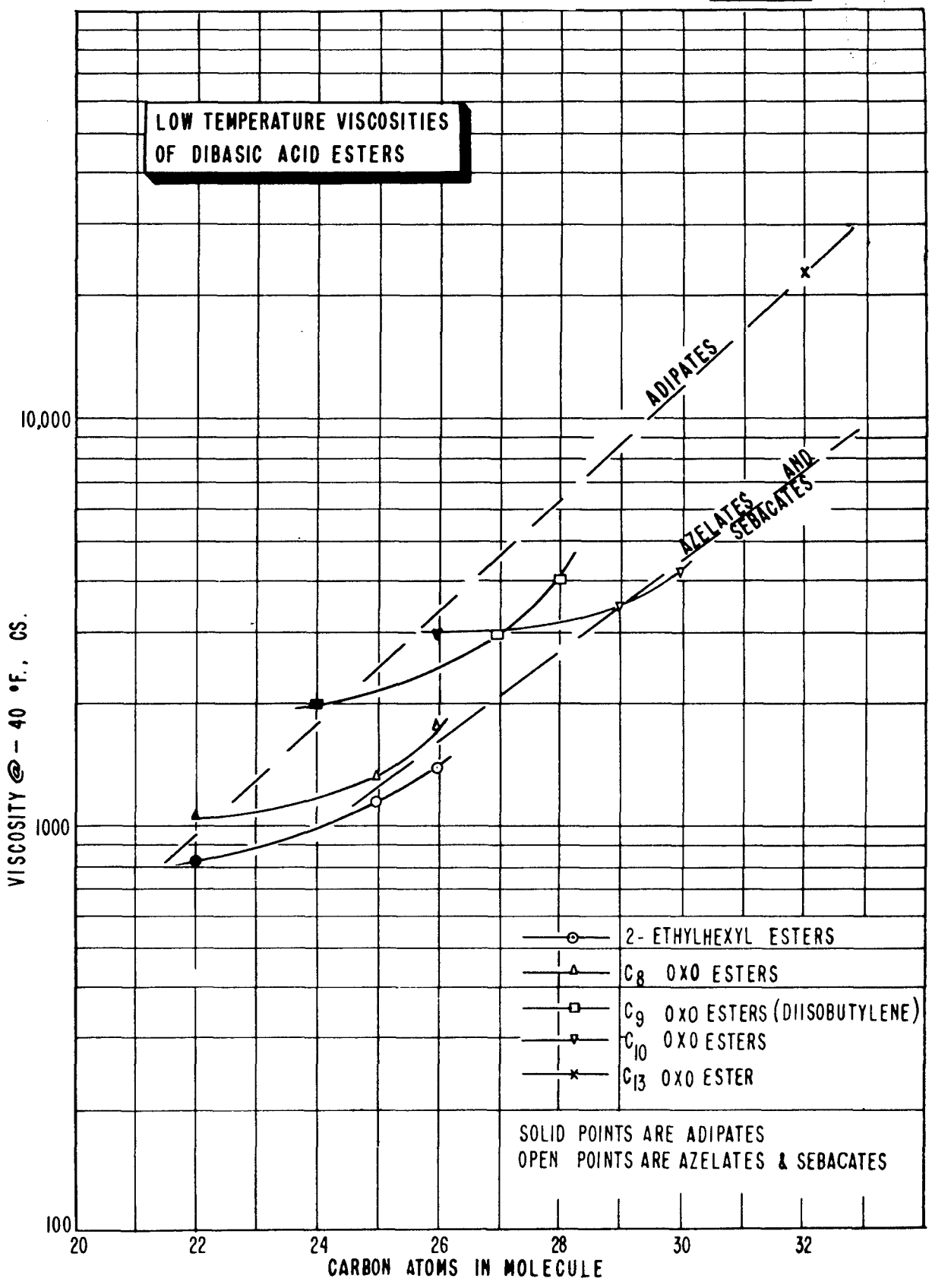

LOW TEMPERATURE VISCOSITIES
OF DIBASIC ACID ESTERS
ADIPATES
AZELATES AND SEBACATES
10,000
1000
100
VISCOSITY @ - 40 °F., CS.
20
22
24
26
28
30
32
CARBON ATOMS IN MOLECULE
2- ETHYLHEXYL ESTERS
C8 OXO ESTERS
C9 OXO ESTERS (DIISOBUTYLENE)
C10 OXO ESTERS
C13 OXO ESTER
SOLID POINTS ARE ADIPATES
OPEN POINTS ARE AZELATES & SEBACATES

FIGURE 4

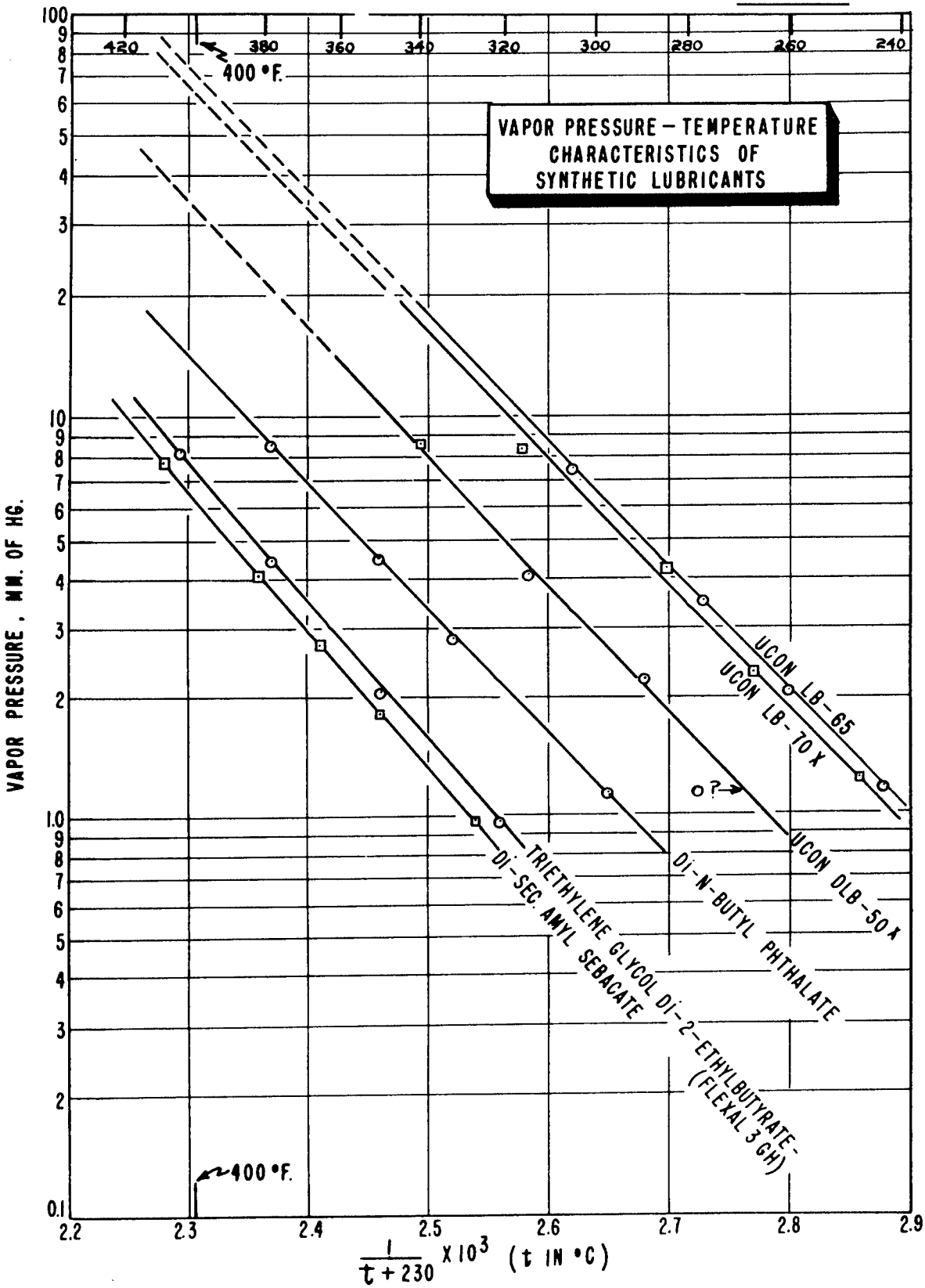

VAPOR PRESSURE – TEMPERATURE CHARACTERISTICS OF SYNTHETIC LUBRICANTS
VAPOR PRESSURE, MM. OF HG.
420
380
360
340
320
300
280
260
240
400 °F.
UCON LB-65
UCON LB-70 X
UCON DLB-50 X
DI-N-BUTYL PHTHALATE
TRIETHYLENE GLYCOL DI-2-ETHYLBUTYRATE-(FLEXAL 3GH)
DI-SEC. AMYL SEBACATE
400 °F.
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
$\frac{1}{t+230} \times 10^3$ (t IN °C)

FIGURE 5

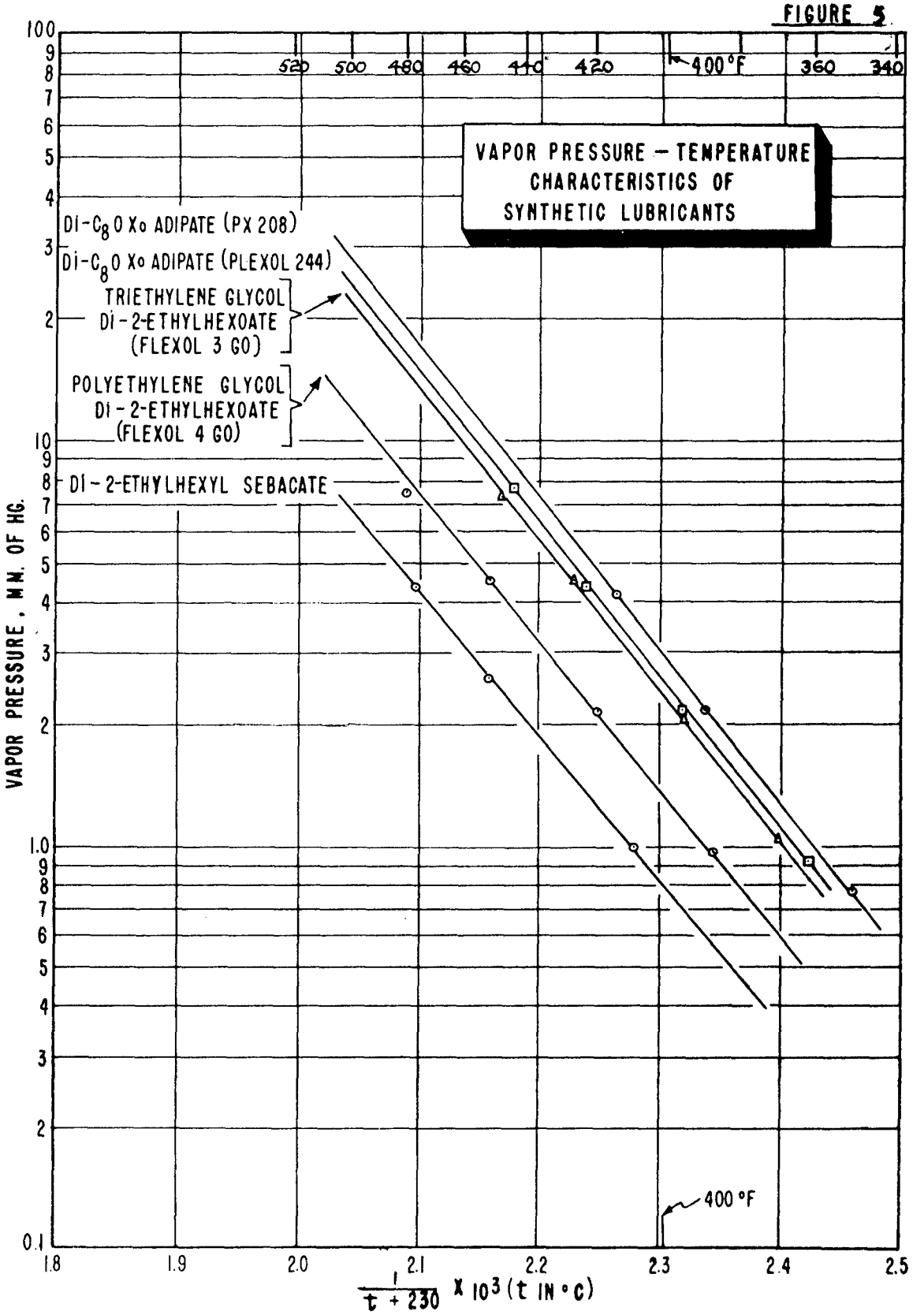

VAPOR PRESSURE – TEMPERATURE CHARACTERISTICS OF SYNTHETIC LUBRICANTS
520
500
480
460
440
420
400°F
360
340
Di-C8 Oxo ADIPATE (PX 208)
Di-C8 Oxo ADIPATE (PLEXOL 244)
TRIETHYLENE GLYCOL Di-2-ETHYLHEXOATE (FLEXOL 3 GO)
POLYETHYLENE GLYCOL Di-2-ETHYLHEXOATE (FLEXOL 4 GO)
Di-2-ETHYLHEXYL SEBACATE
400°F
VAPOR PRESSURE, MM. OF HG.
100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
0.1
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
1/(t + 230) X 10³ (t IN °C)

FIGURE 6

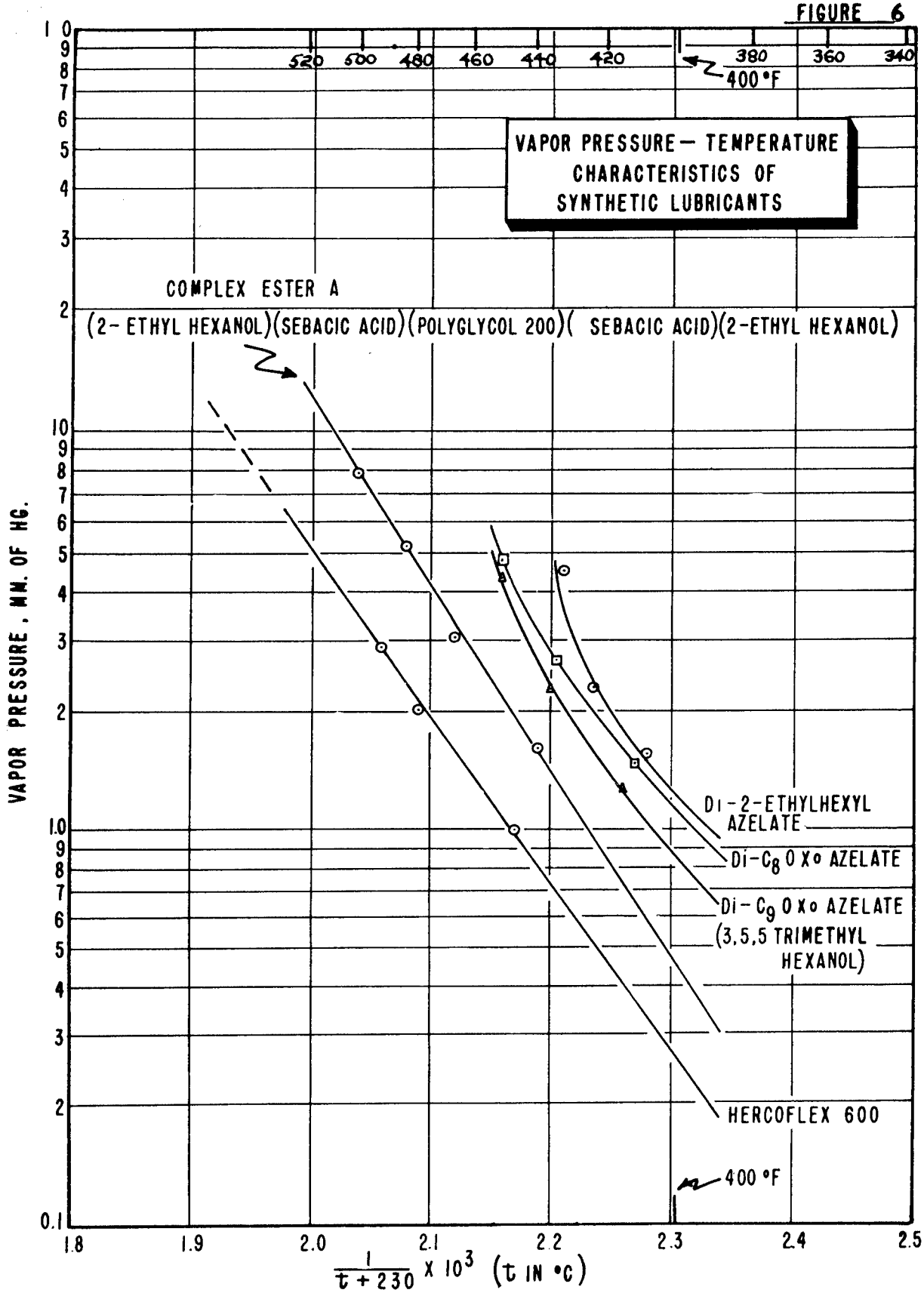

VAPOR PRESSURE — TEMPERATURE CHARACTERISTICS OF SYNTHETIC LUBRICANTS
520 500 480 460 440 420 380 360 340
400 °F
COMPLEX ESTER A
(2- ETHYL HEXANOL)(SEBACIC ACID)(POLYGLYCOL 200)(SEBACIC ACID)(2-ETHYL HEXANOL)
Di-2-ETHYLHEXYL AZELATE
Di-C8 Oxo AZELATE
Di-C9 Oxo AZELATE (3,5,5 TRIMETHYL HEXANOL)
HERCOFLEX 600
400 °F
VAPOR PRESSURE, MM. OF HG.
1.8 1.9 2.0 2.1 2.2 2.3 2.4 2.5
1/(t + 230) X 10^3 (t IN °C)

FIGURE 7

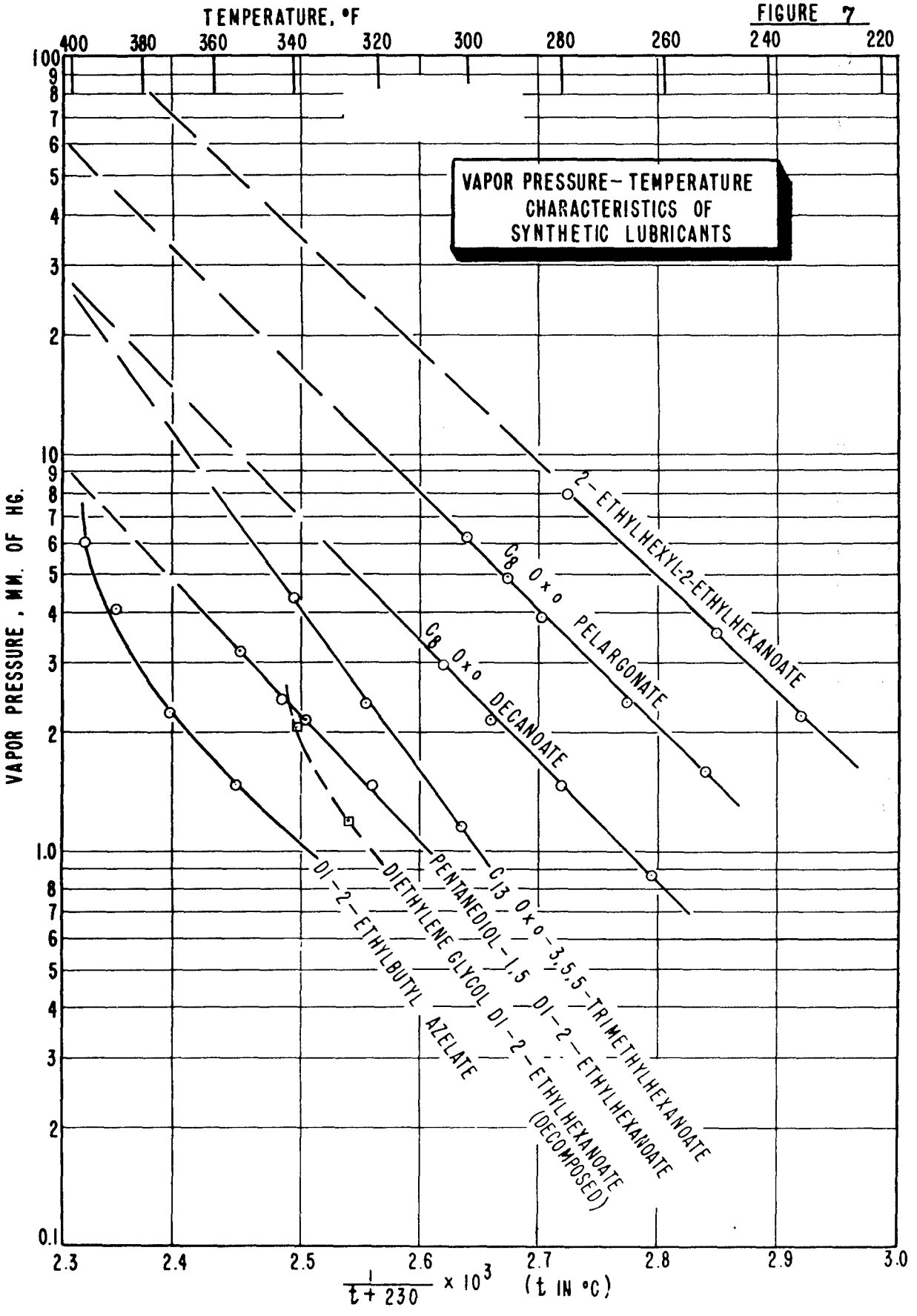

TEMPERATURE, °F
400
380
360
340
320
300
280
260
240
220
VAPOR PRESSURE-TEMPERATURE CHARACTERISTICS OF SYNTHETIC LUBRICANTS
VAPOR PRESSURE, MM. OF HG.
100
9
8
7
6
5
4
3
2
10
9
8
7
6
5
4
3
2
1.0
8
7
6
5
4
3
2
0.1
2-ETHYLHEXYL-2-ETHYLHEXANOATE
C8 Oxo PELARGONATE
C8 Oxo DECANOATE
C13 Oxo-3,5,5-TRIMETHYLHEXANOATE
PENTANEDIOL-1,5 DI-2-ETHYLHEXANOATE
DIETHYLENE GLYCOL DI-2-ETHYLHEXANOATE (DECOMPOSED)
DI-2-ETHYLBUTYL AZELATE
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3.0
1/(t+230) x 10^3
(t IN °C)

FIGURE 8

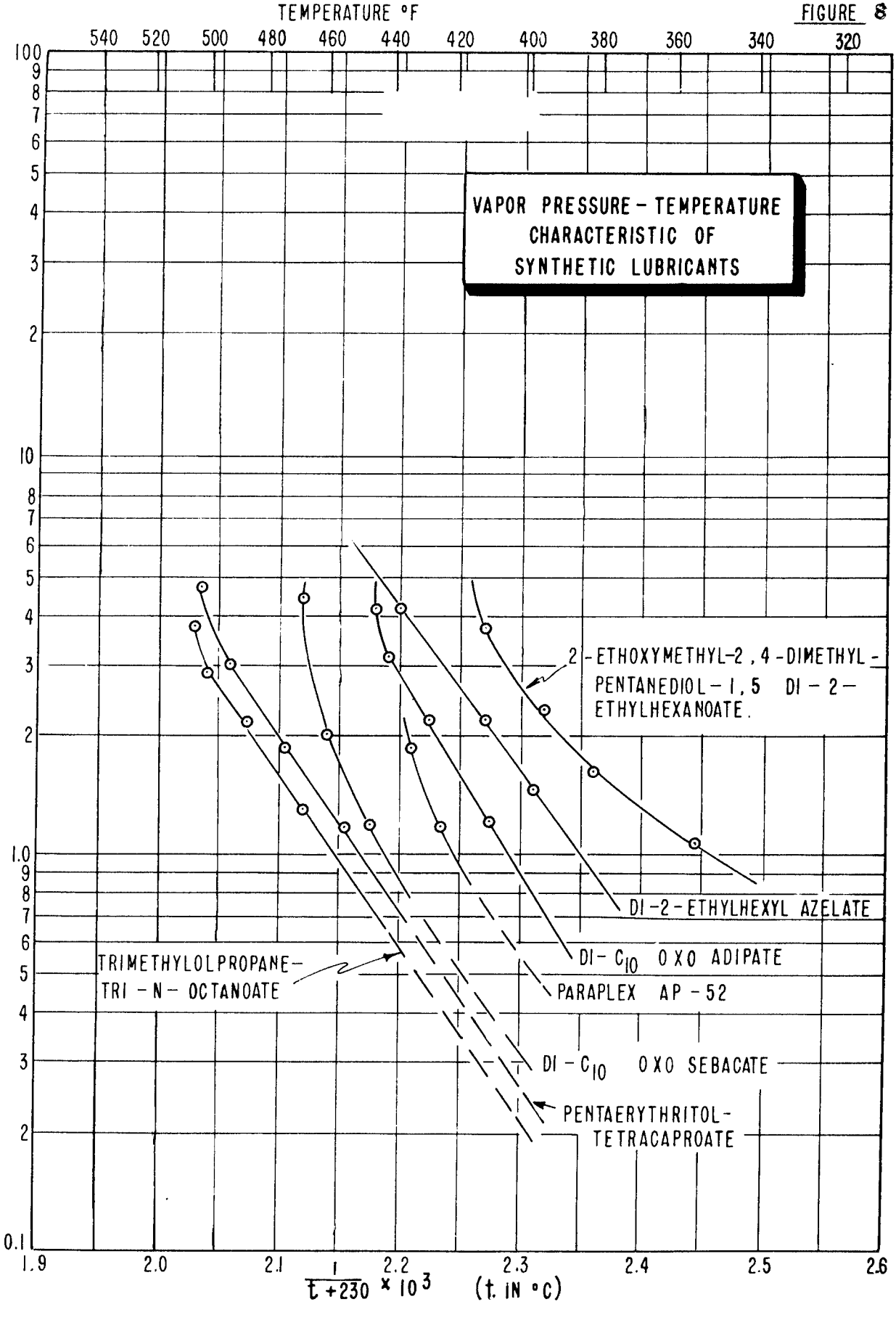

TEMPERATURE °F
540 520 500 480 460 440 420 400 380 360 340 320
100 9 8 7 6 5 4 3 2 10 8 7 6 5 4 3 2 1.0 9 8 7 6 5 4 3 2 0.1
VAPOR PRESSURE - TEMPERATURE CHARACTERISTIC OF SYNTHETIC LUBRICANTS
2-ETHOXYMETHYL-2,4-DIMETHYL-PENTANEDIOL-1,5 DI-2-ETHYLHEXANOATE.
DI-2-ETHYLHEXYL AZELATE
DI-C_{10} OXO ADIPATE
PARAPLEX AP-52
TRIMETHYLOLPROPANE-TRI-N-OCTANOATE
DI-C_{10} OXO SEBACATE
PENTAERYTHRITOL-TETRACAPROATE
1.9 2.0 2.1 2.2 2.3 2.4 2.5 2.6
$\frac{1}{t+230} \times 10^3$ (t. IN °C)

FIGURE 9

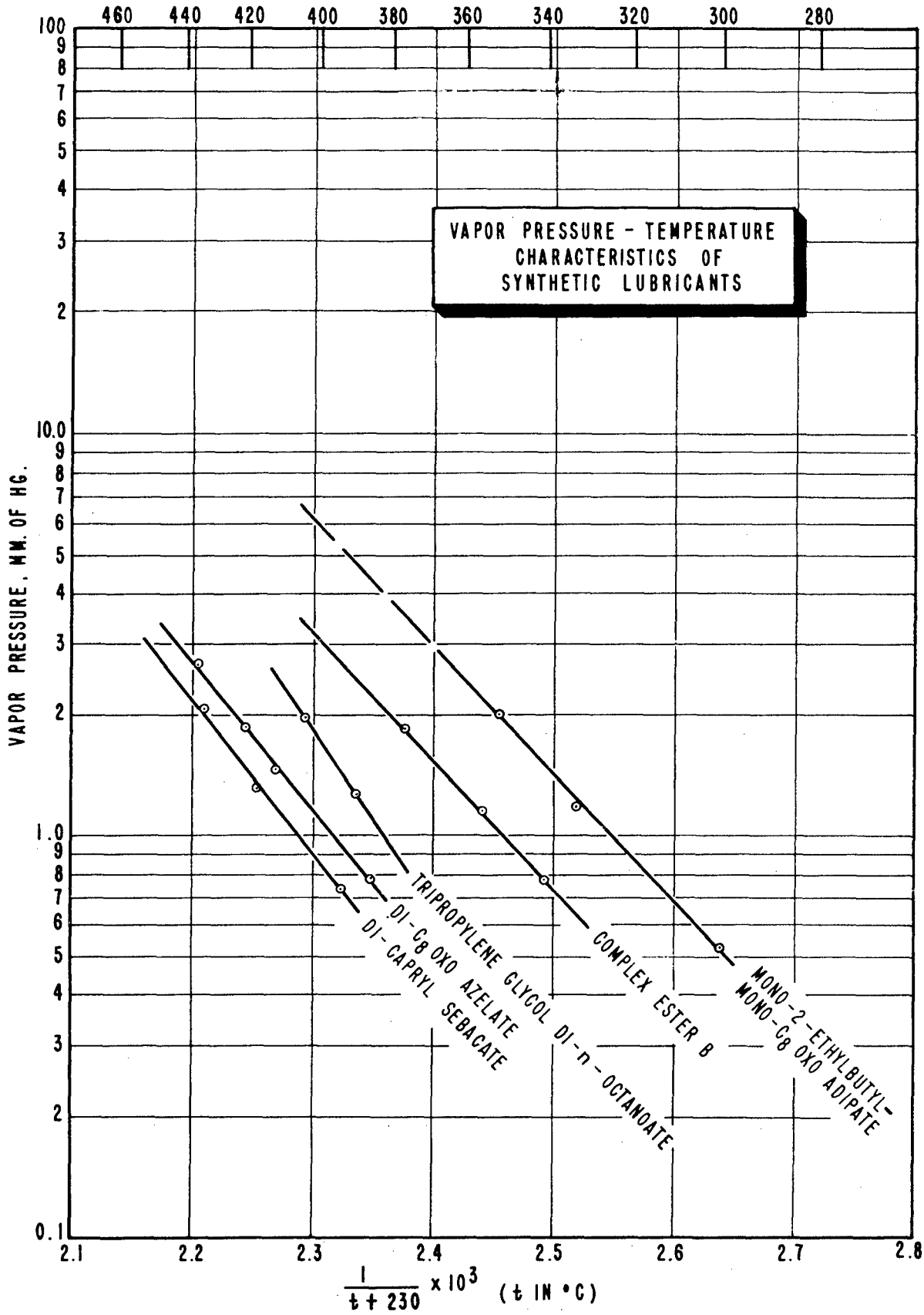

TEMPERATURE, °F.
460
440
420
400
380
360
340
320
300
280
VAPOR PRESSURE - TEMPERATURE CHARACTERISTICS OF SYNTHETIC LUBRICANTS
VAPOR PRESSURE, MM. OF HG.
100
9
8
7
6
5
4
3
2
10.0
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
0.1
TRIPROPYLENE GLYCOL DI-n-OCTANOATE
DI-C8 OXO AZELATE
DI-CAPRYL SEBACATE
COMPLEX ESTER B
MONO-2-ETHYLBUTYL-MONO-C8 OXO ADIPATE
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
1/(t + 230) x 10^3 (t IN °C)

FIGURE 10

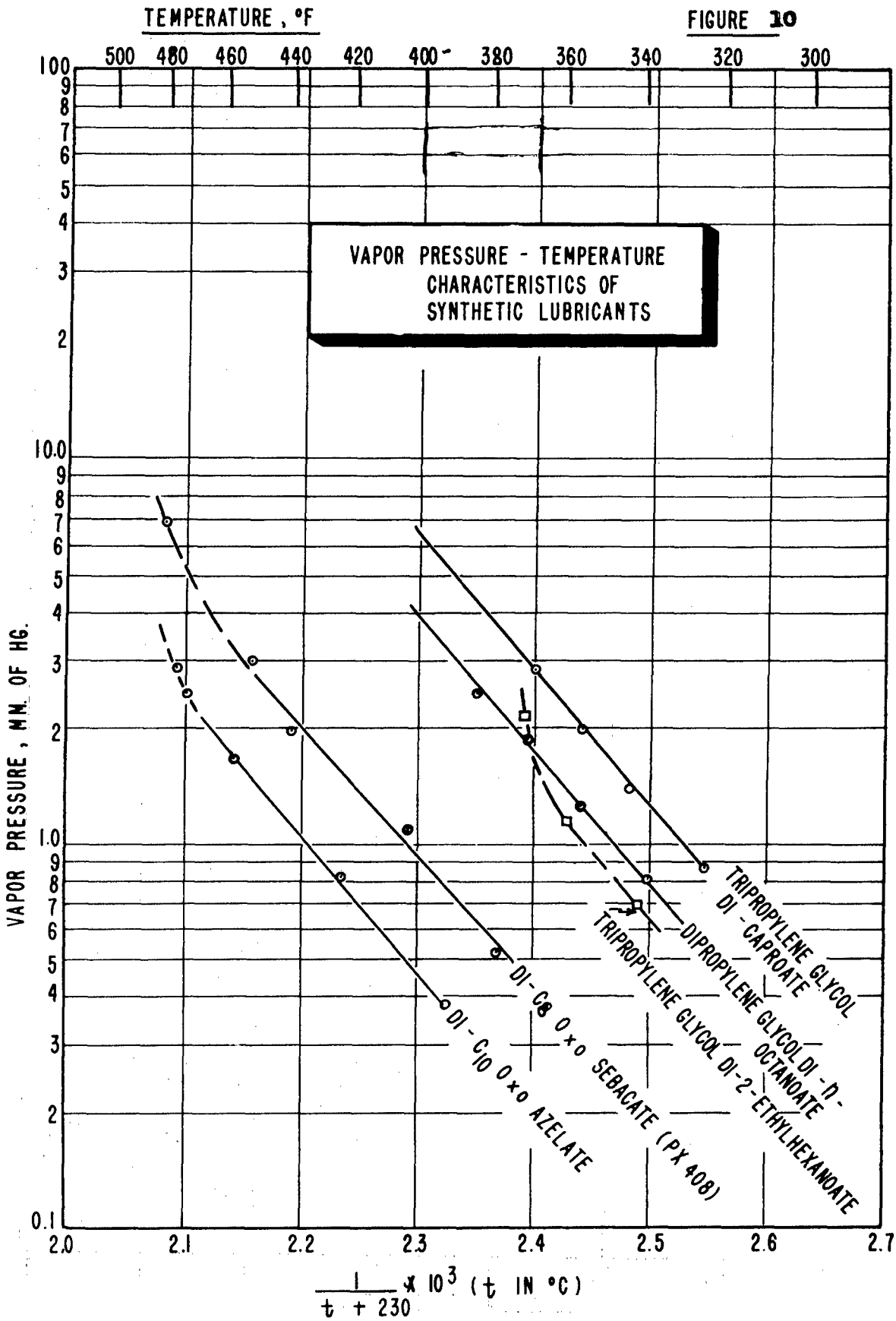

TEMPERATURE, °F
500 480 460 440 420 400 380 360 340 320 300
VAPOR PRESSURE - TEMPERATURE CHARACTERISTICS OF SYNTHETIC LUBRICANTS
VAPOR PRESSURE, MM. OF HG.
100 9 8 7 6 5 4 3 2 10.0 9 8 7 6 5 4 3 2 1.0 9 8 7 6 5 4 3 2 0.1
2.0 2.1 2.2 2.3 2.4 2.5 2.6 2.7
1/(t + 230) x 10^3 (t IN °C)
TRIPROPYLENE GLYCOL DI - CAPROATE
DIPROPYLENE GLYCOL DI -n- OCTANOATE
TRIPROPYLENE GLYCOL DI-2-ETHYLHEXANOATE
DI-C8 Oxo SEBACATE (PX 408)
DI-C10 Oxo AZELATE

FIGURE 11

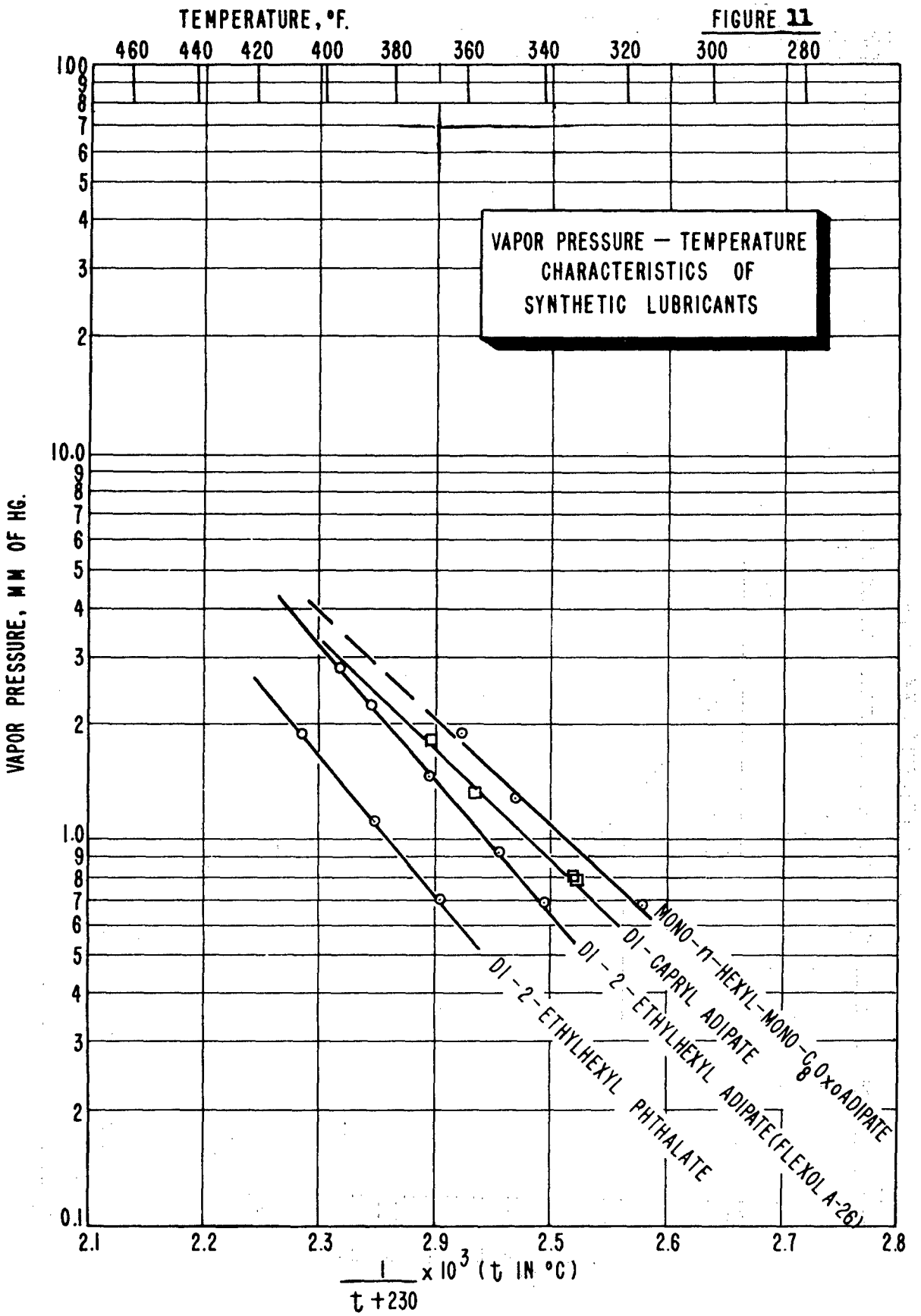

TEMPERATURE, °F.
460
440
420
400
380
360
340
320
300
280
VAPOR PRESSURE — TEMPERATURE CHARACTERISTICS OF SYNTHETIC LUBRICANTS
VAPOR PRESSURE, MM OF HG.
100
10.0
1.0
0.1
MONO-n-HEXYL-MONO-C8 OxoADIPATE
DI-CAPRYL ADIPATE
DI-2-ETHYLHEXYL ADIPATE (FLEXOL A-26)
DI-2-ETHYLHEXYL PHTHALATE
2.1
2.2
2.3
2.9
2.5
2.6
2.7
2.8
1/(t+230) x 10^3 (t IN °C)

FIGURE 12

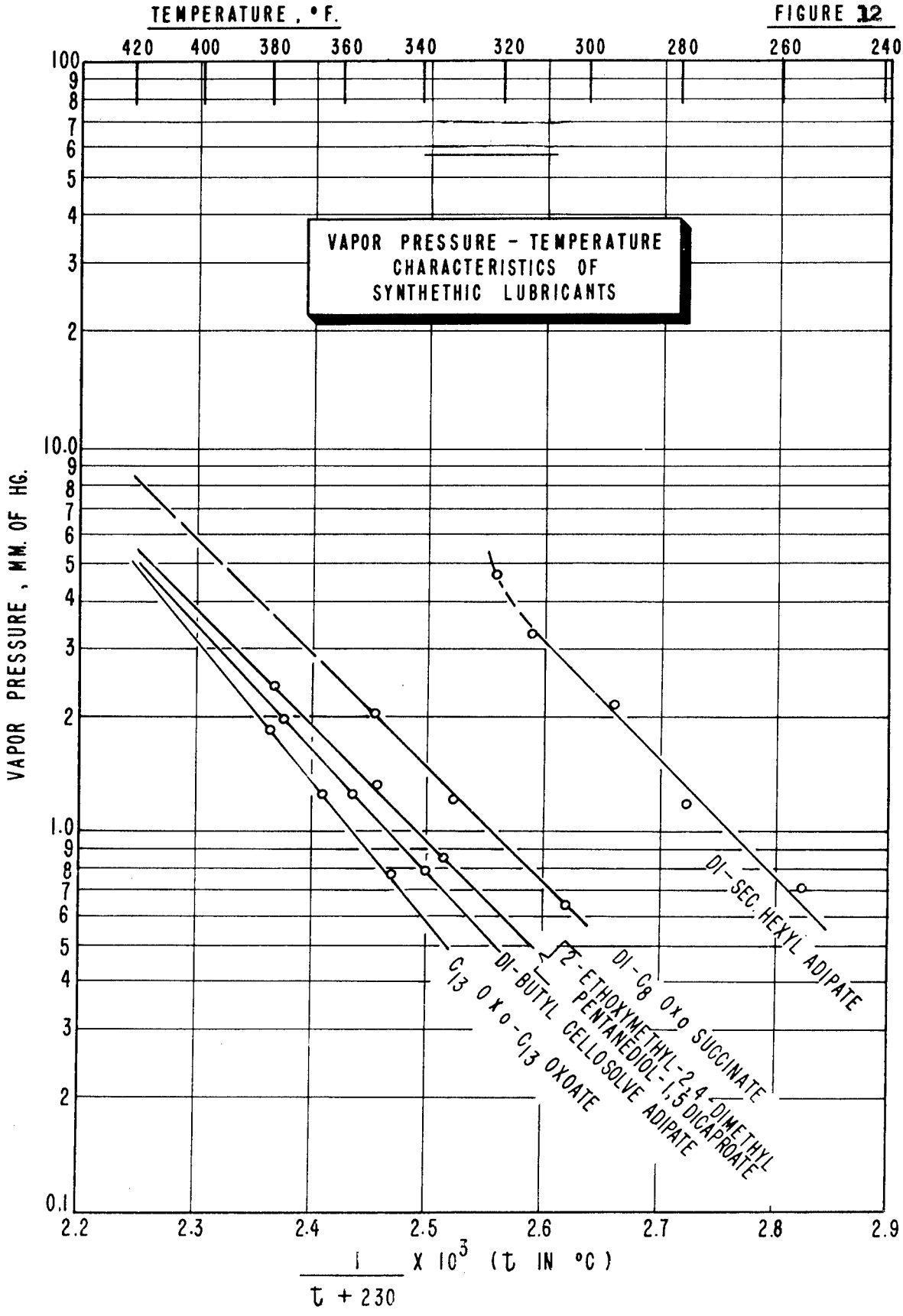

TEMPERATURE , °F.
420
400
380
360
340
320
300
280
260
240
VAPOR PRESSURE - TEMPERATURE CHARACTERISTICS OF SYNTHETHIC LUBRICANTS
VAPOR PRESSURE , MM. OF HG.
100
10.0
1.0
0.1
DI-SEC. HEXYL ADIPATE
DI-C8 OXO SUCCINATE
2-ETHOXYMETHYL-2,4-DIMETHYL PENTANEDIOL-1,5 DICAPROATE
DI-BUTYL CELLOSOLVE ADIPATE
C13 OXO-C13 OXOATE
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
1/(τ + 230) X 10^3 (τ IN °C)

FIGURE 13

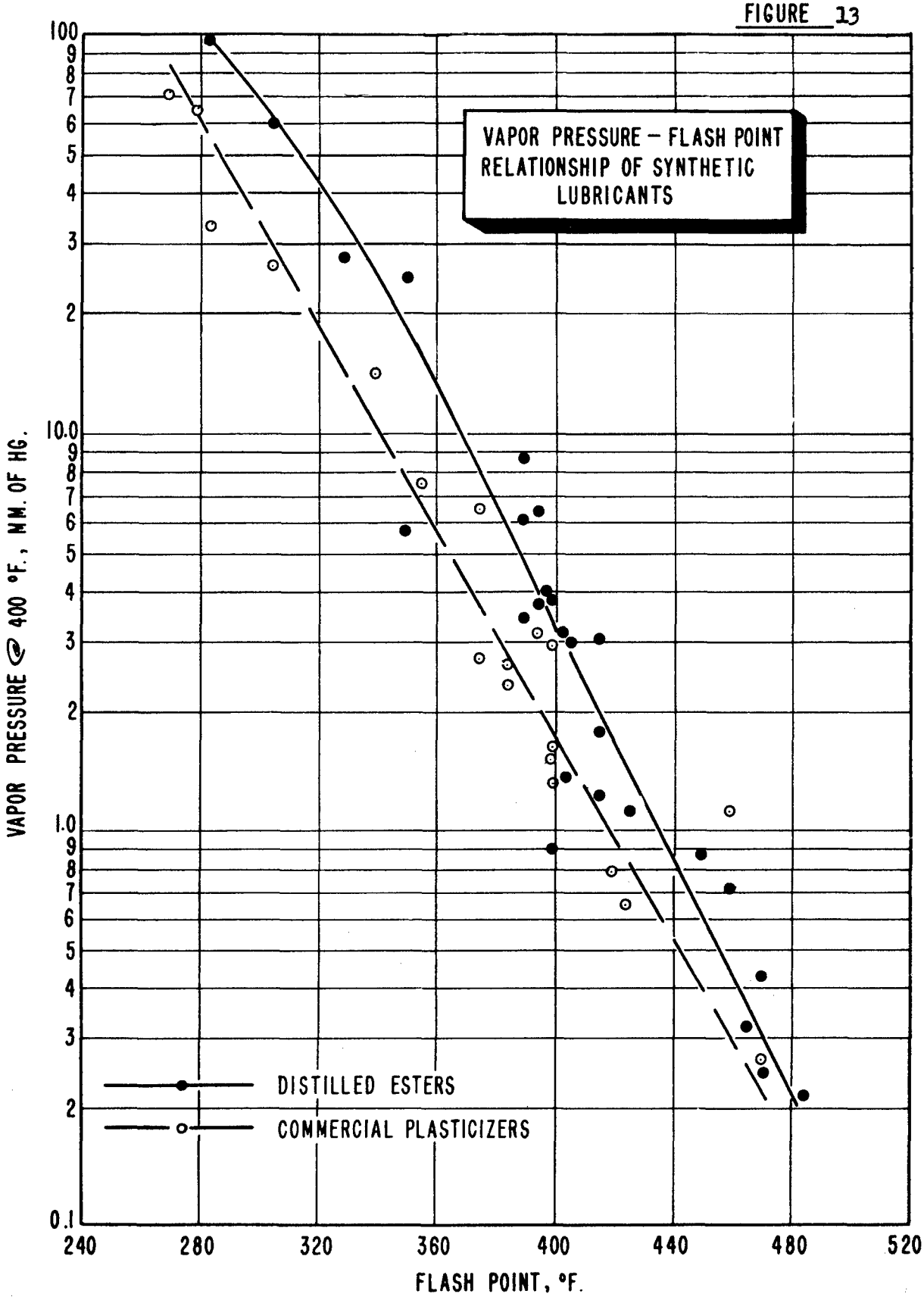

VAPOR PRESSURE – FLASH POINT RELATIONSHIP OF SYNTHETIC LUBRICANTS
VAPOR PRESSURE @ 400 °F., MM. OF HG.
100
9
8
7
6
5
4
3
2
10.0
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
0.1
240
280
320
360
400
440
480
520
FLASH POINT, °F.
DISTILLED ESTERS
COMMERCIAL PLASTICIZERS

FIGURE 14

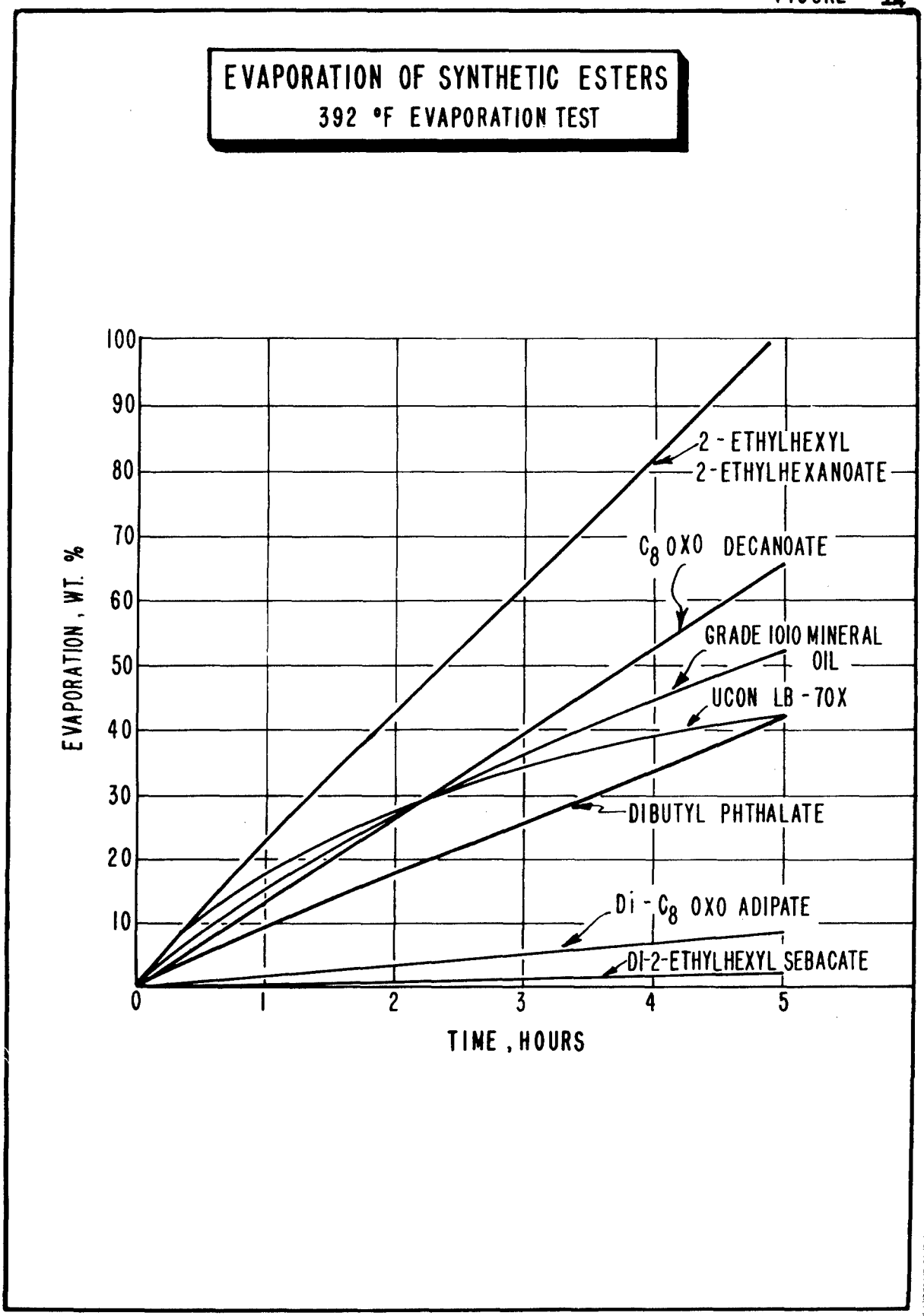

EVAPORATION OF SYNTHETIC ESTERS
392 °F EVAPORATION TEST
EVAPORATION, WT. %
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
TIME, HOURS
2-ETHYLHEXYL 2-ETHYLHEXANOATE
C_8 OXO DECANOATE
GRADE 1010 MINERAL OIL
UCON LB-70X
DIBUTYL PHTHALATE
Di-C_8 OXO ADIPATE
DI-2-ETHYLHEXYL SEBACATE

FIGURE 15

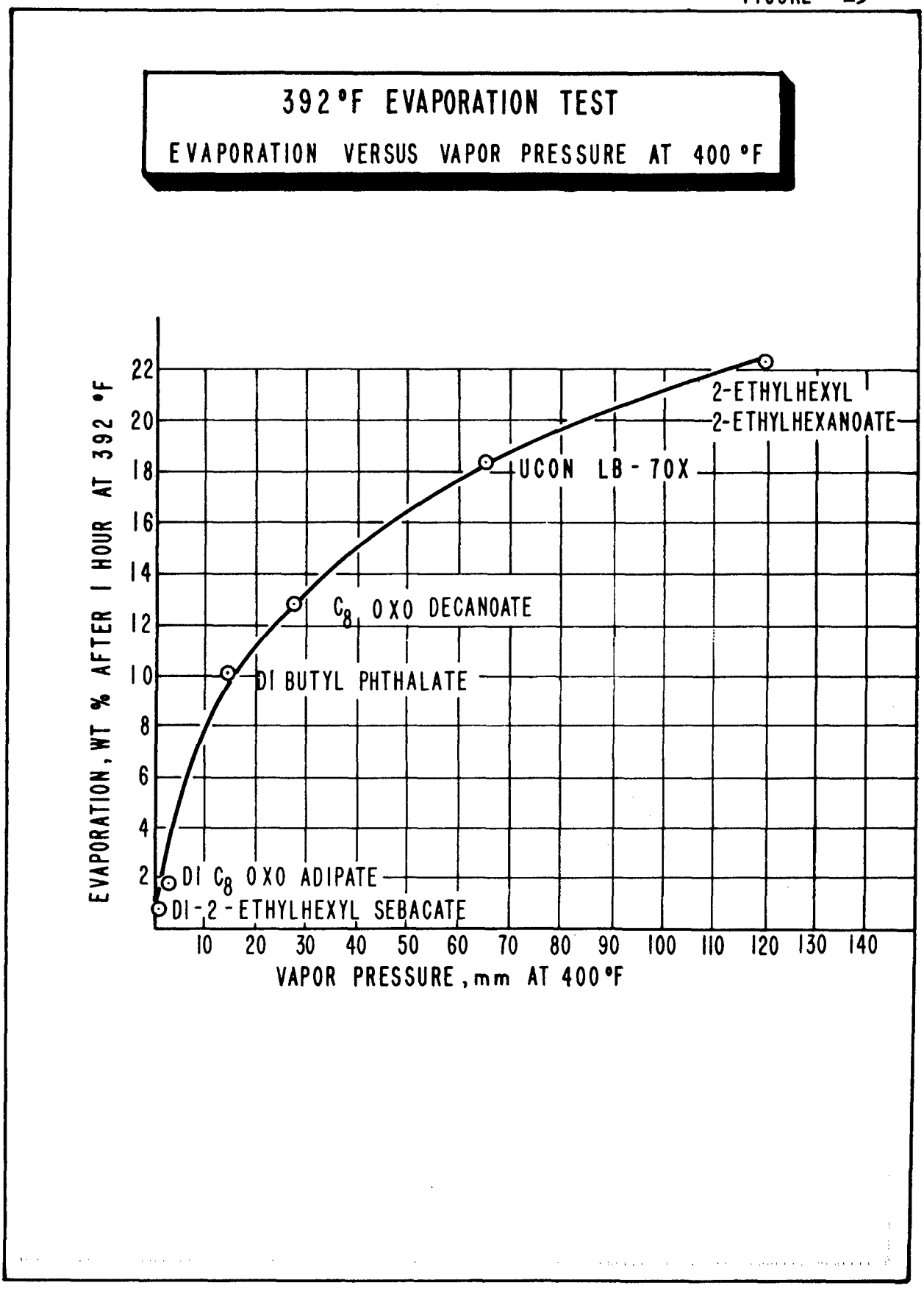

392 °F EVAPORATION TEST
EVAPORATION VERSUS VAPOR PRESSURE AT 400 °F
EVAPORATION, WT % AFTER 1 HOUR AT 392 °F
22
20
18
16
14
12
10
8
6
4
2
10 20 30 40 50 60 70 80 90 100 110 120 130 140
VAPOR PRESSURE, mm AT 400 °F
2-ETHYLHEXYL 2-ETHYLHEXANOATE
UCON LB - 70X
C8 OXO DECANOATE
DI BUTYL PHTHALATE
DI C8 OXO ADIPATE
DI-2-ETHYLHEXYL SEBACATE

FIGURE 16

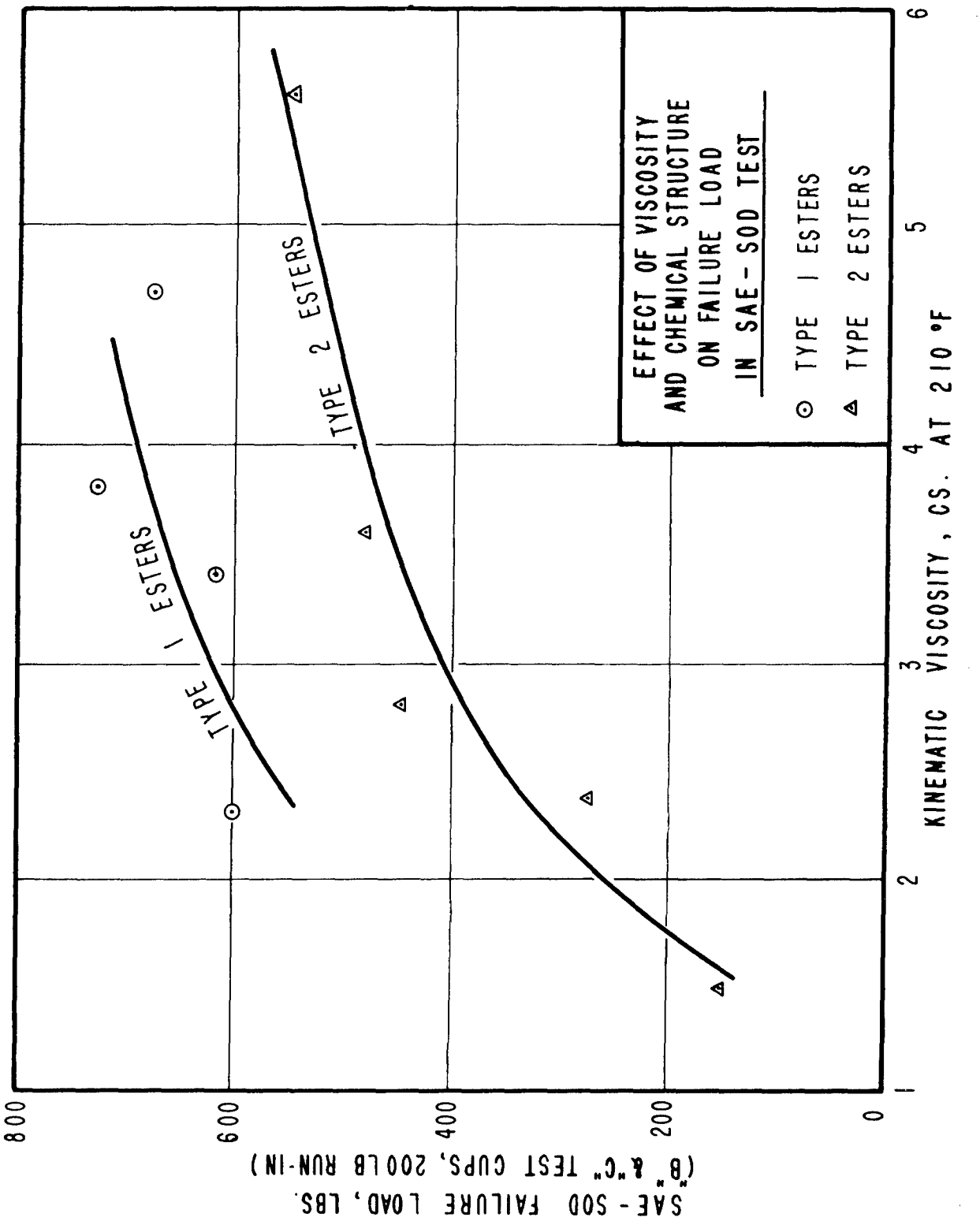

EFFECT OF VISCOSITY AND CHEMICAL STRUCTURE ON FAILURE LOAD IN SAE-SOD TEST
TYPE 1 ESTERS
TYPE 2 ESTERS
TYPE 1 ESTERS
TYPE 2 ESTERS
KINEMATIC VISCOSITY, CS. AT 210 °F
SAE-SOD FAILURE LOAD, LBS. (8" & "C" TEST CUPS, 200 LB RUN-IN)
0
200
400
600
800
1
2
3
4
5
6

FIGURE 17

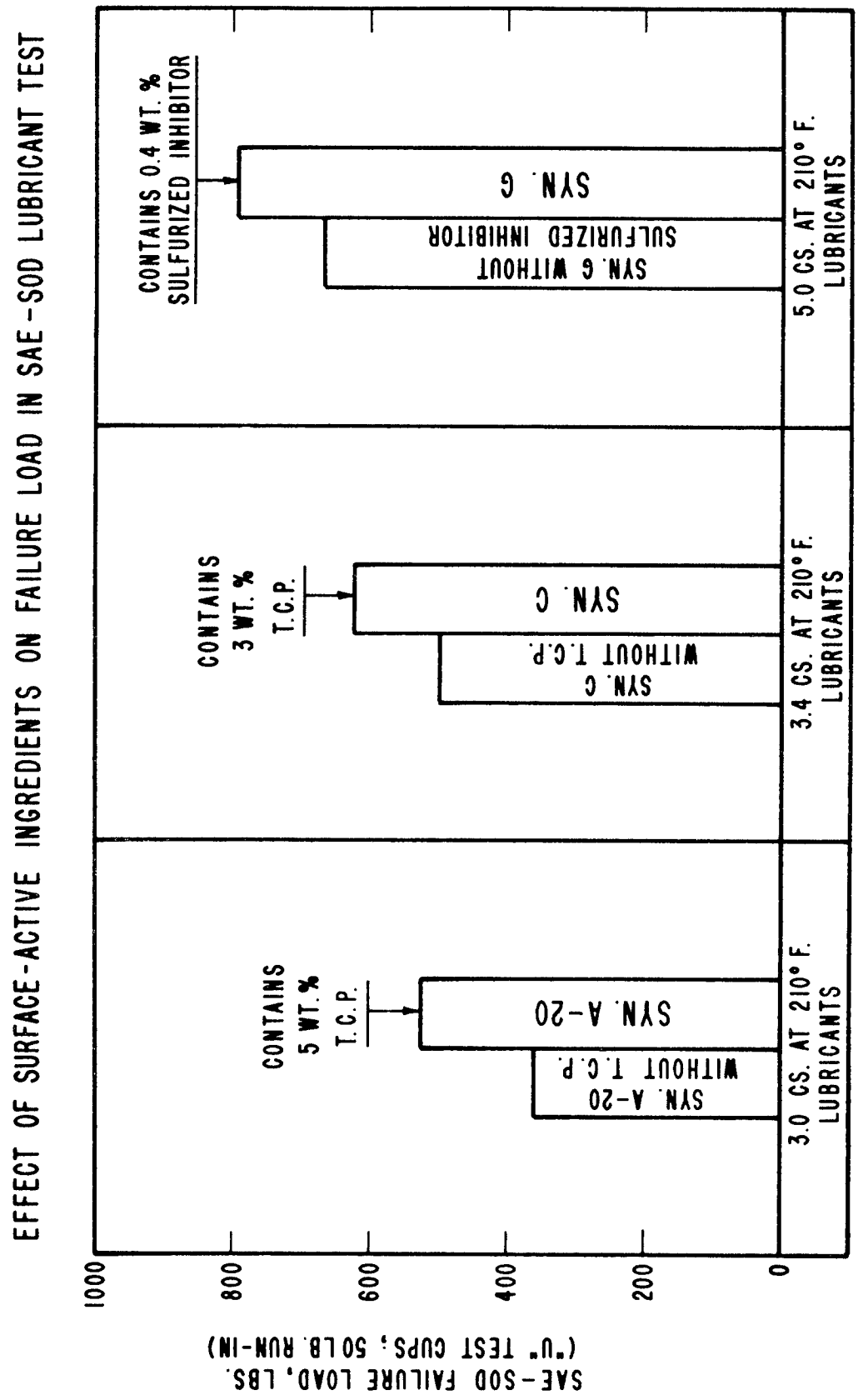
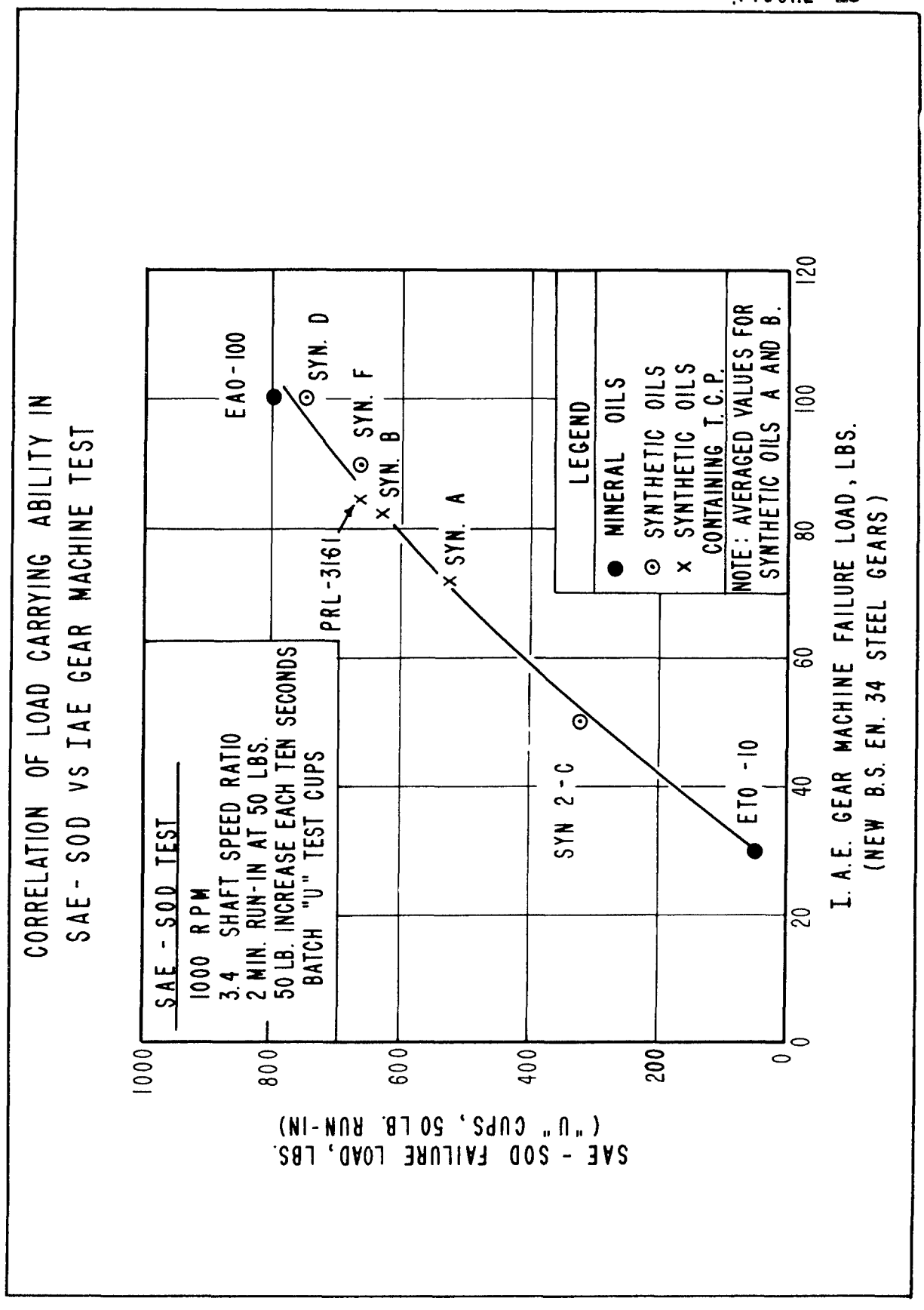

EFFECT OF SURFACE-ACTIVE INGREDIENTS ON FAILURE LOAD IN SAE-50D LUBRICANT TEST
SAE-50D FAILURE LOAD, LBS.
("U" TEST CUPS; 50 LB. RUN-IN)
1000
800
600
400
200
0
3.0 CS. AT 210° F. LUBRICANTS
SYN. A-20 WITHOUT T.C.P.
CONTAINS 5 WT.% T.C.P.
SYN. A-20
3.4 CS. AT 210° F. LUBRICANTS
SYN. C WITHOUT T.C.P.
CONTAINS 3 WT.% T.C.P.
SYN. C
5.0 CS. AT 210° F. LUBRICANTS
SYN. G WITHOUT SULFURIZED INHIBITOR
CONTAINS 0.4 WT.% SULFURIZED INHIBITOR
SYN. G

FIGURE 18


CORRELATION OF LOAD CARRYING ABILITY IN
SAE - SOD VS IAE GEAR MACHINE TEST
SAE - SOD TEST
1000 RPM
3.4 SHAFT SPEED RATIO
2 MIN. RUN-IN AT 50 LBS.
50 LB. INCREASE EACH TEN SECONDS
BATCH "U" TEST CUPS
LEGEND
MINERAL OILS
SYNTHETIC OILS
SYNTHETIC OILS CONTAINING T.C.P.
NOTE: AVERAGED VALUES FOR SYNTHETIC OILS A AND B.
EAO-100
SYN. D
SYN. F
SYN. B
SYN. A
PRL-3161
SYN 2-C
ETO -10
SAE - SOD FAILURE LOAD, LBS.
("U" CUPS, 50 LB. RUN-IN)
1000
800
600
400
200
0
0
20
40
60
80
100
120
I. A.E. GEAR MACHINE FAILURE LOAD, LBS.
(NEW B.S. EN. 34 STEEL GEARS)

CORRELATION OF FAILURE LOAD
IN SAE - SOD TEST
USING DIFFERENT LOADS DURING RUN - IN
AND TEST CUPS FROM DIFFERENT BATCHES

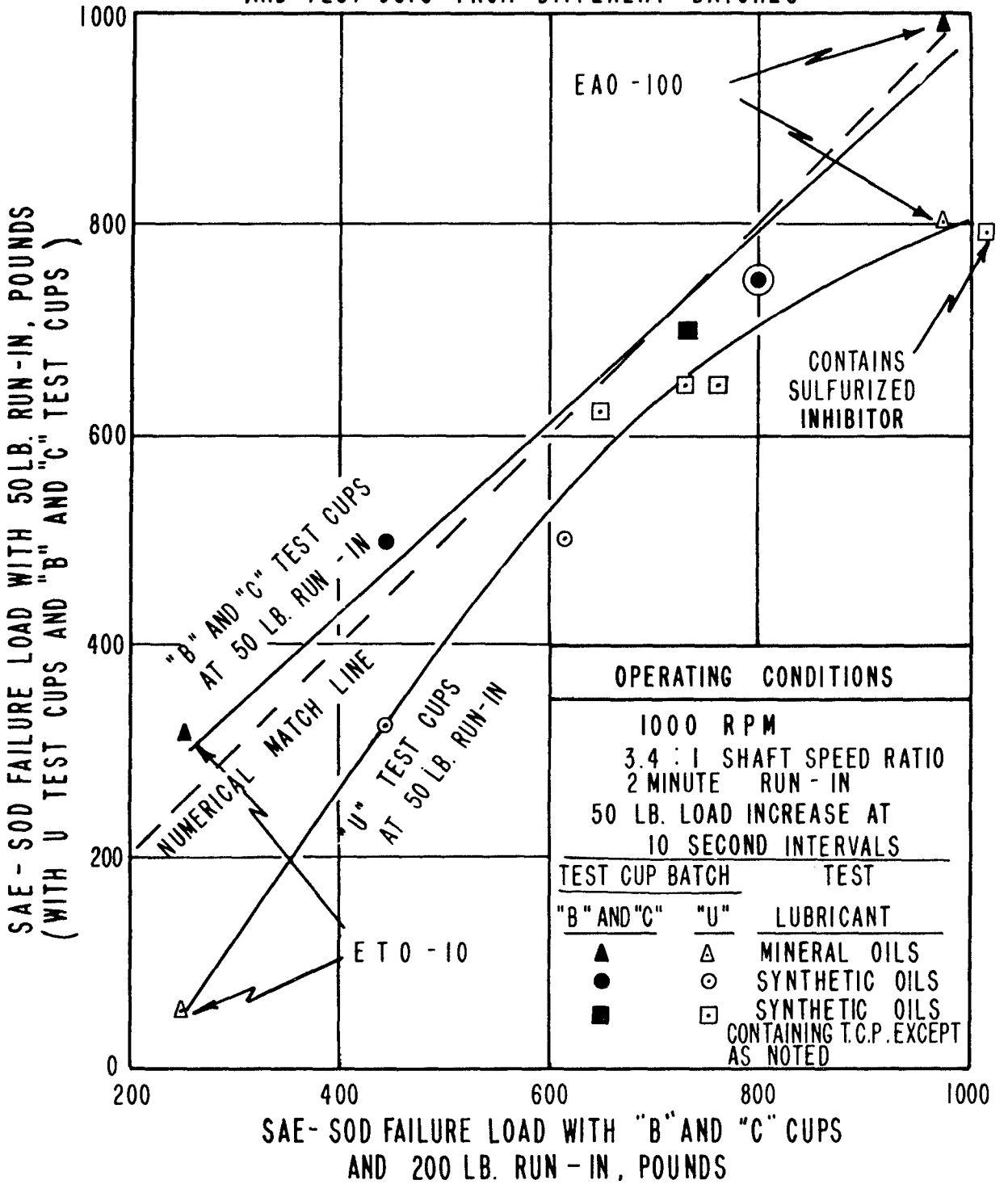


FIGURE 20

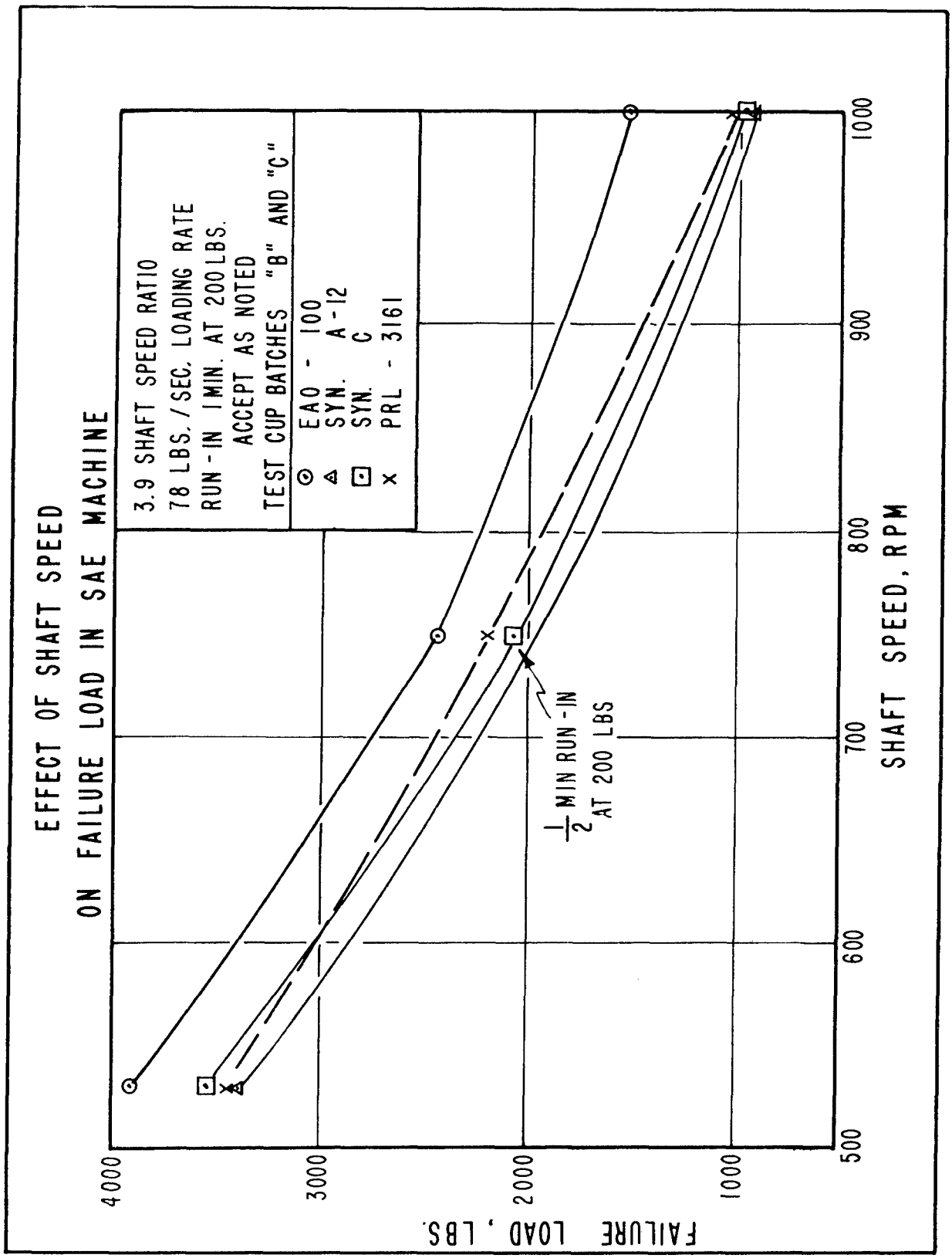

EFFECT OF SHAFT SPEED
ON FAILURE LOAD IN SAE MACHINE
3.9 SHAFT SPEED RATIO
78 LBS./SEC. LOADING RATE
RUN-IN 1 MIN. AT 200 LBS.
ACCEPT AS NOTED
TEST CUP BATCHES "B" AND "C"
EA0 - 100
SYN. A-12
SYN. C
PRL - 3161
1/2 MIN RUN-IN
AT 200 LBS
FAILURE LOAD, LBS.
4000
3000
2000
1000
500
600
700
800
900
1000
SHAFT SPEED, RPM

FIGURE 21

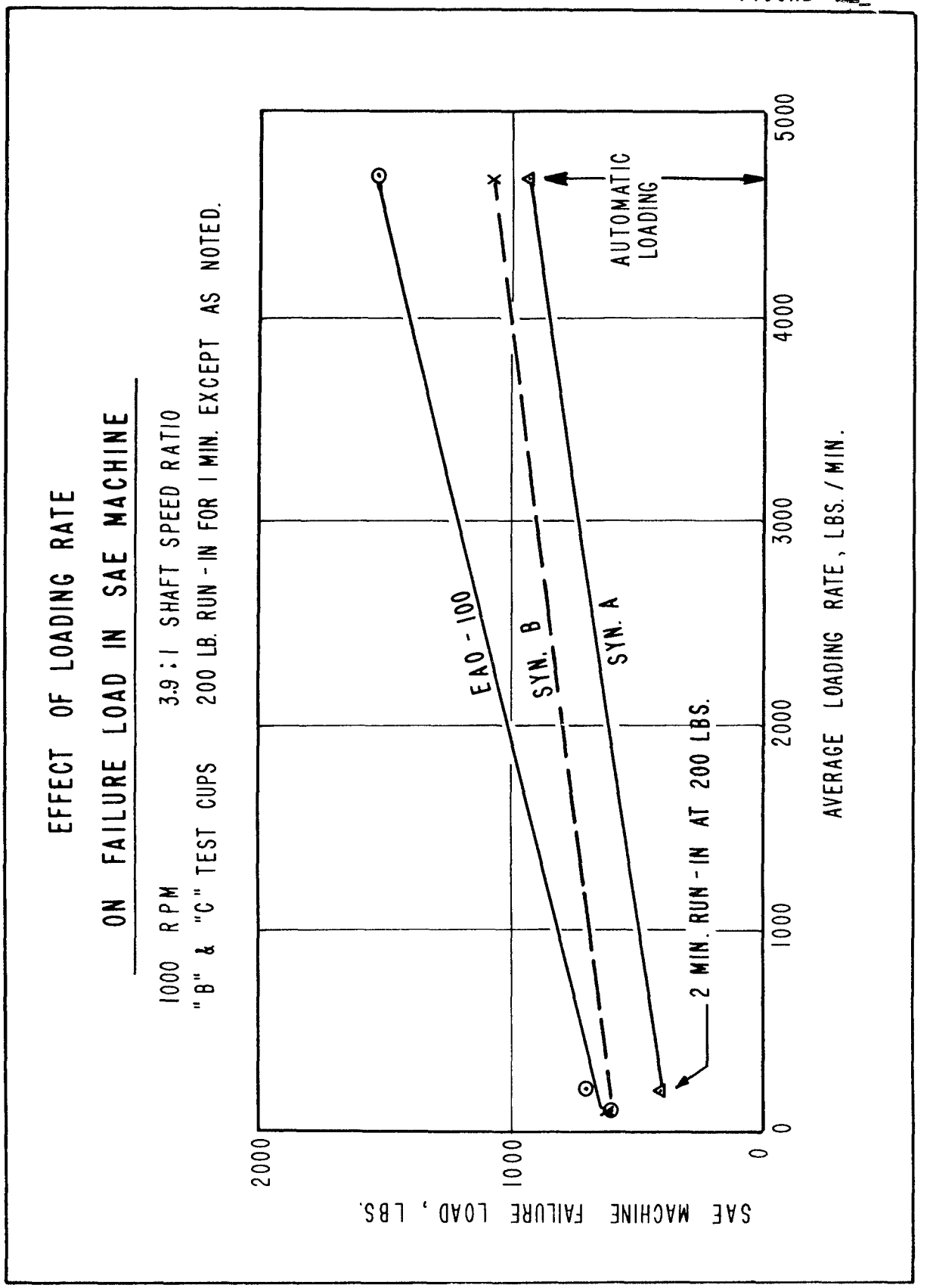

EFFECT OF LOADING RATE
ON FAILURE LOAD IN SAE MACHINE
1000 RPM 3.9 : 1 SHAFT SPEED RATIO
"B" & "C" TEST CUPS 200 LB. RUN-IN FOR 1 MIN. EXCEPT AS NOTED.
SAE MACHINE FAILURE LOAD, LBS.
2000
1000
0
AVERAGE LOADING RATE, LBS./MIN.
0
1000
2000
3000
4000
5000
AUTOMATIC LOADING
EA0-100
SYN. B
SYN. A
2 MIN. RUN-IN AT 200 LBS.

FIGURE 22

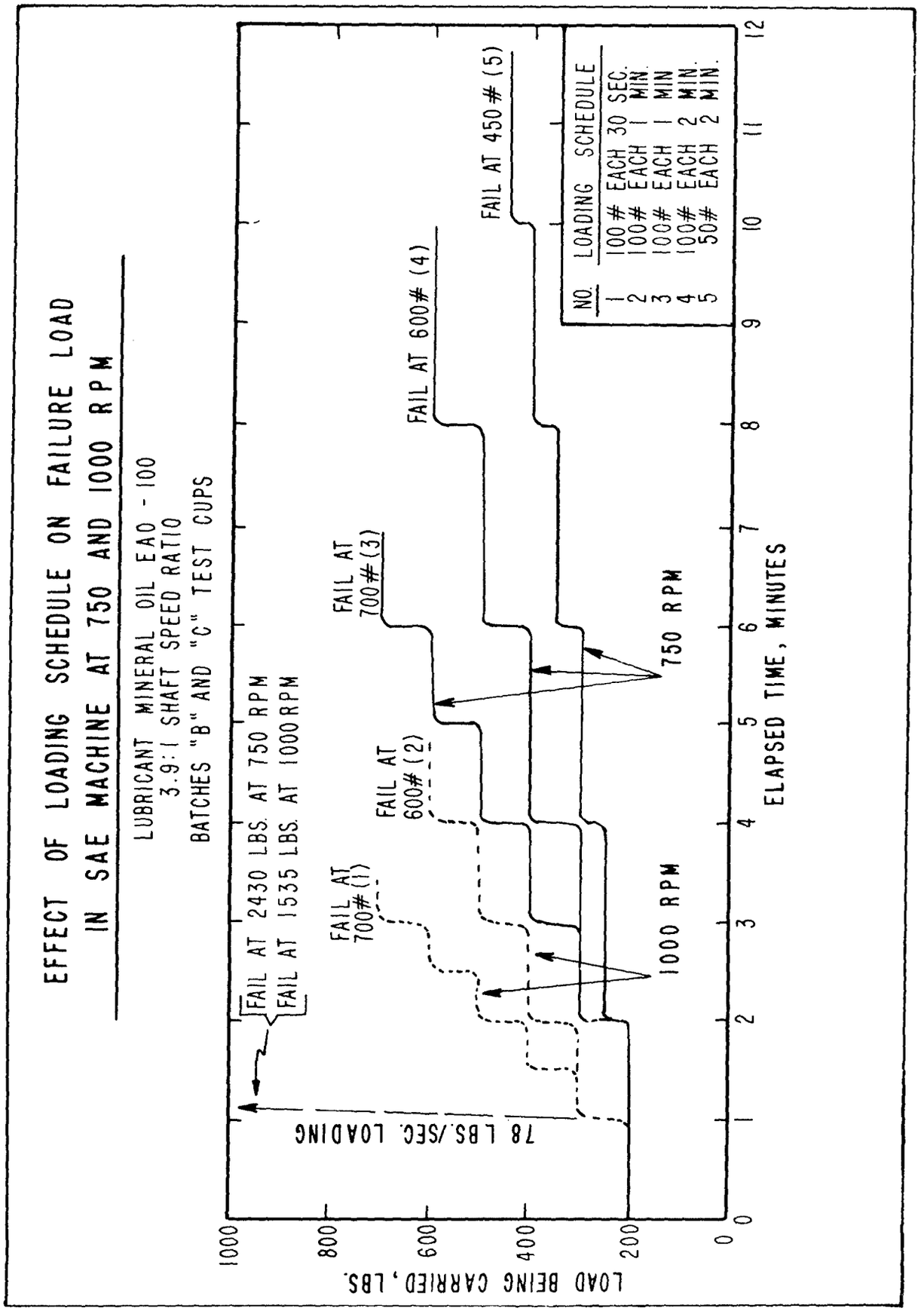

EFFECT OF LOADING SCHEDULE ON FAILURE LOAD
IN SAE MACHINE AT 750 AND 1000 RPM
LUBRICANT MINERAL OIL EAO - 100
3.9:1 SHAFT SPEED RATIO
BATCHES "B" AND "C" TEST CUPS
FAIL AT 2430 LBS. AT 750 RPM
FAIL AT 1535 LBS. AT 1000 RPM
FAIL AT 700#(1)
FAIL AT 600#(2)
FAIL AT 700#(3)
FAIL AT 600#(4)
FAIL AT 450#(5)
78 LBS./SEC. LOADING
1000 RPM
750 RPM
NO. LOADING SCHEDULE
1 100# EACH 30 SEC.
2 100# EACH 1 MIN.
3 100# EACH 1 MIN
4 100# EACH 2 MIN.
5 50# EACH 2 MIN.
LOAD BEING CARRIED, LBS.
ELAPSED TIME, MINUTES
0
200
400
600
800
1000
1
2
3
4
5
6
7
8
9
10
11
12

FIGURE 23

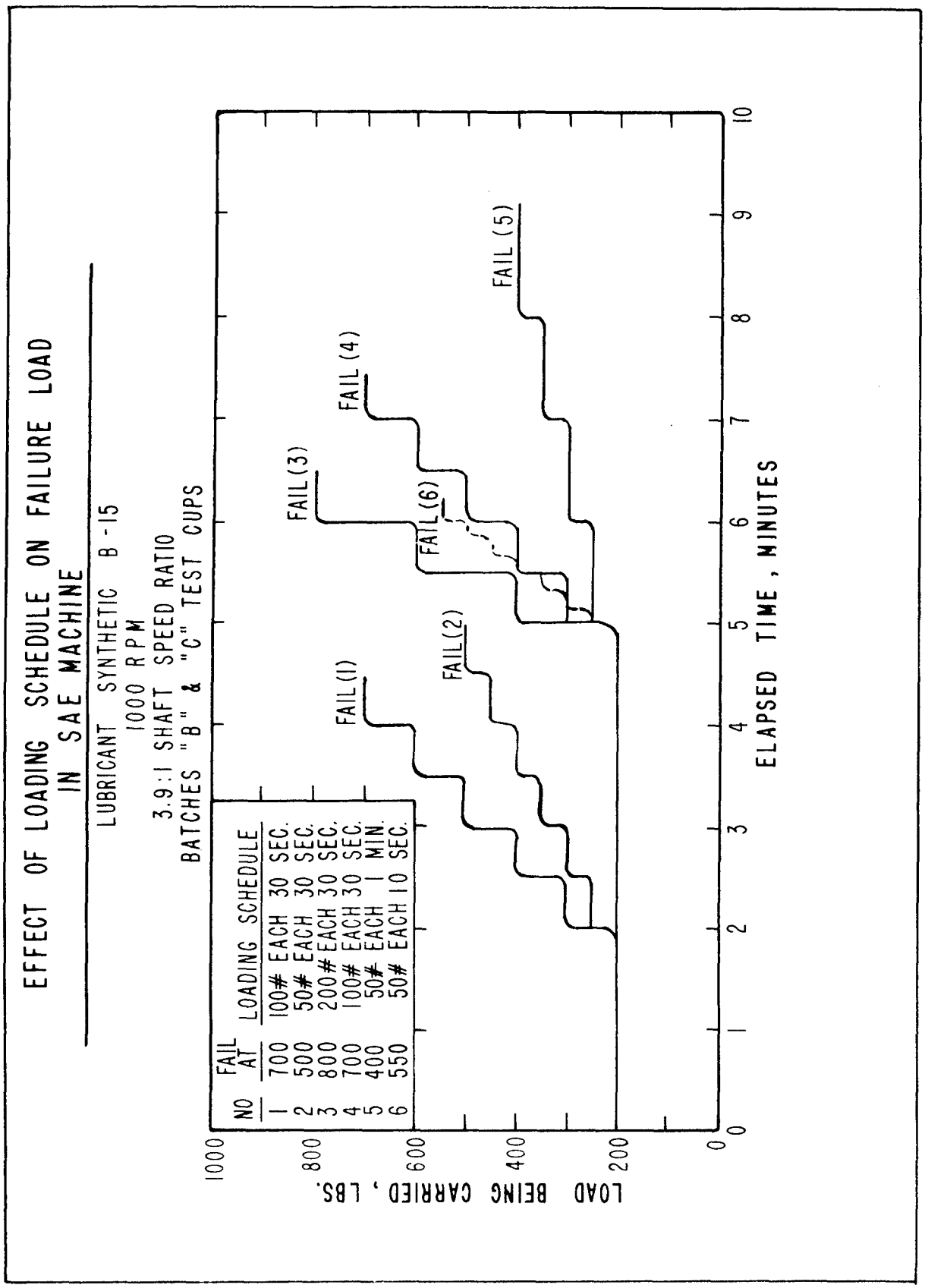

EFFECT OF LOADING SCHEDULE ON FAILURE LOAD IN SAE MACHINE
LUBRICANT SYNTHETIC B-15
1000 R P M
3.9:1 SHAFT SPEED RATIO
BATCHES "B" & "C" TEST CUPS
NO | FAIL AT | LOADING SCHEDULE
1 | 700 | 100# EACH 30 SEC.
2 | 500 | 50# EACH 30 SEC.
3 | 800 | 200# EACH 30 SEC.
4 | 700 | 100# EACH 30 SEC.
5 | 400 | 50# EACH 1 MIN.
6 | 550 | 50# EACH 10 SEC.
FAIL(1)
FAIL(2)
FAIL(3)
FAIL(4)
FAIL(5)
FAIL(6)
LOAD BEING CARRIED, LBS.
1000
800
600
400
200
0
0
1
2
3
4
5
6
7
8
9
10
ELAPSED TIME, MINUTES

FIGURE 24

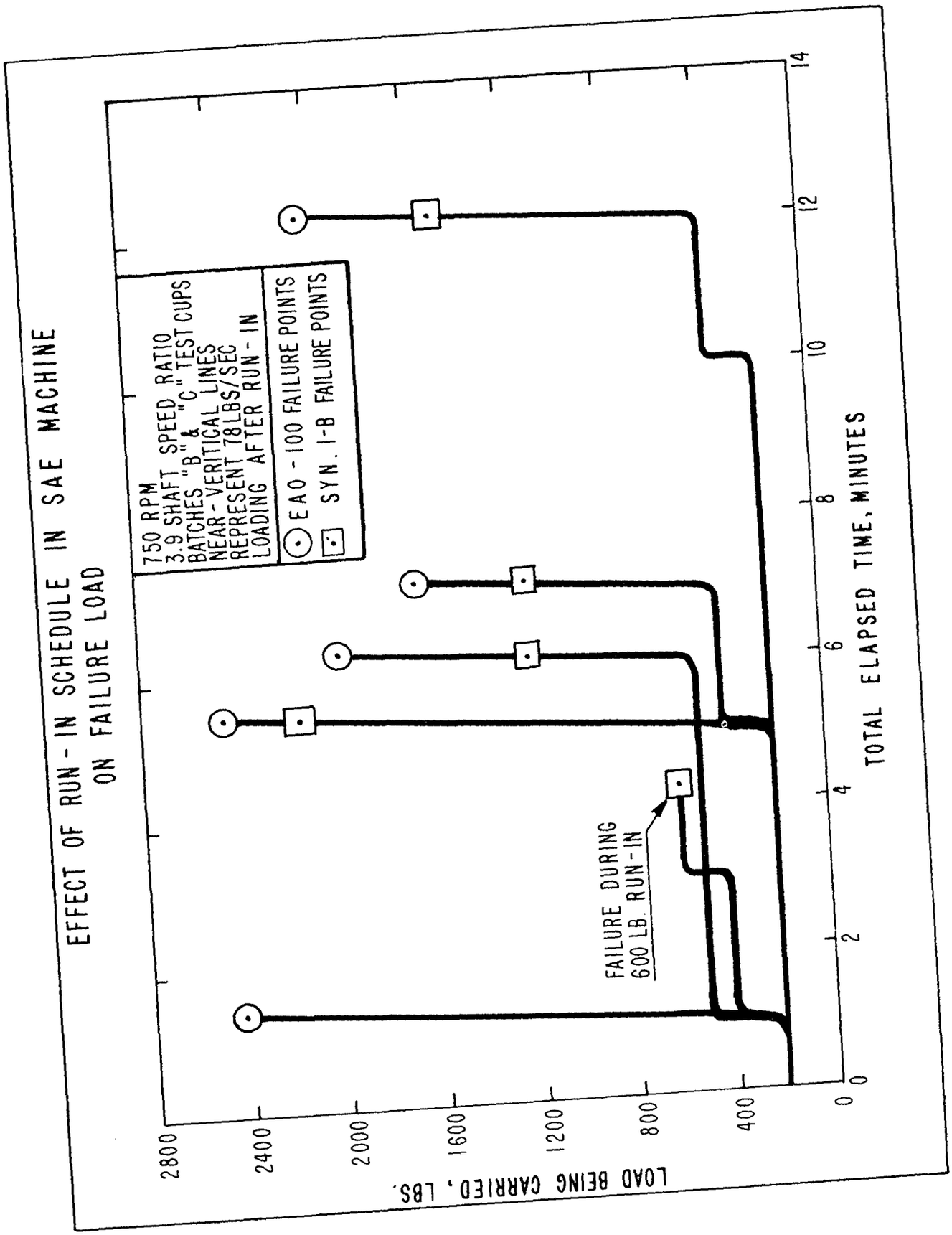

EFFECT OF RUN-IN SCHEDULE IN SAE MACHINE
ON FAILURE LOAD
750 RPM
3.9 SHAFT SPEED RATIO
BATCHES "B" & "C" TEST CUPS
NEAR-VERITICAL LINES
REPRESENT 78LBS/SEC
LOADING AFTER RUN-IN
EA O - 100 FAILURE POINTS
SYN. I-B FAILURE POINTS
FAILURE DURING
600 LB. RUN-IN
LOAD BEING CARRIED, LBS.
2800
2400
2000
1600
1200
800
400
0
0
2
4
6
8
10
12
14
TOTAL ELAPSED TIME, MINUTES

FIGURE 25

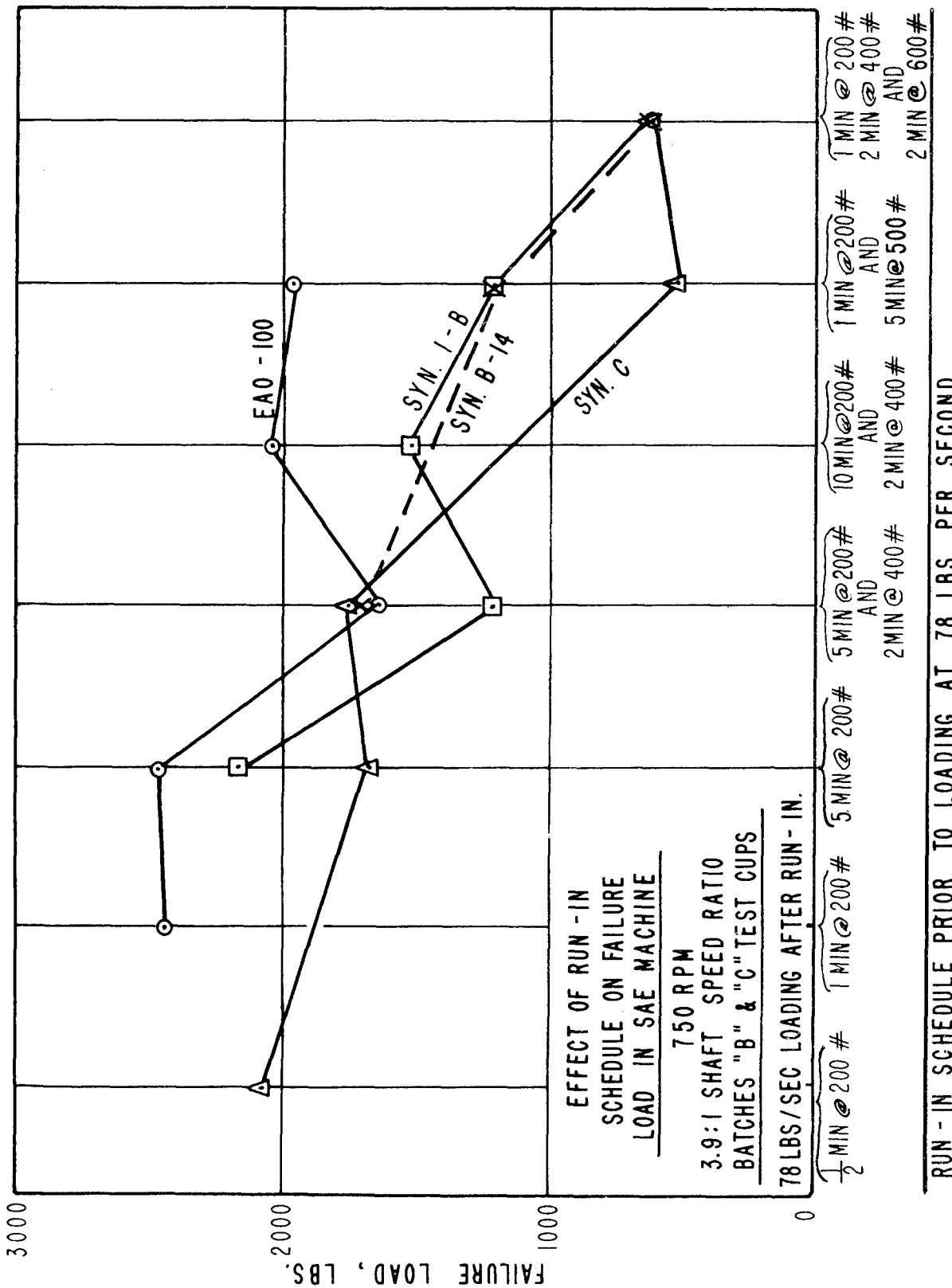
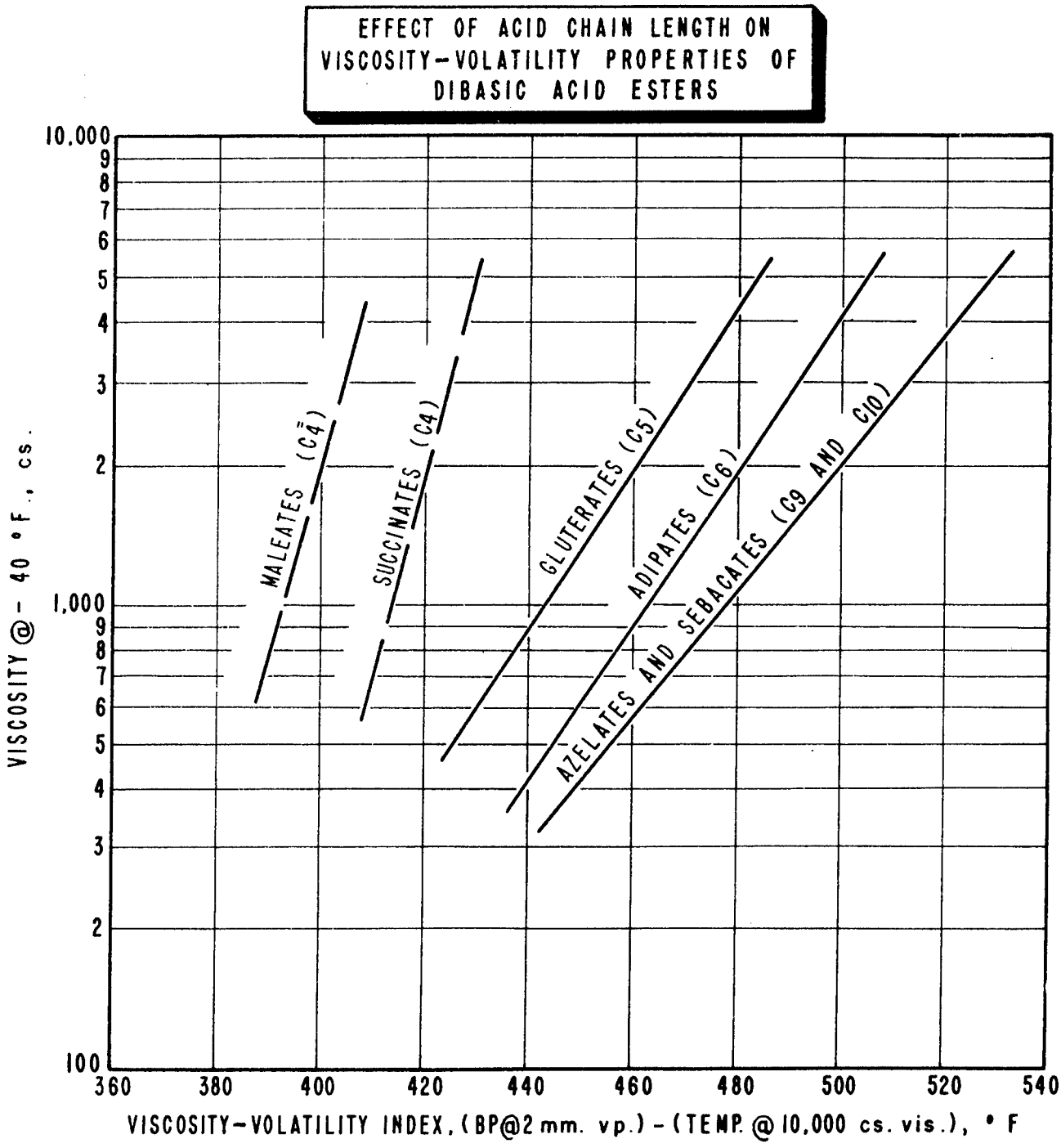

EFFECT OF RUN-IN SCHEDULE ON FAILURE LOAD IN SAE MACHINE
750 RPM
3.9:1 SHAFT SPEED RATIO
BATCHES "B" & "C" TEST CUPS
78 LBS/SEC LOADING AFTER RUN-IN.
EAO - 100
SYN. 1-B
SYN. B-14
SYN. C
FAILURE LOAD, LBS.
3000
2000
1000
0
½ MIN @ 200 #
1 MIN @ 200 #
5 MIN @ 200 #
5 MIN @ 200 # AND 2 MIN @ 400 #
10 MIN @ 200 # AND 2 MIN @ 400 #
1 MIN @ 200 # AND 5 MIN @ 500 #
1 MIN @ 200 # 2 MIN @ 400 # AND 2 MIN @ 600 #
RUN-IN SCHEDULE PRIOR TO LOADING AT 78 LBS. PER SECOND.
(LISTED IN INCREASING ORDER OF LOAD AND LENGTH OF RUN-IN)

FIGURE 26


EFFECT OF ACID CHAIN LENGTH ON VISCOSITY-VOLATILITY PROPERTIES OF DIBASIC ACID ESTERS
VISCOSITY @ - 40 °F., cs.
10,000
9
8
7
6
5
4
3
2
1,000
9
8
7
6
5
4
3
2
100
MALEATES (C4)
SUCCINATES (C4)
GLUTERATES (C5)
ADIPATES (C6)
AZELATES AND SEBACATES (C9 AND C10)
360
380
400
420
440
460
480
500
520
540
VISCOSITY-VOLATILITY INDEX, (BP@2 mm. vp.) - (TEMP. @ 10,000 cs. vis.), ° F

APPENDIX III

FIFTH QUARTERLY PROGRESS REPORT

I. DISCUSSION

Evaluation of materials suitable as synthetic lubricants has continued along the lines pursued during the first year's work under this contract. Data on several of the important lubricant properties have been expanded and are discussed in the following sections. As in the past, materials for evaluation which could not be procured from commercial suppliers were synthesized in the laboratory. Details of this phase of the work are not presented, since the laboratory preparation and treatment of esters has been discussed generally in previous reports.

A. Viscosity and Volatility Studies

The viscosity of a material at low temperatures and its volatility at high temperatures may, for some applications, determine the operating temperature range of this material as a lubricant. Mineral oils do not have particularly good viscosity-volatility properties. In this and several other respects, they do not meet the severe lubrication requirements of high power-output aircraft turbo-engines. Consequently, emphasis has shifted to synthetic lubricants for such applications. Because of its importance, the viscosity-volatility concept has received considerable attention in these synthetic lubricant studies.

Flash point determinations are subject to certain errors but are useful in describing approximate volatility levels. Flash point is likely to reflect the presence of a small quantity of volatile contaminant rather than the volatility of the lubricant itself. This point is illustrated in Appendix II Figure 5, which has been revised from earlier reports. The correlation of vapor pressure and flash point for the esters studied in this work gives some badly scattered points. This is improved, however, if we distinguish between materials procured commercially and those prepared in the laboratory. The esters prepared in the laboratory are distilled, so the volatile impurities are essentially removed. Esters sold as plasticizers undoubtedly do not receive this careful treatment. The difference between a distilled and a commercial ester does not appear in vapor pressure results, since the method used is designed to eliminate the effect of volatile impurities. However, the difference does show up in flash point determinations. The effect of these impurities has been confirmed for one commercial ester. Distillation of Plexol 244 (di-C_8 Oxo adipate) caused a significant increase in flash point but did not change the vapor pressure. This will be discussed further in Section I – E. It is this effect which causes the experimental data in Figure 5 to fit two distinct lines better than a single line. There is still considerable scattering of the points. This is believed to be largely due to the inherent inaccuracies of flash point determinations.

The vapor pressure data have been expanded to cover a number of additional esters. The vapor pressure-temperature relationships for these materials are plotted in the manner described in earlier reports in Appendix II Figures 9, 10, 11, & 12. A full description of the vapor pressure apparatus and method used is presented in Appendix IIIA. As mentioned previously, an important feature of this method is the distilling off of an initial portion of the sample to avoid errors due to volatile contaminants. This method may also lend itself to determination of the thermal stability of the sample. The vapor pressure-temperature lines in Figures 9,10, 11, & 12 are extrapolated as straight lines. However, in the several cases shown where data have been obtained at high temperatures, the lines curve upward indicating thermal break-down to more volatile materials. More data over an extended temperature range are necessary before this test can be relied on as an indication of thermal stability.

Of interest in Figure 9 are the vapor pressure data on Complex Ester B. As described in previous reports, this material was prepared in the laboratory to give the structure --

(C_8 Oxo alcohol)(adipic acid)(tripropylene glycol)
(adipic acid)(C_8 Oxo alcohol).

Vapor pressure data were also reported previously for a similar material, Complex Ester A, having a Polyethylene Glycol 200 center esterified with sebacic acid and terminated with 2-ethylhexanol. The vapor pressures of these complex esters are higher than would be predicted for molecules of this size. These results tend to confirm the suspicion that "complex esters", even when carefully synthesized in the laboratory, may be expected to contain major amounts of side-reaction products. The data summarized below indicate that the simple diester of the dibasic acid involved is likely to be formed and have considerable effect on the vapor pressure of the "complex ester".

Material	Number of Carbon Atoms	Vapor Pressure, mm. @ 400°F.
Complex Ester A	44	0.45
Di-2-ethylhexyl sebacate	26	0.78
Complex Ester B	37	3.1
Di-C_8 Oxo adipate	22	3.0

The viscosity-volatility properties of synthetic lubricants can be described conveniently with reference to an arbitrarily chosen index, used in previous work under this contract. The viscosity-volatility index is defined as the difference between the boiling point of the material at 2 mm. vapor pressure and the temperature at which it will thicken to 10,000 cs. viscosity. This temperature difference may have some practical significance as an indication of the acceptable operating temperature range possible with the lubricant. It has, however, an important shortcoming. Viscosity-volatility, as described by this temperature difference,

varies appreciably with viscosity, as shown in previous reports. Comparisons involving this index must therefore be made with some common viscosity level in mind.

Viscosity-volatility is one of the major properties in which ester lubricants have been shown to excel over mineral oils. However, it is of importance to note that esters do not represent the top of the scale with respect to this property. Studies by the California Research Corporation under Contract AF 33(038)-9831 have shown that certain tetraalkyl silicates have superior viscosity-volatility properties, as well as outstanding viscosity-temperature properties. Furthermore, they are susceptible to thickening and V.I. improvement by the addition of silicone polymers. There may be problems connected with certain other properties of silicates, but if these are solved, silicate-base materials may represent an alternate means of increasing the availability of synthetic lubricants.

Since information on organo-silicon compounds was not included in the initial literature survey conducted under this contract, data on tetra-2-ethylhexyl silicate, taken from California Research Corporation reports, are compared in the following table with similar data on a typical diester, di-2-ethylhexyl adipate, and a Grade 1010 mineral oil. All three materials have similar viscosities at 210°F., but the viscosity-volatility index is appreciably poorer for the mineral oil than for either of the synthetic materials. The superiority of the silicate over the adipate is reflected in the lower vapor pressure and lower viscosity at low temperatures. If higher viscosity is required for satisfactory lubrication, the silicate can be thickened with silicone polymer to give about the same viscosity at -65°F. as the adipate, but much higher viscosity at high temperatures. Assuming the vapor pressure of the silicate-silicone blend remains the same as the base fluid, (it may actually decrease), the viscosity-volatility index of the blend is still better than that shown by the adipate.

Viscosity-Volatility Properties

Material	Viscosity, cs. @ °F. 210	-40	-65	Vapor Pressure, mm. @ 400°F.	Viscosity-Volatility Index, °F.
MIL-O-6081 Mineral Oil, Grade 1010	2.54	2500	--	--	311
Di-2-ethylhexyl adipate	2.36	833	4920	3.1	455
Tetra-2-ethylhexyl silicate	2.36	260	1320	1.3	506
Tetra-2-ethylhexyl silicate + 10% diethyl silicone (80,000 cs. @ 77°F.)	8.69	1250	4675	(1.3)	(485)

Among carboxylic acid esters, the diesters of dibasic acids were shown in previous work to have, generally, the best viscosity-volatility properties. There are now indications that certain types of diesters may

be better than others. It appears that esters of short, straight-chain (C_4, C_5) dibasic acids have poorer viscosity-volatility characteristics than those of longer chain acids (C_6-C_{10}) when compared at a given viscosity level. Although extensive vapor pressure data on maleates ($C_4^=$), succinates (C_4), and glutarates (C_5) have not actually been obtained in this work, it is possible to estimate vapor pressures (using Appendix II Figure 13) from the flash points given in literature for several of these materials. The viscosity-volatility index can then be determined as it is for the many adipates, azelates, and sebacates evaluated in this program. When this index is plotted against viscosity at -40°F., as in Appendix I, Figure 26, the effect of acid chain length can be illustrated. Although the correlations for the maleates, succinates, and glutarates are based on just two or three points each, the data are firm enough to be directionally correct. They indicate that, for a given viscosity at -40°F., as the acid chain length of the ester increases, volatility decreases faster than low temperature viscosity increases, thus improving the viscosity-volatility indix. The effect becomes less and less pronounced, until between the C_9 and C_{10} acid chain lengths there appears to be no difference. This phenomenon is illustrated in the following table, summarizing the data in Figure 26 at the common viscosity of 1000 cs, at -40°F.

Viscosity-Volatility - Effect of Acid Chain Length

	For an Ester of 1000 cs. Viscosity at -40°F.				
	Maleates $C_4^=$	Succinates C_4	Glutarates C_5	Adipates C_6	Azelates and Sebacates C_9 and C_{10}
Viscosity-Volatility Index, °F.	391	417	443	462	477

On the basis of this theory, the development of a diester lubricant with given viscosity requirements should favor where possible the longer chain acids, (and consequently lower molecular weight alcohols), for best viscosity-volatility properties. However, as other literature data show, this can be carried too far, since esters with extremely short-chain terminal groups generally have high melting points. Moreover, esters can never be chosen on the basis of viscosity-volatility alone. Among other criteria, availability is of prime importance, and adipic, sebacic, and azelaic acids (in that order) have been shown to be potentially the most available of the dibasic acids. Fortunately, the esters of these acids, as seen above, are in the upper viscosity-volatility range.

It has been previously postulated that the viscosity-volatility properties of dibasic acid diesters could be improved through the use of structures having the optimum degree of branching. As an example, mono-C_8 Oxo-momo-n-hexyl adipate was shown to have lower viscosity but a higher flash point than di-C_8 Oxo adipate. Flash points were

the only indication of volatility available at the time. However, as pointed out previously, flash points are subject to large errors, particularly when the esters evaluated have not all been refined to the same degree. It is not surprising, therefore, that this picture is revised somewhat, in the light of more recent vapor pressure data. The following table summarizes the viscosity-volatility data which are based on vapor pressures. The viscosity-volatility index is not shown, since it is misleading when compounds of significantly different viscosity levels are compared. Di-C_8 Oxo adipate is more viscous than di-2-ethylhexyl adipate but has a slightly lower vapor pressure, so that these materials are considered to have about equivalent viscosity-volatility properties. The mixed ester, mono-C_8 Oxo-mono-n-hexyl adipate, having less branching, appears less volatile than these plasticizer-grade diesters on the basis of flash point. However, it is more volatile on the basis of vapor pressure determinations, since they do not recognize the presence of minor contaminants in the plasticizers. Also, it is insufficiently branched to prevent crystallization at -65°F. Substitution of 2-ethylbutanol for n-hexanol in the mixed ester gives enough branching to avoid low temperature difficulties. But this branching, in turn, increases the vapor pressure. Therefore, the combination of viscosity and volatility obtained with mono-C_8 Oxo-mono-2-ethylbutyl adipate actually represents little improvement over that shown by di-C_8 Oxo- or di-2-ethylhexyl adipate. In fact, this mixed ester matches almost exactly the properties of di-sec. amyl sebacate, when flash points are ignored.

Viscosity-Volatility Properties of Diesters

Compound	Viscosity, cs. @ °F. 210	-40	-65	Flash Pt., °F.	Vapor Pressure, mm. @ 400°F.
Di-2-ethylhexyl adipate	2.36	833	4920	395	3.1
Di-C_8 Oxo adipate	2.79	1040	6460	385	2.6
C_8 Oxo, n-hexyl adipate	2.34	456	Cryst.	400	3.8
C_8 Oxo, 2-ethylbutyl adipate	2.28	532	2830	390	6.0
Di-sec. amyl sebacate	2.27	528	2970	375	6.4

The above data illustrate that the structures obtained in diesters which utilize available alcohols such as C_8 Oxo or 2-ethylhexyl contain very nearly the optimum degree of branching already. It is difficult to improve their properties by the mixed ester route. These data also show that flash point may be misleading in comparisons of this sort.

Esters having polyhydric alcohol centers may also be of interest as a means for increasing the availability of synthetic lubricants. Particularly promising are the esters having polypropylene glycol centers

$$\left[HO - \overset{\overset{C}{|}}{C} - C\,(O - C - \overset{\overset{C}{|}}{C})_n - OH\right]$$ and straight chain mono-basic acid terminal

groups. Materials of this structure have properties which match those attainable with dibasic acid diesters. On the other hand, esters having polyethylene glycol centers seem to require branched chain terminal groups for satisfactorily low melting points, and these materials are markedly inferior to the dibasic acid esters. The superiority of the propylene glycol over the ethylene glycol esters is attributed to the position of the branching. It appears that the branching necessary to give low melting point glycol esters is least detrimental to viscosity-volatility and viscosity-temperature properties when it is present near the center of the molecule, rather than at the ends.

Dipropylene glycol di-n-octanoate has about the same viscosity at 210°F. as di-2-ethylhexyl adipate. Although its vapor pressure is somewhat higher, its low temperature viscosity is lower, thus giving viscosity-volatility properties which at least match those of the adipate. Triethylene glycol di-2-ethylhexanoate, having also about the same viscosity at 210°F. as these materials, has a lower vapor pressure but, because of a lower V.I., has much higher low temperature viscosity. Thus, this compound actually has poorer viscosity-volatility properties than either the adipate or the propylene glycol ester.

Viscosity-Volatility Properties - Glycol Diesters

Compound	Viscosity, cs. @ °F. 210	-40	-65	Vapor Pressure, mm. @ 400°F.
Di-2-ethylhexyl adipate	2.36	833	4920	3.1
Dipropylene glycol di-n-octanoate	2.37	647	3405	3.8
Triethylene glycol di-2-ethylhexanoate	2.35	1830	16,260	2.3

Di-C_8 Oxo adipate and tripropylene glycol di-n-octanoate show a similar comparison. In this case, the low temperature viscosities are about equivalent, but the glycol ester has a lower vapor pressure, resulting in slightly better viscosity-volatility properties. Tetraethylene glycol di-2-ethylhexanoate, again because of poor viscosity-temperature properties and the resulting high viscosity at low temperatures, is inferior to both these materials in viscosity-volatility. Evidence of excessive branching exists in tripropylene glycol di-2-ethylhexanoate. This material has very poor viscosity-temperature properties, and it is too unstable thermally to allow a satisfactory vapor pressure determination to be made.

(Data on following page)

Viscosity-Volatility Properties - Glycol Diesters

Compound	Viscosity, cs. @ °F. 210	-40	-65	Vapor Pressure, mm. @ 400°F.
Di-C_8 Oxo adipate	2.79	1040	6460	2.6
Tripropylene glycol di-n-octanoate	2.76	1040	7000	1.75
Tetraethylene glycol di-2-ethylhexanoate	2.81	2980	30,980	1.3
Tripropylene glycol di-2-ethylhexanoate	2.64	3840	42,670	unstable

The viscosity level of these glycol esters can be varied by changing the size of either the glycol or the mono-basic acid employed. However, for the best combination of properties it appears that the center of the ester should be a propylene glycol, in which case the terminal groups must be straight chain. As another example, at a lower viscosity level, a satisfactory ester can be made from tripropylene glycol and caproic acid (normal C_6). This material is only slightly inferior to di-sec. amyl sebacate.

Viscosity-Volatility Properties - Glycol Diesters

Compound	Viscosity, cs. @ °F. 210	-40	-65	Vapor Pressure, mm. @ 400°F.
Di-sec. amyl sebacate	2.27	528	2970	6.4
Tripropylene glycol di-caproate	2.13	591	3570	6.3

On the basis of these results, there would be little or no degradation in viscosity-temperature or viscosity-volatility properties if a dibasic acid ester were replaced in a lubricant formulation by a polypropylene glycol ester. There are, of course, other properties to be considered before these materials can be regarded as an alternate supply source in the synthetic lubricant field. However, one expected drawback may be less serious than anticipated. The thermal stability of the propylene glycol esters, viewed with some doubt because of their secondary hydroxyl linkages, is surprisingly good up to 392°F. This will be discussed further in Section I – D. Other important properties of these esters have not yet been thoroughly evaluated, but serious deficiencies are not expected.

B. Low Temperature Studies

Low temperature viscosity and the persistance of the liquid state at low temperatures are important properties of a synthetic lubricant, if it is to perform satisfactorily in cold climates or at high altitude. Evaluation of the latter of these properties is difficult because of the tendency of esters to super-cool (sometimes!). Pour point determinations are therefore not reliable, and melting points, of course, can only be determined when the ester can be induced to crystallize. Methods for freezing these materials are being investigated. However, some esters have frozen when stored at -94°F. for 15 hours. Melting points have been obtained on these compounds and are presented along with some other low temperature properties in Appendix II Table 42.

Because of the limited nature of the melting point data available to date, specific conclusions regarding the effect of ester structure on this property are not possible. Several generalizations have already been made in previous reports. It was found that esters utilizing C_9 Oxo alcohol, produced by the Oxo process from diisobutylene (giving predominantly 3,5,5-trimethylhexanol), are generally high melting. The same is true of secondary alcohols, such as sec. hexyl or capryl alcohol, although di-sec. amyl sebacate is quite low melting. With reference to some melting point data reported in the literature, one further generalization is possible. The effect of ether-oxygen linkages in lowering the melting point can be seen in the table below. Di-butyl Cellosolve adipate, a straight chain diester containing two ether-oxygen atoms and the same number of carbon atoms as di-n-butyl sebacate, has a significantly lower melting point than the sebacate. Similarly, tetraethylene glycol di-caproate is better than butanediol-1,4-di-n-octanoate. Other structural differences in these compounds may also account for some of the difference in melting points, but the ether-oxygen atoms are believed to be chiefly responsible.

Melting Points

Compound	Number of Carbon Atoms	Melting Point, °F.
Di-n-butyl sebacate*	18	+20
Di-butyl Cellosolve adipate	18	- 3
Butanediol-1,4-di-n-octanoate*	20	+55
Tetraethylene glycol di-caproate	20	+ 1

Along with low melting points, it is desirable for synthetic lubricants to exhibit low viscosities at low temperatures. This characteristic is, of course, involved in the viscosity-temperature and viscosity-volatility properties of the lubricant. However, another factor may be

important. Certain esters have been shown in previous reports to deviate noticeably at low temperatures from the linear viscosity-temperature relationship usually obtained on an ASTM chart for other esters. Generally speaking, diesters containing ether-oxygen linkages and diesters produced from Oxo alcohols give undesirable upward curvature at low temperatures; "dense center" materials such as phthalates or pentaerythritol esters give downward curvature, a desirable deviation. It is felt that a study of the possible causes of this phenomenon may lead to a method for improving the properties of those esters showing an upward hook.

The change in ASTM Slope from 210/100°F. to 210/-40°F. is indicative of the magnitude of deviation from a linear ASTM viscosity-temperature relationship. Slope changes for a number of esters are presented in Appendix II, Table 42. There was reason to believe that the viscosity hook might be related to the separation of contaminants as a second phase at low temperatures. Cloud points were therefore obtained on these esters and are also presented in Table 42. However, the cloud point data do not follow any understandable pattern, and do not correlate with change in ASTM Slope values. Some of these cloud points undoubtedly reflect the presence of moisture. No attempt was made to dry the esters, since any moisture was also present during the viscosity determinations. Refinement of a sample of di-C8 Oxo adipate (Plexol 244) by stripping or distillation seems to cause erratic changes in cloud point, but does not affect the increase in ASTM Slope. Based on these results, it does not appear that the low temperature viscosity deviations are caused simply by the existance of a contaminant or second phase at low temperatures.

There does appear to be a rough correlation between the change in ASTM Slope and the melting point of the ester. Although the data are not firm, high melting esters generally seem to have the largest Slope changes, while the low melting materials have more nearly linear ASTM viscosity-temperature relationships. This suggests supercooling as a factor. In theory, however, truly supercooled liquids are believed to follow the same principles of flow as normal liquids, i.e., those at temperatures above their melting points. No satisfactory explanation can be given for this relationship of Slope change and melting point. It may be due merely to chance. It is illustrated in the following table, where data, taken from Table 42, on two similar diesters of sebacic acid and two similar glycol esters are compared. The low melting sebacate and glycol ester show negligible change in Slope, while the higher melting esters exhibit considerable upward curvature. The high melting point of tripropylene glycol di-n-octanoate is particularly difficult to understand, since branching and ether-oxygen atoms are both present in this molecule. But compared with the low melting dipropylene glycol ester of the same acid, it constitutes a striking, though possibly coincidental, example of the general relationship observed between melting point and change in ASTM Slope.

(Data on following page)

Low Temperature Properties

Compound	Melting Point, °F.	ASTM Slope Values 210/100°F.	210/-40°F.	Difference
Di-sec. amyl sebacate	-108	0.756	0.755	-0.001
Di-sec. hexyl sebacate	+10	0.732	0.761	+0.029
Dipropylene glycol di-n-octanoate	-100	0.759	0.756	-0.003
Tripropylene glycol di-n-octanoate	+7	0.725	0.740	+0.015

C. Oxidation Stability Studies

Previous work has shown phenothiazine to be a satisfactory oxidation inhibitor for use in a study of the oxidation stability of various esters. For this evaluation a modification of the MIL-L-6387 Oxidation/Corrosion Stability Test (347°F.) is being employed. The neutralization number of the test sample is determined periodically until a sharp increase in acidity occurs. This indicates the stable life of the material under severe oxidizing conditions. A concentration of 0.3 wt. % phenothiazine has been chosen for the study of various esters in this test. This concentration appears to give a stable life level at which differences can be shown, but does not prolong the tests to an inconvenient length.

A very important factor which must be considered in this work is the effect of impurities on oxidation stability. Data reported by the Petroleum Refining Laboratory of the Pennsylvania State College show that a distilled grade of di-2-ethylhexyl sebacate (inhibited with phenothiazine) is more stable to oxidation than the less pure plasticizer grade. This is confirmed by the results shown in the following table, taken from Appendix II, Table 59. Differences in purity is also the likely reason for the variation in stable life (duplicate determinations) between two batches of di-C_8 Oxo adipate (Plexol 244). An attempt was made to remove impurities from this commercial ester by conventional means to learn if the oxidation stability could be thus improved. Unfortunately, before the difference between the two batches of this ester was known, the better of the two was chosen for this study. In this case, stripping, distilling, or charcoal treating did not improve stability. The stable lives of the treated samples appear somewhat lower than the untreated ester, but these variations may be within the repeatability range of the test. Not enough of these tests have yet been run to establish firmly what this repeatability range might be.

Oxidation Stability at 347°F.

(Each Ester Inhibited with 0.3 Wt. % Phenothiazine)

Compound	Refinement	Average Stable Life, Hrs.
Di-2-ethylhexyl sebacate (Plexol 201)	plasticizer grade	65
Di-2-ethylhexyl sebacate (Plexol 201W)	distilled grade	87
Di-C_8 Oxo adipate (Plexol 244-Batch I)	plasticizer grade	45
Di-C_8 Oxo adipate (Plexol 244-Batch II)	plasticizer grade	85
" " " " " " " "	stripped	75
" " " " " " " "	distilled	72
" " " " " " " "	distilled + charcoal treated	80

Data for several other esters procured from commercial suppliers are also presented in Appendix II, Table 59. However, comparisons based on these results are not reliable, since significant differences in the purities of these materials may exist. It is interesting, however, that an ester produced from a secondary alcohol (di-sec. amyl sebacate) appears reasonably stable to oxidation, at least at this temperature. It is believed that a comprehensive study of the oxidation stability of various ester types will require that each material tested be first given a common treatment.

D. Thermal Stability Studies

A variety of esters have been evaluated in a thermal stability test, in which the sample is held at 392°F. for 48 hours in a nitrogen atmosphere. The change in neutralization number occuring during the test is indicative of the extent to which the molecule has been thermally decomposed. Originally, viscosity change was also measured in this test. However, the change in viscosity was generally quite small, except for large polymers, which showed substantial viscosity decreases due to thermal break-down. The most recent thermal stability data are shown in Appendix II, Table 51. Neutralization number increases have been converted to % decomposition by assuming that any increase in acidity is due to the formation of the acid which was originally esterified. On this basis, 100% decomposition would represent complete break-down to give the stoichiometric quantity of the original acid. These assumptions most likely do not depict what actually happens, but they do provide a consistent basis for comparison of esters having known molecular weights.

As in the case of oxidation stability, the quality or purity of the ester may have a marked effect on its thermal stability. Several different samples of the same two diesters, di-C_8 Oxo adipate and di-C_8 Oxo sebacate, have been evaluated. As shown by the following data taken from Table 51, they may vary considerably in their resistance to decomposition at 392°F. Presumably the instability in certain cases is caused by some impurity with which the manufacturers need not be concerned when producing diesters for plasticizer applications. These impurities do not appear to show up simply as residual acidity in the ester, since decomposition does not line up with the initial neutralization numbers obtained on these materials.

Thermal Stability Studies

Compound	Initial Neut. No., mg. KOH/gm.	Neut. No. Increase, mg. KOH/gm.	Decomposition, %
Di-C_8 Oxo adipate			
Plexol 244 (Batch I)	0.35	0.17	0.06
Plexol 244 (Batch II)	0.14	0.09	0.03
Hardesty	0.23	1.43	0.47
PX-208	0.33	5.43	1.8
Di-C_8 Oxo sebacate			
Hardesty (Batch I)	0.70	1.07	0.41
Hardesty (Batch II)	0.19	4.69	1.8
PX-408	0.40	5.86	2.2

As in the case of oxidation stability, stripping, distilling, or charcoal treating did not improve the thermal stability of Plexol 244 (Batch II), which was already quite good. This particular ester, as pointed out before, was an unfortunate choice for these impurity removal studies. With the data now on hand, it appears that more information will be obtained by studying the effect of impurity removal using an ester such as the particular sample of PX-408, a material which appears deficient in both oxidation and thermal stability in its present form.

Even when the effects of impurities are taken into account, dibasic acid esters produced from secondary alcohols show a tendency toward less stability than the primary alcohol counterparts. Although the repeatability of this thermal stability test has not been adequately determined, the data shown in Table 51 indicate that esters of sec. amyl, sec. hexyl, and capryl (sec. octyl) alcohols undergo considerable degradation. Di-capryl adipate appears particularly bad, giving nearly 14% decomposition. It is surprising, therefore, that certain esters having polypropylene glycol centers seem quite stable, despite the secondary hydroxyl linkages. Several thermal stability tests have been run on each of the propylene glycol esters synthesized in this work. Results are shown in Table 51. When 2-ethylhexanoic acid is used, the resulting ester has borderline stability. This has been confirmed in vapor pressure determinations, where this excessively branched type of ester appears to decompose readily. However, when straight chain mono-basic acids (caproic, n-octanoic) are employed, the resulting propylene glycol esters have consistently shown good thermal stability. In fact, these esters have, in several tests, shown a slight decrease in acidity. The reason for this is not known, but it may indicate a thermal reaction which runs to completion rather than one which produces acidic materials that, in turn, may catalyze further decomposition.

E. Effect of Impurities on Ester Properties

Results of this study, discussed separately in preceding sections of this report, are summarized in Appendix II, Table 60. Attempts were made to purify a sample of di-C_8 Oxo adipate (Plexol 244) by conventional means to determine what effect purity might have on its properties. Three methods of refinement were used. One sample was stripped under vacuum to remove the first 5%; another was distilled at reduced pressure to obtain a 5-95% heart cut; the third consisted of a 5-95% heart cut which was treated with animal charcoal. The charcoal treatment has been found quite efficient in reducing residual acidity of esters, and it was desired to learn if it might provide some other benefits.

As disclosed by recent results, the particular sample of ester chosen for this study was already quite stable in the untreated form. Refinement therefore made no significant improvement in stability. This is not believed to be a true indication of what effect purification might have on the stability of an ester which is initially poor in this respect. Treatment of Plexol 244 by these means does result in one change in its properties which bears remembering. As shown in Table 60, stripping or distilling this material increases its flash point from about 380°F. to over 400°F. However, the vapor pressure remains essentially the same. This indicates that the vapor pressure method used in this work succeeds reasonably well in minimizing the effects of the volatile contaminants which cause the flash point lowering.

APPENDIX III A

METHOD FOR VAPOR PRESSURE DETERMINATION

APPENDIX III A

A. Description of Vapor Pressure Apparatus and Method

1. Apparatus

The general appearance of the apparatus is shown in Figure 27. Details of the still and related parts are given in Figure 28.

The specially designed still head containing a built-in automanometer is patterned after the design recommended by Hickman and Weyert(1) for the accurate distillation of samples ranging from 5 to 100 grams. The openings to the bulbs of the column are relatively large to minimize pressure drop of entering vapor, to allow excellent drainage, and to remove superheated vapors. The automanometer operates directly from the wall of the expansion of the column. The still is connected to a receiver, a cold trap, a manometer, and a surge tank which in turn is connected by stopcocks to a vacuum pump and to a supply of dry nitrogen. The glass tubing connecting the various parts of the apparatus is constructed from 20 mm. tubing.

The thermometric system consists of a calibrated iron-constantan thermocouple, a type K potentiometer, and a suspension type galvanometer.

The pressure of the permanent gas is measured by means of a three-scale McLeod type gauge (Todd Universal Vacuum Gauge obtained from Todd Scientific Company, Springfield, Pennsylvania).

The Dubrovin gauge, while not an essential part of the apparatus, is useful as a continuous indication of the pressure of the system and as an aid while bleeding in the proper amount of nitrogen into the system.

The still is heated with a Glascol heater. Excessive bumping is prevented by means of a magnetic stirrer.

For boiling points below 100°C., merely insulating the upper part of the still pot and column with asbestos is sufficient to minimize condensation so that reflux and fractionation may be prevented. For temperatures above 100°C., heat should be applied to the outside of the upper part of the still pot and column in an amount equal to that lost by radiation.

2. Procedure

The apparatus is assembled as shown in Figures 27 & 28. The thermocouple is mounted as shown in Figure 28. The glass sheath should be coincidental with the center line of the column, and the tip of the encased thermocouple should extend to the same level as the lower outlet of the automanometer. All stopcocks, ball joints and standard tapered

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(1) J. Am. Chem. Soc., 52, 4714, (1930).

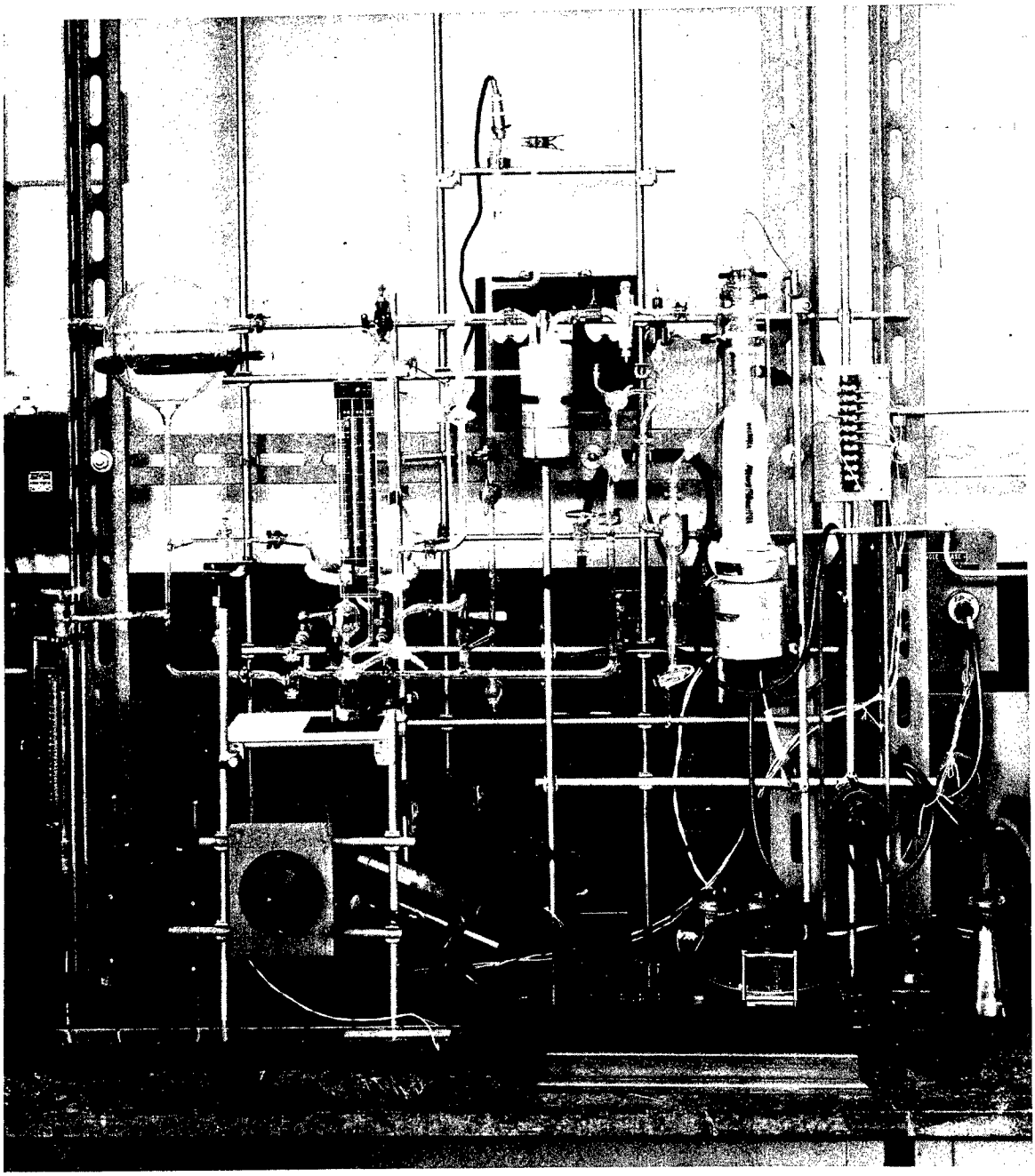
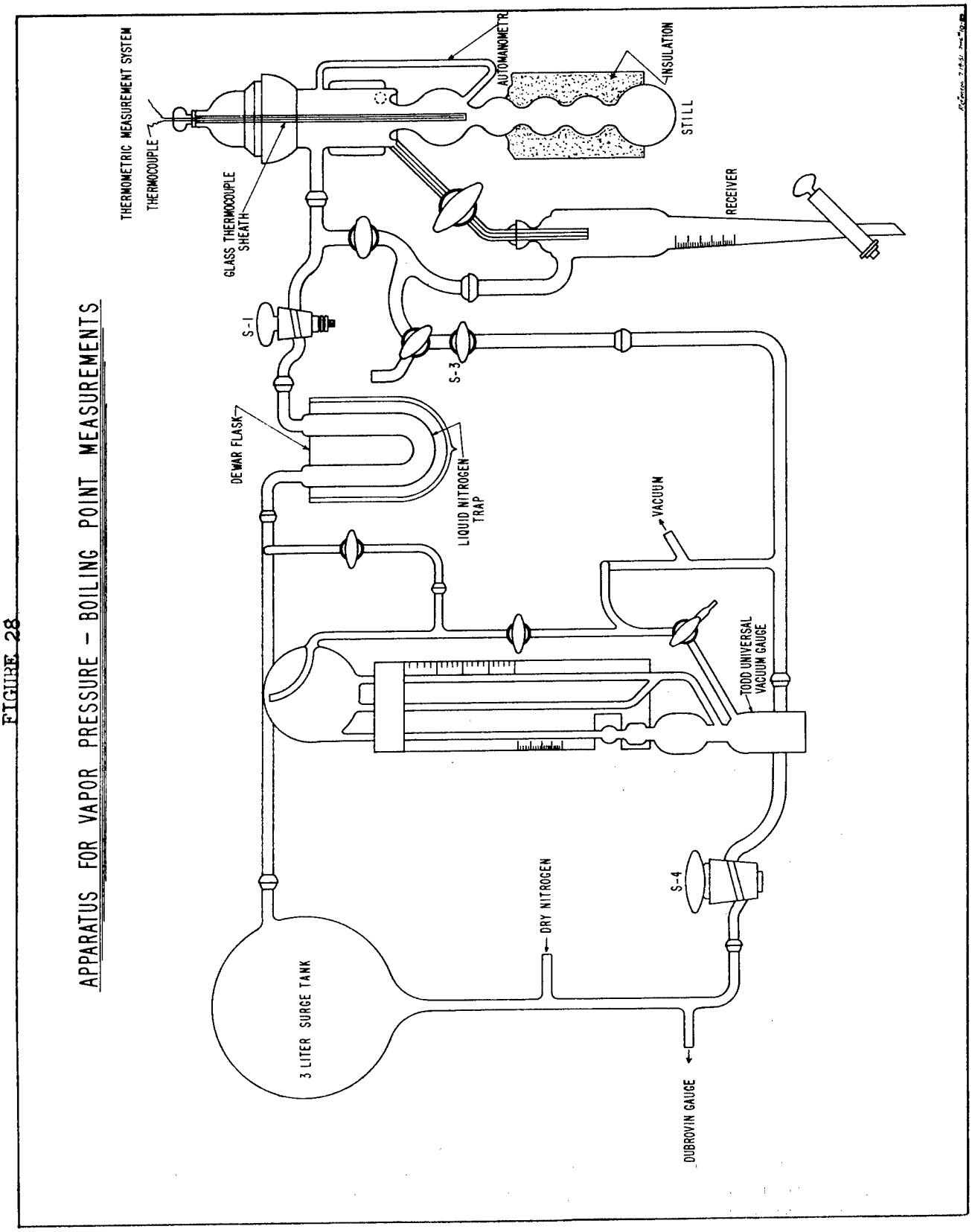


FIGURE 27

GENERAL APPEARANCE OF THE
VAPOR PRESSURE-BOILING POINT APPARATUS

FIGURE 28

APPARATUS FOR VAPOR PRESSURE - BOILING POINT MEASUREMENTS



joints are lubricated with a thin film of Apiezon N or other suitable high vacuum type grease. The stopcock and ball joint leading from the still pot to the receiver should be lubricated with a silicone high vacuum grease.

The entire apparatus is evacuated and tested for leaks by appropriate means. The system is returned to atmospheric pressure by admitting dry nitrogen. Fifty milliliters of the liquid under investigation is then pipetted into the bottom of the still into which a magnetic stirring bar has previously been placed. A sufficient amount of the liquid is added to the automanometer through the top outlet in order to set the zero mark on the sliding scale attached to the automanometer. The ball joint is attached to the top of the still and the thermocouple is replaced.

Stopcocks 1 and 4 are closed to isolate the still and receiver from the rest of the apparatus. The magnetic stirrer is turned on and the dissolved air and moisture in the sample are removed by evacuating through stopcock 3. Low heat may be applied to facilitate their removal.

Stopcock 3 is then closed and the rest of the apparatus evacuated through stopcock 4. The trap is immersed in liquid nitrogen. After closing stopcock 4, an appropriate amount of dry nitrogen to indicate a pressure of approximately 1 mm. on the Dubrovin gauge is bled into the system. The still is then connected with the rest of the apparatus by opening stopcock 1.

Heat is gradually applied to the still pot and, when the condensation of the liquid is visible in the lower end of the condenser, it is adjusted to a reasonable boiling rate. The condensate is allowed to collect in the annulus and flows back down the column. The temperature of the jacket surrounding the column is adjusted to a temperature about 10°C. below the boiling point if it is above 100°C. As soon as a steady, slow boil-up rate has been achieved, simultaneous readings are taken of the vapor temperature, the pressure of the permanent gas by means of the McLeod gauge, and the automanometer pressure. Several sets of data are recorded until successive readings are essentially constant. After equilibrium is established, several milliliters of the condensate are removed into the receiver through the side arm attached to the annulus. This procedure serves to remove any traces of low boiling condensable impurities present. The process of recording the necessary data after equilibrium is again established is repeated until successive readings are essentially constant. For a pure substance, the two sets of readings should be practically identical.

For further measurements at higher pressures, the heating is discontinued, and more dry nitorgen gas is charged into the system to the desired pressure. The whole process given above is repeated at pressures of 2, 3, and 4 mm.

The vapor pressure-temperature relation is obtained graphically by plotting the logarithm of the pressure against the inverse of the absolute temperature. All four points should fall in a straight line. By extrapolation, the vapor pressure at other temperatures can be obtained.

B. Results and Conclusions

The procedure outlined above was primarily designed for the measurement of vapor pressures and boiling points of high boiling or difficultly volatile pure liquids of limited thermal stability. It may be extended with modifications to include mixtures of these types of substances. However, the method is also applicable to high boiling compounds which are thermally stable.

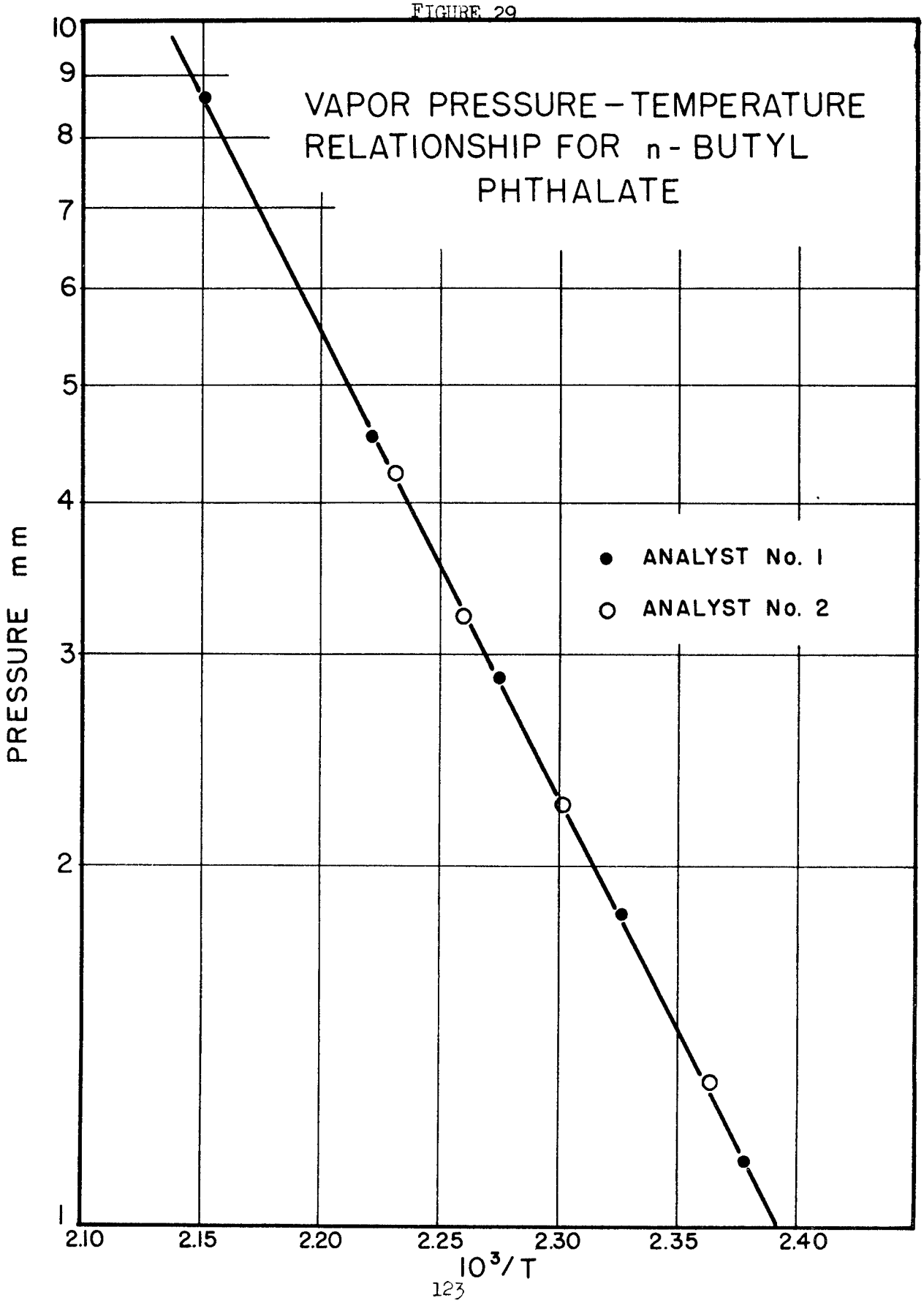
This equipment will give reliable results between 0.03 mm. and 5 mm. pressure. Above this range, accurate measurements are rather difficult to obtain due to excessive bumping and splashing and, below this range, due to the fact that the random velocity is small compared with the forward velocity of the vapor molecules and by the interdiffusion between the vapor and residual gas.

If the thermometer is located in the vapor phase, the vapor, although it may be somewhat superheated when it is formed, soon cools and condenses. This temperature of condensation at slow rates of distillation is the true boiling point at the prevailing pressure when the liquid is absolutely pure and is also not affected by bumping of the liquid.

The absolute accuracy of the procedure may be established by determination of the boiling points at these low pressures of a relatively high boiling liquid which is thermally stable and by extrapolation of the vapor pressure-temperature relationship, the true boiling point at atmospheric pressure may be calculated. This result can then be compared to the best literature data or determined. However, a straight line obtained by plotting the logarithm of the pressure against the inverse of the absolute temperatures is indicative of the accuracy.

To test the accuracy and reproducibility of this method, it was applied to the determination of the vapor pressure-temperature relationship of pure n-dibutyl phthalate by two analysts. The results obtained, plotted graphically, are shown in Figure 29. By extrapolation, the boiling point at exactly 1 mm. pressure was found to be 143°C. This compares favorably with the best literature values of 143°, 145° and 144°C.

FIGURE 29


VAPOR PRESSURE – TEMPERATURE RELATIONSHIP FOR n - BUTYL PHTHALATE
ANALYST No. 1
ANALYST No. 2
PRESSURE mm
10
9
8
7
6
5
4
3
2
1
2.10
2.15
2.20
2.25
2.30
2.35
2.40
10³/T

APPENDIX IV

SIXTH QUARTERLY PROGRESS REPORT

I. DISCUSSION

Work pursued under this contract has been directed toward a study of the properties of synthetic lubricants, in particular, the carboxylic acid esters. The properties which have been investigated most include the following:

1. Viscosity-temperature
2. Viscosity-volatility
3. Melting and pour point
4. Stability (oxidation, hydrolytic, chemical and thermal)
5. Lubrication.

Those materials which have a good combination of these properties are considered to be very promising lubricants. However, other more specific properties may also be necessary depending upon the service to which the lubricants are to be subjected. This study has dealt primarily with the evaluation of materials suitable as components or bases for synthetic lubricants. No attempts have been made to formulate finished blends. The work has continued along the lines discussed in earlier reports. A large number of known and commercial synthetic esters have been evaluated. Data on most of the important lubricant properties mentioned above have been enlarged and several types of esters, which the literature indicates to be promising, have been synthesized to determine their relative position in this field. The results obtained during this quarter, and concerned mainly with expanding existing data on esters containing ether oxygens and esters of the dense center type, are discussed in the following sections.

A. Viscosity-Temperature Characteristics and General Properties

The physical properties of all ester materials either purchased from commercial suppliers or synthesized in the laboratory and evaluated since the first yearly report are presented in Appendix II Tables 38 & 39. The viscosity-temperature relationships are shown over the range of 210 to -65°F. by ASTM slope, Dean and Davis V.I., and Hardiman and Nissan V.I. This latter V.I. system(1) gives a more realistic picture of viscosity-temperature properties by avoiding the irregularities normally experienced at high V.I. levels when the Dean and Davis V.I. system is used. Other general data to be found in Tables 38 & 39 and discussed in the following paragraphs include neutralization numbers, flash, fire, pour, melting points, and vapor pressure data.

- - - - - - - - - - -

(1) Hardiman and Nissan, J. Inst. Petroleum Tech., 31, 255(1941).

1. Monoesters Containing Ether Oxygen

Synthetic lubricants having extremely low viscosities can be made from monoesters. These may find use as special aircraft instrument oils, where low viscosity and low volatility along with moderately good high temperature properties are required. Monoesters could also find application where mechanical lag or sight glass fogging are problems, as well as in hydraulic fluids and as bases for low temperature greases. Earlier work on monoesters described in the literature showed that excessive branching gave poor viscosity-temperature characteristics and high volatility (low flash points), whereas no branching presumably gave high melting materials. The optimum degree of branching was found to be obtained when only one portion of the ester was branched -- either the alcohol portion or the acid portion, but not both. Furthermore, the C_{16} to C_{18} materials with their ester group near the center of the molecule showed the best monoester properties.

When similar monoesters are made from alcohols containing ether oxygen atoms (i.e., Carbitols, Dowanols, etc.) poorer viscosity-temperature characteristics result. As shown in Appendix Table 38 and in the summary table below, isopropoxyethoxyethyl n-octanoate (Dowanol 18 n-octanoate) is not sufficiently branched to give a satisfactory low pour point. The 2-ethylbutoxyethoxyethyl caproate (2-ethylbutyl Carbitol caproate), on the other hand, having the same 210°F. viscosity does have sufficient branching to give a very low pour point. In viscosity-temperature properties these oxy esters are nearly equivalent to the excessively branched C_8 Oxo ester wherein branching occurs on both sides of the ester group. They are, however, poorer than the optimum branched C_8 Oxo pelargonate. Like most monoesters, they show a tendency toward downward curvature when plotted on the ASTM viscosity-temperature chart but the changes, as shown by the ASTM slopes, are much smaller than those shown by the non-ether-oxygen monoesters so that essentially a straight line results. It will be noted that the only beneficial effect of the ether oxygen is to increase the flash point. This appears to be real and will be discussed later under viscosity-volatility characteristics.

(Data on following page)

Viscosity-Temperature Properties - Monoesters

Monoester	Viscosity Cs. At °F. 210	-40	-65	ASTM Slope 210°F. to 100	-65	Flash Pt., °F.	Pour Pt., °F.
Isopropoxyethoxyethyl n-octanoate	1.363	104	Solid	0.821	0.815*	315	-55
2-Ethylbutoxyethoxyethyl caproate	1.367	114	501	0.826	0.828	330	<-75
C_8 Oxo pelargonate	1.374	78.8	259	0.810	0.785	305	<-75
C_8 Oxo C_9 Oxoate	1.390	103	410	0.827	0.810	285	<-75

* Slope 210/-40°F.

2. Monoesters Versus Diesters

The C_{21} monoester, C_{13} Oxo 3,5,5-trimethylhexanoate, were shown in AF Technical Report 6663 to be inferior to dibasic acid diesters of equivalent carbon content. Its poor showing at low temperatures is undoubtedly due, in part at least, to the terminal butyl group in the acid portion. More recent data for other monoesters, C_{13} Oxo C_{13} Oxoate and n-hexyl C_{13} Oxoate, confirm the earlier observation that low pour monoesters in the C_{18} to C_{26} range are inferior in viscosity-temperature properties to dibasic acid diesters of the same carbon content or 210°F. viscosity. This also holds generally for glycol diesters although here a number of exceptions exist, especially when they are compared with a monoester having nearly optimum branching (n-hexyl C_{13} Oxoate). The presence of the second ester linkage in both types of diesters is particularly effective in lowering the volatility (raising the flash point). The monoesters, C_{13} Oxo C_{13} Oxoate and n-hexyl C_{13} Oxoate, are compared in the following table with dibasic acid esters having the same 210°F. viscosity and with glycol diesters having approximately the same carbon content. The superior low temperature viscosities of the dibasic acid diesters are particularly noteworthy.

(Data on following page)

Monoesters Versus Diesters

	Carbon Content	Viscosity, Cs. @ °F 210	-40	-65	ASTM Slope 210/ 100°F.	H&N V.I.	Flash Pt., °F.
C_{13} Oxo C_{13} Oxoate	C_{26}	3.38	7230	76500	0.775	115	405
Di-2-ethylhexyl Sebacate	C_{26}	3.39	1480	8380	0.693	150	430
Tripropylene glycol di-n-octanoate	C_{25}	2.76	1040	7000	0.725	152	415
n-Hexyl C_{13} Oxoate	C_{19}	1.74	307	1480	0.814	157	315
Di-3-methylbutyl Adipate	C_{16}	1.73	165	650	0.778	173	325
Diethylene glycol di-2-ethylhexoate	C_{18}	1.97	1150	8580	0.842	129	360

3. Diesters Containing Ether Oxygen

There are four effects noted in diesters derived from alcohols containing ether oxygen, known commercially as Cellosolves, Carbitols, and Dowanols. As shown in the summary table below with data taken from the literature, the addition of ethylene oxide to C_9 Oxo alcohol results in (1) greater viscosity, (2) increased Dean and Davis viscosity indexes, (3) higher flash points, and (4) poorer pour points. It will be noted that the optimum viscosity-temperature relationship and flash point consistent with a good pour point are obtained when about two ethylene oxide units are added.

Effect of Ethylene Oxide on Diester Properties

Adipate (Diester)	Viscosity, Cs. @ °F. 210	100	ASTM Slope 210/ 100°F.	D&D V.I.	H&N V.I.	Flash Pt., °F.	Pour Pt., °F.
C_9 Oxo (from diisobutylene)	3.21	12.7	0.728	136	142	415	<-98
C_9 Oxo + 1 m. Ethylene Oxide	4.30	18.3	0.678	165	144	420	-82
C_9 Oxo + 2 m. " "	5.74	27.4	0.652	154	144	465	-72
C_9 Oxo + 4 m. " "	7.72	40.9	0.622	147	140	440	-62
C_9 Oxo + 6 m. " "	10.0	54.1	0.591	148	144	435	-36

The changes resulting from the addition of ethylene oxide units are due mainly to the increased molecular weight but they also reflect the effect of the ether oxygen, which becomes more pronounced with the lower alcohol diesters, where the alkylene oxide portion constitutes a greater proportion of the molecule. As shown in the table below with esters of low molecular weight alcohols, the alkylene oxide actually improves the pour points but this effect diminishes as successive alkylene oxide units are added. The effect of ether oxygen in raising the viscosity level and lowering the pour point is shown by comparing the adipate of butyl alcohol + 2 mols of ethylene oxide with n-octyl adipate, both having the same carbon content and straight chain structure. Propylene oxide is shown to have an effect similar to ethylene oxide. The properties of the propylene oxide derivatives of isopropanol are compared below with those of di-sec. hexyl and di-C_9 Oxo adipates, which have similar viscosities but lack the ether oxygen. The sec.-hexyl adipate is shown to be inferior while the C_9 Oxo adipate is superior to the ether oxygen counterparts.

Effect of Alkylene Oxides on Diester Properties

Adipate (diester)	Viscosity, Cs. @ °F. 210	100	ASTM Slope 210/ 100°F.	V.I.	H&N V.I.	Flash Pt., °F.	Pour Pt., °F.
n-Butyl	1.49	3.68	0.748	--	--	340	-13
n-Butyl + 1 m. Ethylene Oxide	2.24	7.31	0.755	129	154	390	-40
n-Butyl + 2 m. Ethylene Oxide	3.47	13.3	0.694	158	145	450	<-35
n-Octyl	2.85	8.75	0.652	187	170	420	+39
Isopropyl	1.16	2.92	0.863	--	--	225	+30 (MP)
Isopropyl + 1 m. Propylene Oxide	2.08	6.99	0.796	102	147	325	<-75
Isopropyl + 2 m. Propylene Oxide	3.52	14.7	0.724	137	138	360	-65
Sec.-Hexyl	1.81	5.79	0.822	--	149	305	+50 (MP)
C_9 Oxo	3.21	12.7	0.728	136	142	415	<-98

To expand the literature data on the properties of oxygen containing esters, several compounds were synthesized from alcohols containing two ethylene oxide units. Secondary alcohols were selected since their alkylene oxide derivatives might serve as a means of increasing the availability of synthetic esters. By this means a large number of low cost, readily available alcohols, which otherwise are not suitable because their esters are thermally unstable, can be utilized. Several of these Carbitol type diesters are compared in the summary table below with promising diesters having equivalent 210°F. viscosities. Complete data are given in Appendix Table I. It will be noted that diisopropoxyethoxyethyl adipate is a perfect match for di-2-ethylhexyl azelate in flash, pour, ASTM slope, V.I. and viscosities at the higher temperature levels. However, at low temperatures the viscosities and ASTM

slopes increase markedly revealing its inferior viscosity-temperature characteristics over the full temperature range. Dicaproxyethoxyethyl adipate, which utilized capryl alcohol, a by-product of sebacic acid manufacture, appears to have somewhat better viscosity-temperature characteristics than C_{10} Oxo sebacate based on the high temperature viscosities, but here again the tendency of the ether oxygens to cause an upward hook (increased ASTM slope) becomes evident at low temperatures. Similar diesters made from a primary alcohol base (di-2-ethylbutyl Carbitol adipate) appear to be in no way superior to the secondary derivatives.

Comparison of Dibasic Acid Diesters With and Without Ether Oxygen

(All Pour Points are Less Than -75°F.)

Material	Viscosity, Cs. @ °F. 210	Viscosity, Cs. @ °F. -65	H&N V.I.	ASTM Slope 210/°F. 100	ASTM Slope 210/°F. -40	ASTM Slope 210/°F. -65	Flash Pt., °F.
Diisopropoxyethoxyethyl Adipate	2.948	26500	149	0.723	0.764	0.779	420
Di-2-ethylhexyl Azelate	2.944	6260	149	0.721	0.726	0.724	400
Dicaproxyethoxyethyl Adipate	4.700	57870	147	0.655	0.693	0.704	415
Di-C_{10} Oxo Sebacate	4.702	28860	142	0.671	0.682	0.680	465
Di-2-ethylbutyl Carbitol Adipate	3.686	40310	151	0.679	0.730	0.743	440
Di-C_{10} Oxo Adipate	3.598	23000	146	0.702	0.727	0.728	450

Most secondary alcohols tend to give diesters having high melting or pour points. The conversion of these alcohols to alkylene oxide derivatives provides a useful means by which satisfactory low pour materials can be obtained from these otherwise unattractive alcohols. This is considered to be an important advantage which can be cited for these materials, along with the improved thermal stability which will be discussed in Section E. As shown in the table below, dicapryl and diisopropyl adipates are transformed by the use of alkylene oxides into products having considerably better viscosity-temperature, flash and pour point characteristics.

(Data on following page)

Properties of Diesters Utilizing Secondary Alcohols and Their Derivatives

Adipate (Diester)	Viscosity, Cs. @ °F. 210	100	-40	-65	V.I.	Flash Pt., °F.	Pour or (MP), °F.
Capryl	2.42	8.67	Crystalline		110	370	-60
Caproxyethoxyethyl	4.70	19.9	5340	57900	170	415	<-75
Isopropyl	1.16	2.92	Crystalline		--	225	(+30)
Isopropoxyethoxyethyl	2.95	10.9	2210	26500	142	420	<-75
Isopropoxyisopropoxyisopropyl	3.52	14.7	--	--	137	380	-65

4. Glycol Diesters Containing Ether Oxygen

Esters derived from glycols by reaction with monobasic acids have been found, in general, to be inferior to dibasic acid diesters. Several polypropylene glycol diesters were shown in the last quarterly report to be equivalent to dibasic acid diesters of the same viscosity and carbon content. These were dipropylene glycol di-n-octanoate, and tripropylene glycol di-n-octanoate and dicaproate. It will be noted that all of these esters require straight chain acids which may be in short supply in time of national emergency. These esters may serve, however, as a possible alternate supply of lubricant materials along with dibasic acid diesters. The straight chain C_9 pelargonic acid which is available commercially as a by-product from azelaic acid manufacture probably would not become short in an emergency but it does not give a satisfactory ester with tripropylene glycol. As shown in the Appendix Table 40 and in the summary table below, tripropylene glycol dipelargonate is inferior in viscosity-temperature properties to similar diesters made from shorter straight chain acids. The reason for the crystalline formation and consequently poor showing of the pelargonate ester is probably associated with the low purity of the commercial pelargonic acid employed.

Tripropylene Glycol Diesters

(<-75°F. Pour Points)

Tripropylene Glycol Diester	Viscosity, Cs. @ °F. 210	-40	-65	ASTM Slope 210/100	210/-40	H&N V.I.	Flash Pt., °F.
Dipelargonate	2.900	1178	Crystals	0.725	0.732	140	420
Di-n-octanoate	2.756	1040	7000	0.725	0.740	152	415
Dicaproate	2.134	591	3572	0.775	0.784	153	395

It will be noted that the tripropylene glycol diesters exhibit the upward viscosity-temperature hook characteristic of esters containing ether oxygens. Dipropylene glycol di-n-octanoate, on the other hand, gives a downward curvature which permits this ester to surpass many others diesters in viscosity-temperature properties throughout the temperature range investigated (-65 - 210°F.). This unusual but desirable behavior may possibly be due to some tendency for the glycol portion of this diester to form a pseudo ring or loop, giving rise to the dense center configuration which has been found associated with this downward curvature in many other instances. As shown below, certain other glycol diesters exhibit the same tendency. In the three cases cited a 1,5-glycol is involved which would be optimum for permitting the formation of a strain free ring or loop. Insufficient data are available to show whether polymethylene glycols other than the 1,5-type behave similarly.

Unusual Viscosity-Temperature Properties of Certain Glycol Diesters

Material	ASTM Slope, 210°F. to		
	100°F.	-40°F.	-65°F.
Dipropylene glycol di-n-octanoate	0.759	0.756	0.752
Pentanediol-1,5 di-2-ethylhexoate	0.829	0.817	0.807
2-Ethoxymethyl-2,4-dimethyl pentanediol-1,5 dicaproate	0.781	0.776	0.776
2-Ethoxymethyl-2,4-dimethyl pentanediol-1,5-di-2-ethylhexoate	0.815	0.813	--

It would appear from these data that dipropylene glycol dipelargonate, which should likewise exhibit downward curvature, might possess reasonably good viscosity-temperature characteristics, and could be made from readily available materials.

Polyethylene glycols, like polypropylene glycols, can be produced on a much larger scale than they are now being made commercially. Their application to synthetic ester lubricants, therefore, would be desirable at least from an availability standpoint. The use of polyethylene glycols in diesters has not been considered very promising since poor viscosity-temperature characteristics are obtained with branched chain acids and high pour materials are produced with straight chain acids, according to the literature. It was observed in the work on Carbitol type diesters and in previous work that the presence of ether oxygen tended to lower the pour points of diesters in which the alkylene oxide portion constituted a sizeable

proportion of the molecule. Several diesters were synthesized to expand the existing data, especially at low temperatures, on compounds of the glycol diester type. Literature references indicate Polyethylene Glycol 200 and tetraethylene glycol would give better diester properties than lower polyethylene glycols. This is undoubtedly due to the fact that they are similar in carbon content to octanediol-1,8 and would give diesters in the C_{22}-C_{26} range wherein the diesters having the best properties have been found. Low pour points would be anticipated for the diesters of these glycols, because the three ether oxygens in the glycol portion should have appreciable effect when not masked by the size of the monobasic acid used. As is shown in Appendix Table 40 and in the table below, low pour diesters can be obtained with straight chain acids. Thus, with Polyglycol 200 and caproic acid a pour of -65°F. is obtained, compared with +60 for ethylene glycol di-n-octanoate. Lower pour diesters can be obtained with very little sacrifice in viscosity-temperature characteristics by introducing a moderate amount of branching, as is shown for Polyglycol 200 mono-2-ethylbutyrate mono-caproate. The same result could possibly be obtained by employing a slightly higher molecular weight polyethylene glycol (more ether oxygens), although this has not been demonstrated. The viscosity-temperature characteristics of these glycol diesters are inferior to dibasic acid diesters over the full temperature range (210 to -65°F.) because of their upward hook at low temperatures. The flash points are high compared with di-2-ethylhexyl azelate and hexane-diol-1,6 di-n-octanoate. This difference may reflect in part the degree of purification or stripping, but it is probably also associated with the presence of the ether oxygens.

Viscosity-Temperature Properties - Glycol Diesters

	Viscosity, Cs. @ °F.		ASTM Slope 210/°F.		H&N	Flash Pt.,	Pour Pt.,
	210	-40	100	-40	V.I.	°F.	°F.
Polyglycol 200 di-n-butyrate	2.566	1423	0.735	0.780	154	390	-60
Tetraethyleneglycol dicaproate	2.552	1055	0.729	0.764	156	415	-60
Polyglycol 200 dicaproate	2.920	1532	0.706	0.747	157	420	-65
Polyglycol 200 mono-2-ethyl-butyrate mono-caproate	2.918	1851	0.711	0.757	153	420	<-75
Di-2-ethylhexyl Azelate	2.944	1132	0.721	0.726	149	400	<-75
Hexanediol-1,6 Di-n-Octanoate	2.62	--	0.697	--	149	380	+46

5. Dense-Center Polyesters

Polyesters in which the acid or alcohol portions appear to emanate from a common source or dense center generally exhibit a desirable downward curvature of their ASTM viscosity-temperature relationship at low

temperatures. These include esters of tri or tetrahydric alcohols such as triethanol amine, trimethylolpropane, and pentaerythritol. Aconitates, dimerates, phthalates, phosphinates, phosphonates, phosphates, phosphites, silicates, and the like also show the same phenomenon. The esters of pentaerythritol and trimethylolpropane are of special interest in this work since they have fairly attractive properties and can be made from available materials (acetaldehyde, butyraldehyde, formaldehyde and monobasic acids). They could possibly serve, therefore, as alternates for dibasic acid esters where moderately good viscosity-temperature characteristics would suffice. Unfortunately, these polyhydric alcohol esters of straight chain acids have undesirably high melting points. As shown in Appendix Table 40 and in the summary table below, introduction of some branching eliminates the high melting point difficulties but, as might be expected, imparts poorer viscosity-temperature characteristics, as indicated by lower H&N V.I. and higher low temperature viscosities. Pentaerythritol dicaproate di-2-ethylbutyrate appears to be excessively branched. It is believed that the pentaerythritol tricaproate mono-2-ethylbutyrate would provide the optimum degree of branching. Trimethylolpropane dicaproate mono-2-ethylbutyrate has about the optimum amount of branching for a trimethylolpropane triester; hence, no further improvement can be expected. At the suggestion of the project engineer, another polyester, tri-n-butyl aconitate, was given a preliminary evaluation, since the American Sugar Refining Company proposes to recover reasonably large quantities of aconitic acid (1,2,3-propenetricarboxylic acid) from molasses. As shown in Appendix Table 38 and in the summary table below, this aconitate does not have outstandingly good viscosity-temperature properties but is similar in this respect to the pentaerythritol and trimethylolpropane polyesters, It is unsaturated and consequently has poor oxidation stability. It does not crystallize at low temperatures but has a lower flash point than diesters of similar viscosity.

(Data on following page)

Dense-Center Polyesters

Polyester	Viscosity, Cs. @ °F. 210	Viscosity, Cs. @ °F. -40	ASTM Slope 210/°F. 100	ASTM Slope 210/°F. -40	H&N V.I.	Flash Pt., °F.	Melting Pt., °F.
Pentaerythritol tetra-caproate	4.133	4656	0.734	0.717	125	470	+21
Pentaerythritol di-caproate di-2-ethyl-butyrate	4.660	16400	0.764	0.746	106	470	WNC
Trimethylolpropane tri-n-octanoate	4.046	3276	0.717	0.703	133	485	+18
Trimethylolpropane di-caproate mono-2-ethyl-butyrate	3.163	2959	0.780	0.761	121	415	WNC
Tri-n-butyl aconitate	2.438	1509	0.829	0.799	116	370	WNC
Di-2-ethylhexyl Adipate	2.362	833	0.770	0.774	147	395	-90

WNC: Would not crystallize after 15 hours at -94°F.

B. Viscosity–Volatility Characteristics

In order for a lubricant to withstnad the extremes in temperature anticipated for newer design turbine type aircraft engines, the lubricant must combine low volatility at high temperatures with low viscosity at low temperatures. Mineral oils do not possess a satisfactory combination of these properties and therefore have poorer viscosity–volatility characteristics than desired for these engines. In contrast, ester–type synthetic lubricants are quite good in this respect. In the absence of impurities, the flash points of synthetic lubricants are influenced to a large extent not only by the number of carbon atoms and branchiness but also by the type, position, and number of functional groups present in the molecule. The flash points of mineral oils, on the other hand, depend generally only on carbon chain length and branchiness since no functional groups are present. Flash point determinations are used to give a fair indication of volatility in mineral oil work but since they are generally subject to considerable error, they should not be relied upon to give an accurate indication of volatility for non–hydrocarbon synthetic lubricants. Actual vapor pressure determinations have been used to measure the volatility of the esters evaluated in this work. The method used is that described by Hickman and Weyerts(2) and is presented as Appendix III A. In brief, the experimental data obtained at 0.4 to 8 mm. pressure are plotted as log V.P. versus $1/(t+230)$ where t is in °C. A straight line results from which fair values for any vapor pressure at any temperature can be obtained. Vapor pressure–temperature and viscosity–volatility data of all compounds evaluated in this program are tabulated in Appendix Tables 43 and 44. The viscosity–volatility characteristics of synthetic lubricants were discussed in some detail in Appendix III. Additional work has been concerned with diesters containing ether oxygen atoms, and is discussed in the following sections.

1. Monoesters

As discussed above, the volatility of non–hydrocarbon synthetic lubricants is influenced to a great extent by several factors. The degree and position of branchiness appears to be important. Comparison of monoesters (Appendix Table 43) shows that branchiness occurring on only one side of the ester linkage, preferable in the alcohol portion(3), is optimum,

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(2) Hickman and Weyerts, J. Am. Chem. Soc., 52, 4714 (1930).
(3) Recent brochure on Esters (Carbide and Carbon) shows n–hexyl 2–ethylhexanoate to have higher volatility than 2–ethylhexyl caproate.

giving less volatile esters than when the branching is on both sides of this group. Thus, C_8 Oxo n-octanoate has only half the vapor pressure of 2-ethylhexyl 2-ethylhexanoate although both esters have the same carbon content. Since the viscosity is also improved by this selective distribution of branchiness, the C_8 Oxo n-octanoate has the better viscosity-volatility properties. The presence of ether oxygen also has an effect. The introduction of two ether oxygens tends to lower the volatility. As shown in the table below, isopropoxyethoxyethyl n-octanoate and 2-ethylbutyl Carbitol caproate have lower vapor pressures at 400°F. than C_8 Oxo pelargonate, yet all three esters have the same 210°F. viscosities and about the same degree of branchiness. However, because of their slightly poorer low temperature properties these ether-monoesters are considered to have viscosity-volatility properties which are essentially equivalent to the C_8 Oxo pelargonate.

Viscosity-Volatility Properties of Monoesters

Monoester	Viscosity, Cs. @ °F. 210	-40	-65	Flash Pt., °F.	Vapor Pressure, mm. @ 400°F.	Viscosity-Volatility Index
Isopropoxyethoxyethyl n-octanoate	1.363	104.1	Solid	315	50	--
2-Ethylbutyl Carbitol caproate	1.367	113.9	501	330	35	382
C_8 Oxo pelargonate	1.374	78.8	259	305	60	373

A rough measure of viscosity-volatility properties is given by the viscosity-volatility index. This is an arbitrarily chosen index and is defined as the difference between the boiling temperature of the material at 2 mm. and the temperature at which it has a 10,000 cs. viscosity. A shortcoming of this index is its variation with viscosity, necessitating comparisons at common viscosity levels. Where the material is a solid at the lower temperature, as is the case with isopropoxyethoxyethyl n-octanoate, the viscosity-volatility index has no real significance. For reference, however, this index has been calculated for all materials evaluated and the data are compiled in Appendix Tables 43 and 44.

2. Dibasic Acid Diesters

The Carbitol type diesters are considered to be poorer in viscosity-volatility properties than conventional diesters not having ether oxygens. These ether-diesters (of dibasic acids) have generally lower volatilities, but they also have considerably higher viscosities at low temperatures. As shown below with data taken from Appendix Tables 43 and 44, diisopropoxyethoxyethyl adipate is at least equivalent to di-2-ethylhexyl azelate in all the properties examined except low temperature

viscosity, where it is inferior (26,500 cs. versus 6260 at -65°F.). Di-heptyl Carbitol and di-2-ethylbutyl Carbitol adipates likewise have lower vapor pressures at 400°F. and higher low temperature viscosities than the conventional diesters with which they are compared. Comparison of 2-ethylbutyl Carbitol adipate with esters having about the same vapor pressure at 400°F. (di-C_{10} Oxo sebacate; trimethylolpropane tri-n-octanoate), shows the large effect that the ether oxygens have on increasing the low temperature viscosity. This factor tends to offset the advantages of the low volatilities obtainable with this type of compound. Their usefulness may lie chiefly in applications where low temperature viscosity requirements are not restrictive, or they may find use as blending components.

Viscosity-Volatility Properties of Diesters

Material	Viscosity, Cs. @ °F. 210	-40	-65	Flash Pt., °F.	Vapor Pressure, mm. @ 400°F.
Di-isopropoxyethoxyethyl Adipate	2.948	2212	26500	420	1.4
Di-2-ethylhexyl Azelate	2.944	1132	6260	400	1.5
Di-heptyl Carbitol Adipate	4.128	5641	61130	440	0.15
Di-C_9 Oxo Azelate	4.241	2907	Viscous	400	0.88
Di-2-ethylbutyl Carbitol Adipate	3.686	3522	40310	440	0.20
Di-C_{10} Oxo Adipate	3.598	2954	23000	450	0.85
Di-C_{10} Oxo Sebacate	4.702	4191	28860	465	0.31
Trimethylolpropane tri-n-octanoate	4.046	3276	22180	485	0.21

3. Glycol Diesters

Diesters in which the center portions are derived from glycols are of interest in this work as a means of increasing the availability of synthetic esters. A few of the glycol diesters are very much like dibasic acid diesters in properties. However, most of them are poorer. In general, the viscosity-volatility properties of polypropylene glycol diesters are good when straight chain acids are used, and poor when branched chain acids are used. The better polypropylene glycol diesters appear to be superior to the best polymethylene glycol (alkane diol) diesters for which data are available. As shown below, tripropylene glycol dicaproate is superior in all respects to pentanediol-1,5 di-2-ethylhexanoate, both esters having about the same viscosity at 210°F. Very little additional data have been obtained on the polymethylene glycol diesters, but they do not appear particularly promising. Diesters made from polyethylene glycols and branched chain acids have poor viscosity-volatility properties. These diesters are better, however, than the corresponding polypropylene glycol diesters utilizing branched acids. For example, the di-2-ethylhexanoate of diethylene

glycol has a lower vapor pressure and lower viscosities than the same acid ester of dipropylene glycol. When straight chain acids are employed with polyethylene glycols, the esters are likely to have high melting points.

Viscosity-Volatility Properties of Glycol Diesters

	Viscosity, Cs. @ °F.			Pour or (Melting) Pt., °F.	Flash Pt., °F.	Vapor Pressure, mm. @ 400°F.
	210	-40	-65			
Tripropylene Glycol dicaproate	2.134	591	3572	<-75 (WNC)	395	6.3
Pentanediol-1,5 di-2-ethylhexanoate	2.115	958	5452	<-75 (WNC)	390	8.6
Di-sec.-amyl sebacate	2.271	528	2970	<-75 (WNC)	375	6.4
Diethylene glycol di-2-ethylhexanoate	1.969	1152	8579	<-75 (WNC)	360	8
Dipropylene glycol di-2-ethylhexanoate	2.204	2522	Viscous	<-75 (WNC)	355	12
Diethylene glycol dipelargonate	2.897	Solid	Solid	0 (+11)	405	--
Tetraethylene glycol dicaproate	2.552	1055	Solid	-60 (+1)	415	1.7

WNC: Would not crystallize after 15 hours at -94°F.

The volatilities and viscosity levels of glycol diesters can be varied over a fairly wide range by judicously choosing the monobasic acids and polyalkylene glycol necessary to give desired properties. It was shown earlier that with tripropylene glycol, the upper molecular weight limit (because of partial crystallization at -65°F.) is reached with pelargonic acid (C_9). In view of the excellent properties shown for di- and tripropylene glycol diesters and the apparent tendency for multi-ether linkages in glycol diesters to give lower melting points, it is felt that tetrapropylene glycol and higher polypropylene glycol diesters (with straight chain acids) would also give esters having satisfactory viscosity-volatility properties. These materials would be comparable to the more viscous dibasic acid diesters, such as di-C_{10} Oxo or di-C_{13} Oxo adipates. However, no data are available to demonstrate this. With polyethylene glycols, which are more readily available than polypropylene glycols, the choice of suitable acids appears to be even more restricted. As stated previously, this has been found true in the case of several polyethylene glycol diesters where high melting points were observed. As is shown below and in Appendix Table 44, optimum viscosity-volatility and pour point properties can be

obtained in polyethylene glycol diesters by employing one branched and one straight chain acid to give a mixed ester. The chief advantage over the non-branched structure is in pour point, whereas two mols of branched acid gives an ester of higher viscosity at low temperatures.

Viscosity-Volatility of Glycol Diesters

	Viscosity, Cs. @ °F.			Pour or	Flash	Vapor
	210	-40	-65	(M.P.), °F.	Pt., °F.	Pressure, mm. @ 400°F.
Polyethylene Glycol 200 dicaproate	2.920	1532	--	-65 (-27)	420	2.9
Polyethylene Glycol 200 mono-caproate mono-2-ethylbutyrate	2.918	1851	18860	<-75 (WNC)	420	3.5
Polyethylene Glycol di-2-ethylhexanoate	2.810	2977	30985	<-75 (WNC)	400	1.3

4. Dense Center Polyesters

The introduction of some branching into such esters as pentaerythritol tetra-caproate to reduce the melting point has an adverse effect on the viscosity-volatility properties. The vapor pressure increases and, as discussed previously, the low temperature viscosity is higher as a result of the expected poorer viscosity-temperature relationship. This effect is illustrated in the following table. Data on di-C_{10} Oxo sebacate are shown for reference.

Dense Center Polyesters - Viscosity-Volatility Properties

	Viscosity, Cs. @ °F.		Melting Pt., °F.	Flash Pt., °F.	Vapor Pressure, mm. @ 400°F.
	210	-40			
Pentaerythritol tetra-caproate	4.133	4656	+21	470	0.25
Pentaerythritol dicaproate di-2-ethylbutyrate	4.660	16400	WNC	470	0.60
Di-C_{10} Oxo sebacate	4.702	4191	-76	465	0.31

C. Evaporation Rate of Synthetic Lubricants

The development of a test to measure lubricant volatility under more realistic conditions than are employed in flash point or vapor pressure determinations was recently undertaken in this work. It was felt that flash point was too easily influenced by volatile contaminants which might actually constitute only a very small proportion of the lubricant material. On the other hand, the closely controlled conditions and rather complex apparatus used in determining vapor pressure can hardly be likened to actual equipment in which synthetic lubricants are used, and where conditions may be conducive to evaporation losses. Consequently, to learn more about the property of volatility, a high temperature evaporation test has been employed. In this test a 30 gram sample of the test oil is heated in a glass tube (35 mm. i.d.), immersed in an oil bath at 392°F. for 5 hours. Nitrogen, at a rate of 2 liters per minute, is passed over the surface from a 10 mm. orifice located about 2 inches above and directed at the surface of the lubricant. The gas exit arm of the 11 inch tube is located 4 inches above the surface of the bath. Hourly weighings are made to determine the weight of the sample evaporated. Analysis of the test results of a number of lubricant materials evaluated showed that the rate of evaporation for pure esters remains virtually constant, as expected, for the duration of the test. This is shown in Appendix Figure 14 by the linear relationship obtained when per cent evaporation is plotted against time. The evaporation rates of a Grade 1010 mineral oil and a polyglycol lubricant were not linear, reflecting the fact that these compositions are mixtures of compounds of varying volatilities. The correlation between flash point and evaporation in this test was rather poor. However, the evaporation after 1 hour was found to be related fairly reliably to the vapor pressure at 400°F. These results are tabulated below and shown graphically in Appendix Figure 15.

Evaporation of Synthetic Lubricants

	Wt. % Evaporated, 1 Hour @ 392°F.	Vapor Pressure mm. @ 400°F.	Flash Pt., °F.
Di-2-ethylhexyl sebacate	0.7	0.78	430
Di-C_8 Oxo adipate	1.7	2.6	385
Di-butyl phthalate	10.0	14.0	340
C_8 Oxo decanoate	12.7	27.0	330
MIL-O-6081, Grade 1010 Mineral Oil	14.8	--	290
UCON LB-70X	18.3	65	280
2-Ethylhexyl 2-ethylhexanoate	22.3	120	270

These results indicate that the evaporation test gives about the same information on volatility as that obtained in vapor pressure determinations. The evaporation test has the advantage of simplicity, however. Several obvious modifications can be made to this test to simulate still more realistic conditions. Exposure of the test oil to air and agitation as well as high temperatures would be more like service conditions, but a combined oxidation stability-evaporation test of that type would probably be a less useful tool in exploratory work.

D. Oxidation Stability Studies

One of the most important properties of a synthetic lubricant designed for high temperature operation is its stability in the presence of oxygen and its corrosiveness to metals normally used in the equipment being lubricated. A limited amount of work has been undertaken to determine the oxidation stabilities of synthetic esters and what factors cause variations in their stabilities. A modification of the MIL-L-6387 Oxidation-Corrosion Stability Test was used in this work. It consists of bubbling air at a rate of 5 liters per hour through a 100 gram sample in the presence of strips of copper, aluminum, magnesium, and steel at a temperature of 347°F. (175°C.). The test is continued until a sharp increase is obtained in the neutralization number, which is determined every 24 hours by removing a 10 gram sample. The stable life of the ester is indicated by the point at which this relatively rapid increase in acidity occurs. The gain or loss in weight of the metal strips is recorded, but in these tests little significance is given to these data, since corrosion may become unrealistically severe when the oil has been oxidized to a high neutralization number. The stable life of an uninhibited ester is very short. Consequently, an 0.3 wt. % concentration of phenothiazine has been used as the oxidation inhibitor. This concentration will not prolong the test to an inconvenient length of time, as would be the case for many esters if higher concentrations were used.

It was pointed out in Appendix III of this report that impurities are considered to be the chief antagonist in causing variations in ester stability. For example, a distilled grade of di-2-ethylhexyl sebacate (Plexol 201W) appeared to be more stable than the less pure plasticizer grade (Plexol 201). The stability of a batch of plasticizer grade di-C_8 Oxo adipate (Plexol 244) could not, however, be improved by stripping, distilling, or charcoal treating. In the current study a number of other esters have been partially purified mainly by stripping off the first 5% and then evaluating the undistilled 5-100% portion. Information on any effects of low boiling impurities and the relative stabilities of esters could thus be obtained. These esters were run in duplicate to give an indication of the reproducibility of the test. As shown in the summary

table below and in Appendix Table 49, stripping gave no definite improvement in stability. In all cases the difference between the untreated and the stripped esters appears to be within the reproducibility of the test, which is not as good as desired. It will be noted that wide variations in stabilities can be obtained depending on the ester selected. Certain esters have substantially higher stable lives than others even though they may be only different batches of the same material. Di-2-ethylhexyl adipate has a surprisingly good stable life of about 150 hours whereas di-C_8 Oxo adipate is stable in this test for about 85 hours (Batch II), 45 hours (Batch I), and 25 hours (PX-208). Certain glycol diesters are at least equivalent to the better dibasic acid diesters. Esters derived from secondary alcohols possess oxidation stabilities equivalent to primary alcohol esters in this test. However, at higher temperatures (above about 400°F.), the secondary alcohol esters would be expected to be poorer based on thermal stability studies at these temperatures, although no substantiating data have been obtained in this program.

Oxidation Stability at 347°F.

Ester + 0.3% Phenothiazine	Stable Life, Hours	
	Untreated, 0-100%	5% Stripped Off, 5-100%
Di-2-ethylhexyl adipate (Flexol A-26)	140, 160	115,140
Di-C_8 Oxo adipate, Batch II (Plexol 244)	85, 85	75
Di-C_8 Oxo adipate, Batch I (Plexol 244)	45, 45	40, 40
Di-C_8 Oxo adipate (PX-208)	30, 20	35, 20
Dipropylene glycol di-n-octanoate	95	--
Triethylene glycol di-2-ethylhexanoate (3GO)	70, 55	70, 60
Di-sec. amyl sebacate	90	80, 75

E. Thermal Stability Studies

Besides good oxidation stability, it is also desirable for a synthetic lubricant to have good thermal stability. This is a property which is inherent in the molecule and probably cannot be improved by physical means, such as by the use of inhibitors or additives. The reaction involved when a synthetic diester is thermally decomposed is generally considered to be one giving olefins, half esters, and the original dibasic acid. Although other products, such as water, carbon dioxide, aldehydes, alcohols, etc., have been reported, olefins and acids appear to be the chief products of this reaction. The thermal stabilities of a number of esters studied under the terms of this contract have been determined by heating a 20 to 50 ml. sample of the ester at 392°F. for 48 hours in a closed tube under a small positive nitrogen pressure. In a few cases the test has been run at 455°F. The change in neutralization number occurring during the test is believed to be indicative of the decomposition that has occurred, and is converted to per cent decomposition assuming that the original dibasic acid is the only acidic decomposition product. As was shown in the fifth quarterly report,*purity of an ester may have a marked effect on the thermal stability of the ester. To obtain further information along this line several esters were stripped to remove any light-end impurities. The undistilled 5-100% portion was then subjected to the thermal test and compared with the original material. As shown by the following data taken from Table 51, any improvement obtained by employing this stripping procedure appeared to be generally small and insignificant in all cases except those of C_8 Oxo adipate (PX-208) and C_8 Oxo sebacate (PX-408). A small amount of water (dissolved or from unreacted alcohols) was present in these materials and was removed during the stripping operation. This water may have been responsible for the poorer stabilities of the original diesters. The presence of water would tend to promote hydrolysis and consequently increase the acidity.

*See Appendix III.

(Data on following page)

Thermal Stability - Effect of Refinement
392°F.

Compound	Neut. No. Increase mg. KOH/gm.	Decomposition % of Theoretical
Di-2-ethylhexyl adipate	0.14	0.05
Same stripped, 5-100%	0.04	0.01
Dicapryl adipate	42.0	13.9
Same stripped, 5-100%	40.9	13.5
Di-C_8 Oxo adipate, Batch I	0.24	0.08
Same stripped, 5-100%	0.20	0.07
Di-C_8 Oxo adipate (PX-208)	5.43	1.79
Same stripped, 5-100%	1.35	0.44
Di-C_8 Oxo sebacate (PX-408)	5.86	2.22
Same stripped, 7-100%	1.02	0.39

The initial ester acidity does not appear to have any appreciable effect on thermal stability although it is conceivable that certain acidic materials could catalyze the thermal decomposition of an ester. A high acidity sample of di-C_{10} Oxo adipate (initial Neut. No. of 8.08) gave essentially the same thermal stability before purification as it did after the acidic materials were removed (Neut. No. of 0.07). No significant differences appear in the stability at 392°F. of adipates and sebacates produced from primary alcohols. However, with secondary alcohol esters, which are generally less stable thermally than the primary alcohol esters, the sebacates appear more stable than the corresponding adipates. For example, capryl sebacate decomposed only 1% compared with 14% for capryl adipate. The sebacates of secondary amyl and hexyl alcohols are likewise reasonably stable at 392°F. At higher temperatures, however, as shown by the Petroleum Research Laboratories of the Pennsylvania State College, secondary alcohol sebacates decompose about 70% in 20 hours (500°F.) compared with 1 to 2% for primary alcohol sebacates, azelates and adipates. This thermal instability of secondary alcohol esters can be conveniently circumvented by converting the secondary alcohol to a primary one through the use of ethylene oxide. The improvement in thermal stability obtained by employing this technique is outstanding, as shown below with data obtained at 392° and 455°F. on dicapryl adipate and dicaproxyethoxyethyl adipate. It will be noted also that several similar Carbitol type adipates made from secondary alcohols are equivalent in thermal stability at these temperatures to one

made from a primary alcohol (2-ethylbutanol) and two ethylene oxide units. Complete data on thermal stability of esters at 392°F. are given in Appendix Table 51, and at 455°F. in Appendix Table 53.

Thermal Stability of Secondary Alcohol Derivatives
392° and 455°F.

Material	Neut. No. Increase, mg. KOH/gm. @°F.		Decomposition, % of Theoretical @°F.	
	392	455	392	455
Dicapryl adipate	42.0	*	13.9	100
Dicaproxyethoxyethyl adipate	1.79	2.90	0.91	1.47
Isopropoxyethoxyethyl adipate	0.33	0.84	0.12	0.31
Diheptoxyethoxyethyl adipate	0.40	1.59	0.19	0.71
Di-2-ethylbutoxyethoxyethyl adipate	0.37	0.68	0.16	0.29

* No liquid sample remained at end of test. White crystals (adipic acid) had sublimed to cool portion of tube.

Propylene oxide can probably be used interchangeably with ethylene oxide in this conversion of secondary alcohols to more stable alcohols, but such esters have not been investigated in thermal stability tests. It is known, however, as discussed in the fifth quarterly report,*that diesters of polypropylene glycols (which are secondary glycols) possess thermal stabilities at 392°F. equivalent to similar diesters made from polyethylene glycols (which are primary glycols and therefore would be expected to give more stable diesters). As shown below with data taken from Appendix Tables 51 and 53, dipropylene glycol di-n-octanoate is essentially equivalent to polyethylene glycol diesters in thermal stability even at 455°F. The thermal stability of tripropylene glycol di-n-octanoate at 455°F. is not as good. The data indicate that this glycol diester would probably be unsatisfactory at a somewhat higher temperature, since at 455°F. it shows 2.34% decomposition.

*See Appendix III.

(Data on following page)

Thermal Stability of Glycol Diesters
392 and 455°F.

Material	Neut. No. Increase, mg. KOH/gm. @ °F.		Decomposition, % of Theoretical @ °F.	
	392	455	392	455
Dipropylene glycol di-n-octanoate	0.34	1.52	0.12	0.52
Tripropylene glycol di-n-octanoate	-0.10	5.79	0.0	2.34
Polyethylene glycol 200 dicaproate	0.41	0.49	0.14	0.17
Polyethylene glycol di-2-ethyl-hexanoate (4GO)	0.0	0.59	0.0	0.23
Di-C_{10} Oxo Sebacate	0.20	2.36	0.09	1.01

Data also presented in Appendix Table 51 show that esters produced from pentaerythritol and trimethylolpropane and straight chain acids possess excellent thermal stabilities at 392°F., and that the introduction of some branchiness does not impair this property. Tri-n-butyl aconitate, which has a point of unsaturation and a structure which might be expected to undergo decarboxylation, is nevertheless fairly stable at 455°F. (Table 53), giving only 3.6% decomposition. This triester, however, does not appear to be a very promising lubricating oil component because of its poor oxidation stability at 347°F. (Table 49).

F. Lubrication Studies

This important phase of work is now being studied intensively under this contract, as described generally in Section H - Future Work. A considerable amount of information has been obtained in the 4-Ball E.P. Machine and the S.A.E. Machine.

APPENDIX V

SEVENTH QUARTERLY
PROGRESS REPORT

I. DISCUSSION

This work on lubrication studies has been confined to the SAE load carrying machine and the 4-Ball E.P. test machine. The work with the SAE machine was directed toward developing a test which would adequately evaluate the load carrying properties of various lubricants for use in aviation turbo engines. The effects of various operating variables such as speed, shaft speed ratio, loading rate, and run-in were first investigated. Based on this work, a test technique was chosen for additional checking. Inasmuch as good results have been obtained to date, the operating conditions used for this work have been set up as the SAE-SOD Load Carrying Test.

In these studies, a number of synthetic oils (with and without load carrying agents) having viscosities in the range of 2.8 to 8 centistokes at 210°F. were used, in addition to two mineral oils. These mineral oils are as follows: Esso Turbo Oil 10 (MIL-L-6081, Grade 1010), which has relatively low load carrying properties; and Esso Aviation Oil 100 (MIL-L-6082, Grade 1100), which has adequate load carrying properties for high output turboprop and turbojet engines, but has unsatisfactory low temperature properties. These two mineral oils will be designated ETO-10 and EAO-100, respectively, in this discussion.

During the course of this work in the SAE machine, different batches of the Timken test cups were used. Initially, cups marked "B" and "C" were used. The supply of these cups ran out, however, and the rest of the work was done with a batch of test cups marked "U". The "B" and "C" test cups were essentially the same in hardness and surface finish, but the batch "U" cups were somewhat harder and had a slightly rougher surface finish. Lower failure loads were obtained with the batch "U" cups. As discussed later in the report, this difference in performance indicates the significance of small variations in the physical properties of the test cups. A similar problem is encountered in various gear rig testers; that is, variations between batches of gears affect the results obtained.

The 4-Ball E.P. Test results, discussed in a succeeding section of this Appendix, were obtained using the conventional procedure. The data reported from this test include only the load required to cause immediate ("no delay") seizure and the load required to cause welding. This is believed to be the most significant information obtained in this test.

A. SAE-SOD Load Carrying Test in SAE Machine

A test has been developed using the SAE E.P. Lubricant Testing Machine[1] for evaluating the load carrying ability of aviation gas

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(1) The SAE Machine is described in the CRC Handbook.

turbine lubricating oils. This test is a modification of one of the tests used by the National Bureau of Standards. Comparison of these two tests and the more widely known CRC E.P. gear oil test is shown in the following table.

Tests in SAE E.P. Lubricant Testing Machine

	SAE-SOD Test for Turbo Oils	Test Used By Nat. Bur. Stds.	CRC L-17 Test for Gear Oils
Main Shaft Speed	1000 RPM	1030 RPM	1000 RPM
Shaft Speed Ratio	3.4:1	3.4:1	14.6:1
Test Cups	Timken T-48651	Timken T-48651	Timken T-48651
Run-in	50 to 200 lbs. for 2 minutes.	200 lbs. for 1 minute.	150 to 200 lbs. for 30 seconds.
Loading after Run-in	Manual stepwise, 50 lbs. at 10 second intervals.	Automatic continuous at 78 lbs. per second.	Automatic continuous at 75 to 85 lbs. per sec.
Failure Load*	Minimum load at which scuffing of the contact surfaces of the test cups occurs.		

* In SAE-SOD test, if failure occurs during load change of 50 lbs., the failure load is taken as the average of the "old" and "new" loads.

The main differences among these tests are in shaft speed ratio and loading rate after run-in. The National Bureau of Standards test uses a lower shaft speed ratio than the CRC test, 3.4 instead of 14.6. The SAE-SOD test uses this lower ratio and also a much lower loading rate than the other two tests. Manual load applications of 50 lbs. at 10 second interavls (300 lbs. per minute) are used instead of the automatic loading at 75 to 85 lbs. per second (4500 to 5100 lbs. per minute).

Results obtained with the SAE-SOD test have shown reasonably good reproducibility, good spread between lubricants of widely different engine performance, and good correlation with the I.A.E. Gear Machine test. In addition, the test is not only sensitive to the viscosity of the lubricant but also to chemical structure and to surface-active ingredients. The results obtained in the SAE machine during the development of this test and under SAE-SOD conditions are tabulated in Appendix Tables 54, 55, and 56.

1. Effect of Viscosity, Chemical Structure, and Surface-Active Ingredients

The effect of differences in chemical structure and viscosity level on load carrying ability are apparent from Appendix Figure16. Increased viscosity gives higher loads before failure. The type 1 esters, a distinct class of compounds, appear to have better inherent lubricating properties than the type 2 esters, a chemically different class of compounds, over the viscosity range investigated. However, this difference

is not necessarily reflected in finished lubricants based on the two types of esters. Lubricating properties can be markedly altered through the use of addition agents.

The effect of surface-active ingredients on failure load is shown in Appendix Figure 17. Tricresyl phosphate increased the failure load 165 and 125 lbs. when used in 5% and 3% concentrations respectively in synthetic oils of 3.0 and 3.4 cs. viscosity at 210°F. The use of 0.4% of a sulfurized inhibitor gave an increase of 125 lbs. in a 5.0 cs. synthetic oil.

2. Correlation with I.A.E. Gear Machine Test

The correlation of the SAE-SOD test failure load with that obtained in the I.A.E. Gear Machine test is excellent for two mineral oils and several synthetics, as presented in Appendix Figure 18. Both the I.A.E. and the SAE-SOD tests also show reasonably good correlations with high-speed gear tests, and with the available field performance in full scale reduction gear set-ups. This correlation with gear tests appears better than that obtained for other simple laboratory lubrication tests. This is probably due to the ability of the SAE machine to recognize some of the same factors which affect gear lubrication.

3. Variation in Results with Different Test Cup Batches

The variation in results using different test cup batches and run-in loads is shown in Appendix Figure 19. Reducing the run-in load from 200 lbs. to 50 lbs. (with batch "B" and "C" test cups) apparently has little effect on failure load, giving essentially a numerical match correlation. There appears to be an advantage with the lower run-in load, in that more reproducible evaluations can be made on lubricants of lower load carrying ability, say in the range of 200 to 400 lbs. To illustrate, with 200 lb. run-in, Esso Turbo Oil 10 (Grade 1010 mineral oil) failed two times during the 200 lb. run-in and ran in a third test to 350 lbs. before failure. When using 50 lb. run-in, in four tests all failures occurred between 300 and 350 lbs. Results obtained at 50 lb. run-in load with batch "U" test cups averaged 130 lbs. lower failure loads than obtained with batches "B" and "C" test cups. The apparent explanation for this difference in performance is differences in the surface finish and hardness of the test cups as shown in the following table.

Physical Properties of Timken Test Cups No. T-48651

Test Cup Batches	Average Hardness Rockwell C-Scale	Surface Finish RMS Microinches	
		Range	Average
"B" and "C"	61.5	16-19	17.5
"U"	62.2	17-22	19.2

It appears that the "U" cups, which are somewhat harder and not quite as smooth, are slightly more resistant to polishing during run-in. Hence, the mating surfaces of the test cups may not be as smooth at the start of the loading period as when using the "B" and "C" test cups. An attempt, however, to obtain a higher failure load with the "U" cups by extending the run-in period to obtain better polishing before loading was unsuccessful. This test involved synthetic lubricant B-15 and "U" test cups, which were run-in in the following manner: 2 minutes at 50 lbs., 2 minutes at 100 lbs., 2 minutes at 150 lbs., and finally 2 minutes at 200 lbs. The equipment was then cleaned and cooled to room temperature without removing the test cups from their shafts. A new charge of lubricant B-15 was charged and the test restarted using the standard SAE-SOD test procedure of a 2 minute run-in (50 lbs.) followed by 50 lbs. loading each 10 seconds. Failure occurred during the load increase from 500 to 550 lbs. (525 lb. failure load). Thus, with the additional run-in, the failure load fell short of the 550 to 700 lbs. range obtained in the usual manner with the "U" cups and is far below the 700 to 775 lb. range obtained with the "B" and "C" test cups on this lubricant. Accordingly, it appears necessary to establish a correlation for each batch of test cups. This procedure has been found useful in the I.A.E. Gear Lubricant Test and is probably advisable in all load carrying tests unless very close limits are set-up on the surface finish, composition, and hardness of the metal test parts.

B. Effect of Operating Variables on Failure Load in SAE Machine

During the development of the SAE-SOD test procedure, a number of operating variables were investigated to determine their effect on failure load. A good part of this work was done at 3.9:1 shaft speed ratio(1).

1. Shaft Speed

Increasing the shaft speed lowered the failure load very significantly as shown in Appendix Figure 20. Roughly doubling the speed from 530 to 1000 RPM reduced the failure load by more than one-half for all four lubricants tested. In these tests, 200 lb. run-in was used followed by 78 lbs. per second loading. At the higher speeds, the relative distance the surface of one cup slides and rolls across the surface of the other is greater and the rate of heat generation is higher. Each of these factors tend to make the test more severe. At the higher speeds,

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(1) It was planned to conduct this work at 3.4:1 shaft speed ratio. However, some gears in the SAE machine were inadvertently interchanged resulting in the higher shaft speed ratio of 3.9:1.

the increase in heat generation means that at any given time (which corresponds to a given load) the temperature of the lubricant is higher. Likewise, at any given time the linear distance for which the cups have been in contact is also greater.

2. Loading Rate

Loading at a faster rate results in failure at a higher load. This is shown in Appendix Figure 21, where loading in a stepwise fashion at an average rate of 100 and 200 lbs. per minute is compared with loading at 4680 lbs. per minute (78 lbs. per second). This same effect is apparent in Appendix Figures 22 & 23 covering the range of 25 to 400 lbs. per minute average loading rate for mineral oil EAO-100 and synthetic oil B-15, respectively.

Loading at a slower rate, means that the sliding distance involved is greater before reaching a given load. This is in the direction of higher severity, causing lower failure loads. Looking at it another way, at loads above the maximum load which can be carried continuously by the oil without failure there is undoubtedly a definite lag time required before oil film rupture and scuffing occur. Therefore, the faster the loading rate, the more the load can be increased above the "maximum continuous" load during this "lag time" before failure occurs.

3. Effect of Run-in

Increasing the run-in load and time of run-in both tend to lower the failure load when using 78 lbs. per second loading rate. Test data on four oils are shown in Appendix Figures 24 & 25. As with speed and loading rate, there is a tendency for failure to occur at lower loads when the test cup surfaces are exposed for a longer time to the same load, or for the same length of time to a higher load.

It appears advisable to have atleast a minimum run-in period of 1 to 2 minutes.

4. Effect of Shaft Speed Ratio

Increasing the shaft speed ratio tends to lower the failure load. The limited data available (on Esso Aviation Oil 100) is presented in the following table.

(Data on following page)

Effect of Shaft Speed Ratio on Failure Load

Lubricant: EAO-100, Grade 1100 Mineral Oil
Speed: 1000 RPM
Test Cups: Timken No. T-48651 Batches "B" and "C"
Temperature: Room Temp. (75-80°F.) at Start

Shaft Speed Ratio	Relative Sliding Between Cups Feet per Min.	Run-in Period	Loading After Run-in	Failure Load, Lbs.
3.4	346	50 lbs. for 2 min.	50 lbs. each 10 sec.	988
3.4	346	200 " " 2 "	50 " " 10 "	975
3.9	365	200 " " 2 "	100 " " 30 "	700
3.9	365	200 " " 2 "	100 " " 60 "	600
14.6	457	50 " " 2 "	50 " " 10 "	200

As shown in the table, at higher shaft speed ratios the sliding distance is greater per unit of time. This means that the same factors are involved as with an increase in speed. Namely, the generation of heat by friction is more rapid and at any given load the sliding distance has been greater. Both these make the operation more severe and bring about failure at a lower load.

C. Lubrication Studies in 4-Ball E.P. Tester

1. Effect of Viscosity

Tests were run in the 4-Ball E.P. Tester to determine the effect of viscosity upon failure load for relatively low viscosity mineral and synthetic oils. The results, shown in Appendix Table 57, indicate essentially no effect of viscosity. Three groups of oils were tried as follows: (1) refined mineral oils from 1.2 to 14.1 cs. at 210°F., (2) Oxo alcohol esters from 1.34 to 5.61 cs. at 210°F., and (3) blends of di-2-ethylhexyl sebacate (Plexol 201) and Acryloid HF-825 from 3.36 to 10.10 cs. at 210°F. Within each group, both seizure and weld loads were within experimental error showing that this 4-Ball E.P. test is not sensitive to variations in viscosity.

2. Effect of Chemical Structure

Although the 4-Ball E.P. Tester is not affected by viscosity, the seizure and weld loads are influenced by chemical structure and surface-active load carrying agents in the low viscosity synthetic oils. The tests which were conducted are shown in Appendix Table 58. The materials containing ether-oxygen linkages exhibited no better load carrying ability in

this test than the sebacates, adipate, and the succinate which were tested. The literature, however, indicates that some improved performance with this type of material is possible for steel-on-bronze lubrication.

The better performance of Complex Ester A over that obtained with the other esters shows that the 4-Ball E.P. test can recognize changes in chemical structure. The esters of Evanacid 3CS also give better performance in this test showing the effect of the sulfur-containing molecule. Tests on blends of the tri-n-hexyl ester of Evanacid 3CS with Plexol 244 (C_8 Oxo adipate) show nearly linear correlation of both seizure and weld loads with the concentration of the sulfur-containing ester. As discussed in previous reports, the esters of Evanacid 3CS, although effective load-carrying agents, are not believed to be satisfactory for turbo engine lubrication because of corrosion difficulties encountered at high temperatures.