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PHYSICAL AND CHEMICAL LABORATORY EVALUATION OF EXPERIMENTAL SILICATE BASE HIGH TEMPERATURE HYDRAULIC FLUIDS

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FOREWORD

This report was prepared by the Lubricants Section, Organic Materials Branch and was initiated under Project No. 7331, "Hydraulic Fluids, Lubricants and Related Materials", Task No. 73313, "Hydraulic Fluids", and was administered under the direction of the Materials Laboratory, Directorate of Research, Wright Air Development Center, with Lt H. M. Schiefer as project engineer. The period of work covered in this report is September 1954 to August 1955.

ABSTRACT

A physical and chemical laboratory evaluation has been conducted by the Materials Laboratory on an experimental high temperature hydraulic fluid, MLO 54-645, blended at Wright Air Development Center in such a manner to pass the MIL-H-8446 (USAF) Specification rubber swell test. This silicate-diester base fluid was evaluated primarily against the requirements outlined in the above specification for a -65° to 400°F (200-500 hours) non petroleum base hydraulic fluid. This fluid passes all specification tests with the exception of the oxidation test at 400°F in which the fluid gave a marginal neutralization number increase and viscosity decrease.

Some additional tests were performed on this fluid, which indicated that, as for other silicate fluids tested, the hydrolytic stability at 400°F seems to be one of the major deficiencies of this type of fluid. It is apparent from mock-up and 400°F laboratory hydrolytic stability tests, that the present hydrolytic stability test at 200°F needs revision. Some wear data were obtained with this fluid at 167° and 400°F which indicated that the fluid should have sufficient lubricity to lubricate high temperature pumps. Some minimum spontaneous ignition temperatures obtained with the fluid when sprayed from varying pressure levels into a glass vessel at atmospheric pressure, showed that the ignition temperature of this fluid decreases to approximately 510°F at high pressures. This phenomenon is also present in other silicate base fluids tested under these conditions.

PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

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GENERAL DISCUSSION ON THE EVALUATION OF WADC EXPERIMENTAL HIGH TEMPERATURE HYDRAULIC FLUID MLO 54-645

The USAF initiated a research and development program toward the development of a -65° to 400°F hydraulic fluid in 1950. A contract between the California Research Corporation and the USAF was negotiated at that time, and the contractor investigated various classes of compounds suitable for a high temperature hydraulic fluid. Of the various classes of compounds studied, it was decided to formulate a final fluid from a disiloxane base fluid and the final blend was coded by the Materials Laboratory as MLO 8200. Since the rubber compatibility of the fluid was not a requirement under the contract and a high temperature elastomer was not available at that time, fluid development proceeded without waiting for completion of parallel elastomer development programs. Futher evaluation of MLO 8200 at this Center, after the termination of the California Research Corporation contract, revealed that the major deficiency of MLO 8200 for a high temperature hydraulic fluid was its shrinkage of a neoprene high temperature elastomer, as reported in WADC Technical Memorandum WCRT TM 56-41.

In order to provide a fluid which had better compatibility with a plasticized neoprene elastomer (such as WADC Compound 453-26C), a blending program was performed at this center using di-2 ethyl hexyl sebacate as a rubber swelling agent in MLO 8200. A final fluid blend was prepared with approximately 15% diester and coded Materials Laboratory number MLO 54-645. The exact composition of this fluid is given in Table I. At the present time, Oronite Chemical Corporation is producing a fluid designated as "Oronite High Temperature Hydraulic Fluid 85/15" which has approximately the same composition as MLO 54-645.

MLO 54-645 fluid has been tested against requirements set forth in Specification MIL-H-8446 (USAF) which covers the requirements for a -65° to 400°F hydraulic fluid. Some other tests have also been performed on this fluid to give additional information about the fluid and to report properties for design purposes. Since MIL-H-8446 is a new specification, it is likely that some of the testing procedures and fluid requirements will be changed in accordance with results obtained from future high temperature pump and system mock-up tests.

Some of the more important tests conducted in MLO 54-645 and the results of such tests are given as follows:

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Viscosity-Temperature Relationships - Viscosity measurements were conducted over a -65° to 400°F range. These data are presented in Table II. The viscometric requirements of Specification MIL-H-8446 are 2500 centistokes maximum at -65°F and 2.5 centistokes minimum at 400°F. The 2500 centistoke maximum at -65°F was established as a practical low temperature limit for maintenance of a reasonable degree of pump efficiency in overcoming fluid friction and allowing flow rates of a magnitude to provide adequate system response. The 2.5 centistoke value at 400°F has been established as an arbitrary value until sufficient hydraulic component tests at 400°F have been performed to realistically determine the minimum viscosity pumps and valves can tolerate and continue to maintain mechanical and volumetric efficiency under the parameters of temperature, pressure, and speed. MLO 54-645 exhibited a good viscosity-temperature slope having a measured viscosity of 2.5 as at 400°F and 2605 at -65°F. The viscosity temperature data are tabulated in Table II, and given as the viscosity temperature curve in Figure 1.

Spontaneous Ignition Temperature (SIT) - The SIT is defined as the temperature at which oil vapor and air ignite without the aid of external sources such as a flame, spark, etc. Briefly the specification test is performed by dropping the test fluid on a heated surface and measuring the temperature required to spontaneously ignite the fluid. Such conditions would be present in an aircraft if a hydraulic fluid line were severed and allowed the fluid to be sprayed over a hot surface. The minimum SIT value required by Specification MIL-H-8446 is 700°F. MLO 54-645 meets this requirement by exhibiting a SIT value of 770° F.

At high temperatures, such as 400°F, the problem of preventing harmful fires is a very important one. As mentioned before, the fluid may be sprayed from a severed line or leak, under pressure, on to a hot surface and ignite. In order to obtain some information as to the value of the ignition temperature of MLO 54-645 when sprayed or ejected from a high pressure level on to a surface at atmospheric pressure, contract work was performed by the Bureau of Mines, AF 18(600)-151, investigating this problem.

The spontaneous ignition temperature data obtained in a 200 cc pyrex Erlenmeyer flask for MLO 54-645, in air, using a fixed injector-to-hot surface distance and one atmosphere pressure are presented in Figure III. These data indicate that a sharp drop in ignition temperature occurs when the fluid is ejected from pressure levels between 50 and 750 psig, and then levels out at an ignition temperature of approximately 510°F at diesel injector pressures exceeding 750 psig. This reduction of spontaneous ignition temperature is an undesirable feature of this fluid, and is also reported for other silicate fluid tested under the above conditions.

Oxidation and Corrosion - The oxidation and corrosion test was conducted in accordance with Federal Specification VV-L-791 e, Method 5308.3, with the following modifications: 400°F test temperature and 72 hour test duration. The metals employed in this test were copper, steel, aluminum, and pure anodic silver.

Specification MIL-H-8446 requires that the weight change of the above metals, with the exception of copper, shall not exceed ± 0.2 mg/cm^2 of surface area after brushing, with copper having a maximum weight loss of ± 0.4 mg/cm^2. The oil shall not be oxidized to the extent of having change more than ± 20% from the original viscosity when measured at 210°F.

The data obtained on the MLO 54-645 fluid are given in Table II. In general, MLO 54-645 exhibited good oxidation-corrosion stability under the conditions of this specification test. There was no apparent weight change in the aluminum, steel, and silver test specimens and the weight gain of the copper metal was within specification limit. Although the copper and steel metals acquired a stained discoloration, this is not considered serious since there was no evidence of pitting or other phenomena associated with corrosion. Although both the viscosity and acid number changes were both above specification limits, this is not considered to be too serious, since they are both very close to the requirements and possibly within the reproducibility of the test. It is possible that the majority of the decrease in viscosity was caused largely by a breakdown of the viscosity index improver XF 371. It should also be noted that no sludge was formed during the test, as would be expected if the fluid were highly oxidized.

Thermal Stability - The thermal stability of MLO 54-645 fluid without the effect of metal catalysis was determined as follows: oil samples were sealed in glass tubes and placed in a constant temperature oven at 400°F for a period of 200 hours and at 550°F for 10 and 24 hour periods. It is estimated that a long service life fluid (e.g. 500 hour fluid) will not be exposed to its highest operating temperature (e.g. 400°F) for a period greater than 200 hours. Thermal stability tests at 550°F were performed to determine if the fluid had any possibility of being used as a short life 550°F hydraulic fluid. At the termination of the tests, MLO 54-645 fluid was examined for viscosity and neutralization number changes. In all three tests the viscosity decrease of the fluid was relatively high but no increase in neutralization number was noted. This would indicate that there was considerable breakdown of the viscosity index improver (XF 371), with relatively small breakdown of the base fluid, giving rise to a large viscosity decrease. If the base fluid would be unstable, it would be expected that a neutralization number change would occur along with the viscosity change. This theory was upheld when some base stock fluid, hexa (2 ethyl butoxy) disiloxane, was tested at 400°F without the viscosity index improver, and showed only a very small viscosity change after the test. It should also be noted that MLO 8200 (WADC Technical Memorandum WCRT 56-41) gave a large decrease in viscosity in the thermal stability test at 400°F, and that MLO 8200 also contains XF 371 as the viscosity index improver.

Hydrolytic Stability - As an obvious corollary to the oxidation-corrosion stability test, there exists the problem of the hydrolytic stability characteristics of hydraulic fluids. This is important since it is difficult to completely divorce fluids from water contamination either in storage, handling, or actual usage in aircraft. The hydrolytic stability test being employed in Specification MIL-H-8446 is essentially the same type test found in the lower operating temperature hydraulic fluid specification, e.g. MIL-F-7100. In this test, the fluid sample is contaminated with 25% by weight of water and, in the presence of a copper test specimen, is agitated, at temperature of 200°F, for 48 hours.

The requirements of this test are as follows: The total change in weight of the copper strip shall not be greater than ± 0.5 mg/cm^2. There shall be no pitting, etching, or visible corrosion on the surface of the copper. A slight discoloration will be permitted on this metal. After completion of the hydrolysis test the acid number increase of either the acqueous or oil layer shall not be greater than 0.5 mg of potassium hydroxide per gram of oil. The viscosity of the oil layer shall not have changed more than ± 20% from the original value, when measured at 210°F. The amount of insoluble materials, after the test, shall not be greater than 0.5 percent by weight of the original test fluid.

MLO 54-645 possessed good hydrolytic stability according to the 200°F specification test. The copper weight gain of .004 mg/cm^2 was negligible, and there was no evidence of pitting or etching on the copper strip. The viscosity change of the oil layer was only -3.3 percent (measured at 210°F), well within specification limits. There were no solids or any sludge formed during the test. The neutralization number increases of both the water and oil layers were negligible. It is of interest to note that acid numbers do not have the same significance in silicate hydrolysis studies as one would expect in the hydrolysis studies in the hydrocarbon type molecule. The products of silicate hydrolysis are usually not sufficiently reactive with KOH to give an accurate indication of the acid components formed.

Some additional hydrolytic stability tests were conducted on MLO 54-645 fluid to determine its resistance to water under conditions more indicative of hydrolysis occurring, in a closed hydraulic system at 400°F. These tests were conducted in a standard Parr, high pressure, rocking, hydrogenation apparatus. The oil samples, in which various concentrations of water were introduced, were made up to a total of 100 grams and placed, with a copper strip, in the bomb's reaction flask. The copper strip used in this test is similar to the one used in the specification test at 200°F. Hydrolysis can be measured in this test by two methods. In the first method, the test is conducted for a specified period at which time fluid and metal changes are measured. In the second method, it is possible to determine with a fair degree of accuracy, the time required for hydrolysis to occur. This is possible by observing pressure and temperature changes through appropriate recording devices connected directly to the sample area. A pressure drop usually denotes the utilization of water vapor in the process of hydrolysis, which in most cases, results in an exothermic type reaction, i.e. increase in fluid temperature. Therefore, a sharp break in both the pressure and temperature recording curves can be termed the threshold of hydrolysis.

In this test at 400°F, MLO 54-645 fluid was tested for 24 hours at water concentrations of 0.5, 1.0, 2.0, 5.0, and 6.0 weight percent. Measurements taken after each test were as follows: weight change in copper strip, appearance of copper strip, neutralization number increase, weight percent insolubles formed, percent viscosity change at 210°F, and the threshold of hydrolysis designated as the breakpoint. The data for these five tests are recorded in Table II. Results from the tests show that no significant hydrolysis of the fluid occured with 0.5 weight percent of water present and no significant breakpoint occured during the 24 hours. If the concentration of water is increased to one weight percent and above, hydrolysis of the fluid occurs. The degree of the hydrolysis reaction seems to increase as the amount of water present increases. The increasing degree of hydrolysis is shown with increasing values of neutralization number, viscosity change, and percent of insolubles. At a water concentration of 6 weight percent, complete hydrolysis of the fluid occurs forming a mass of jelly-like solids. It is interesting to note that the "breakpoint" (rapid rate of hydrolysis) for this fluid occurs at approximately the same time for all percentages of water above 0.5 weight percent, namely 4-5 hours after the start of the test. This fluid doesn't seem to give any indication of copper corrosion in these tests although the copper strip has a dark stain after the 5% water test. This stain is not detrimental in that no pitting, etching or large change in weight of the copper strip was observed.

A hydrolytic stability mock-up test was performed by the Aircraft Laboratory, WCLSM, on MLO 54-645. The fluid test was intentionally contaminated with a 2 volume percent of water and pumped at a temperature of 210°F and pressure of 3000 psig in a mock-up hydraulic system test stand. The fluid was pumped for 92 hour and 45 minutes at which time a high pressure drop developed across the filtering element causing pump cavitation (WADC TN 55-45). The filter plugging resulted from solid formation due to hydrolysis of the fluid. This mock-up test indicates that trouble can be encountered in the use of this fluid in a closed system when contaminated with water.

<u>Foaming</u> - It is essential that the hydraulic fluid be in complete liquid form to insure adequate transmittance of pressure throughout a hydraulic system. The tendency for a liquid to foam while under pumping conditions creates a definite hazard of vapor lock, pump cavitation and consequent malfunction of the hydraulic system.

To eliminate the deleterious effect of excess foaming, Specification MIL-H-8446 requires that the total volume of oil and foam after a 5 minute blowing period at 200°F cannot exceed 600 ml. The foam stability, i.e. the tendency of a fluid to retain its foam-liquid interface, is measured by the time required for the foam to dissipate under static conditions at 200°F.

The foam collapse time has been established at a maximum of 10 minutes in Specification MIL-H-8446. MLO 54-645 fluid exhibited marginal anti-foaming properties in this test. The total volume of oil and foam after a 5 minute blowing period was 600 ml. This value, although within the specification limit, is high being exactly the maximum amount of foam allowed. The collapse time for the foam was determined to be 480 seconds which is well within the specification requirement.

<u>Lubricity</u> - In addition to the primary function of transmitting hydraulic pressure throughout the hydraulic system of the aircraft, the hydraulic fluid has the secondary duty of lubricating the hydraulic pump and other hydraulic system components. There is no universally accepted method for the measurement of lubricity. For preliminary lubricity studies, the Shell 4-Ball Wear Tester was selected as the best choice for evaluating the wear properties, and the Shell 4-Ball Extreme Pressure Tester was selected as the best choice for evaluating the load carrying properties of this fluid. The testing with the Wear Tester was conducted at two temperatures. In the first test, the fluid was held at 75°C (167°F) and the test was run under standard conditions so that the lubricity could be compared to that of the present USAF hydraulic fluid, Specification MIL-0-5606. Rubbing speeds of 1200 rpm, loads of 4, 10, and 40 kg and a test time of 2 hours were chosen since previous experience has indicated that the results obtained under these conditions compare quite favorably with wear data from pump tests. The average scar diameter of the 52-100 steel balls employed in this test after lubrication with MLO 54-645 were 0.34, 0.42 and 0.62 millimeters at loads of 4, 10 and 40 kilograms respectively. Wear evaluation under similar conditions with the present USAF hydraulic fluid meeting Military Specification MIL-0-5606 gave 0.24, 0.26 and 0.86 mm wear scar diameters under the three increasing loads. Specification MIL-0-5606 is a petroleum base oil containing lubricity additives. In the second test, the temperature was increased to the highest operating temperature desired of the fluid, i.e. 400°F, while other testing conditions were kept constant when compared to the low temperature test. Only one jaw load was run with this fluid at the high temperature. The average scar diameter of the steel balls employed in this test after lubrication was 1.03 millimeters at a load of 10 kilogram. The load carrying ability of this fluid was measured with the Shell 4-Ball Extreme Pressure Tester at room temperature for one minute duration using 52-100 steel balls. The seizure point for MLO 54-645 occurred at a 80 kilogram load, while the weld point occurred at a load of 130 kilograms.

If realistic conclusions can be made from these two screening tests, MLO 54-645 is as good a lubricant at 167°F as Specification MIL-0-5606 type fluids, whereas the lubricity of MLO 54-645 is not as good at 400°F as a MIL-0-5606 fluid is at 167°F. However, the difference in lubricity of the two fluids, when compared at their respective operating temperatures, may not be too significant considering the light loads that are experienced in hydraulic systems. The load carrying ability of MLO 54-645 fluid is good at room temperature.

Rubber Compatibility - Since many components of an aircraft hydraulic system, especially hydraulic pumps, contain rubber packings and gaskets, it is essential that a hydraulic fluid be sufficiently compatible with these elastomers to enable such materials to retain their original desired properties. USAF Specification MIL-H-8446 requires that a swelling of standard synthetic rubber (L or R stock), by the test fluid, shall be 25 ± 5 percent when aged at 250°F for 70 hours. Briefly, the test is conducted by measuring the difference in the water displacement of the rubber specimen before and after the test. The rubber swell with MLO 54-645 was found to be 23 percent which is within the specification requirement. Additional high temperature rubber tests were conducted in an attempt to simulate the effect that fluids have on elastomers in a closed system at 400°F. In this test, a plasticized neoprene type rubber was placed in a test tube filled with MLO 54-645 fluid. The weight ratio of fluid to rubber was approximately 20 to 1. The test tube was then sealed, with a gas torch, and aged for 168 hours at 400°F. Such properties as volume swell, tensile, percent elongation, hardness and brittle point of the elastomer were measured after aging. The results of this testing are given in Table II. MLO 54-645 is relatively compatible with the plasticized elastomer used in this test as all properties of the aged elastomer were close to the desired values. The desired properties of the elastomer after aging are as follows: swell = 5-20%; tensile =800lbs/in^2 minimum; elongation = 100% minimum; shore "A" hardness = 60-70; and brittle point = -65°F maximum.

Other Properties - The values for the following additional properties of MLO 54-645, which were not discussed in the above paragraphs, are given in Table II: flash point; fire point; pour point; neutralization number; specific gravity; evaporation at 400°F; low temperature stability; vapor pressure; and heat capacity. MLO 54-645 meets all of the specification requirements set forth for some of the above properties, i.e. pour point, etc. The curve for heat capacity versus temperature for this fluid is given on Figure II.

Summary and Conclusions - A sample of an experimental high temperature hydraulic fluid, MLO 54-645, has been evaluated by this Center for physical and chemical properties. This di-siloxane base fluid was mainly evaluated against an USAF specification designated as MIL-H-8446. Both the requirements and testing procedures are subject to change in this specification as more experience and knowledge is obtained in fluid and test development in the area of high temperature hydraulic fluids and their system components.

The MLO 54-645 fluid has an excellent viscosity-temperature slope over the range of -65°F to 400°F. The viscosity at -65°F (2605) is slightly greater than the 2500 centistoke maximum permitted in Specification MIL-H-8446 but this is not considered to be significant. Another batch of MLO 54-645 blended may easily fall within the requirement. The viscosity at 400°F (2.5 centistoke) just meets the minimum requirement, but this requirement is still subject to change as more pump and system tests are being conducted at 400°F with silicate fluids to help answer some questions on the relationship of viscosity and lubricity.

MLO 54-645 fluid exhibits good oxidation-corrosion properties at 400°F in the presence of copper, aluminum, steel, and silver. There was no gum or insolubles formed in this test nor was there any indication of corrosion on the metals. The oxidation resistance of this fluid could stand some improvement in that both the viscosity and neutralization number changes were borderline in not meeting the specification requirements. It should be pointed out that the oxidation resistance of this type of blend could be improved with further development work in the use of better diesters, inhibitors, and viscosity index improvers.

It appears that MLO 54-645 possesses good thermal stability at 400°F for 200 hours in that no insolubles were formed and no acid number increase was observed. Although the viscosity decreased in the closed test tube thermal stability test, this may be improved with the possible use of a better viscosity index improver. The addition of the diester permits the use of viscosity index improvers which were previously insoluble in MLO 8200.

The hydrolytic stability characteristics of MLO 54-645 when evaluated at 200°F showed that the fluid was resistant to the effect of water at that temperature.

MLO 54-645 fluid, when tested at 250°F in the presence of standard stock "R" elastomer, gave sufficient amount of swell to the rubber. The fluid also is relatively compatible with a plasticized elastomeric packing (453-26 C) that has been proposed for the -65° to 400°F hydraulic system. This elastomer had a -59°F brittle point after aging 168 hours at 400°F with MLO 54-645 fluid. This is only eight degrees higher than the -65°F brittle point desired in this test. Changes in other properties of the elastomer after the test show that the final properties are marginal and that improvements in elastomer compounding would be desirable.

The anti-foaming tendencies of MLO 54-645, and equally important, the ability to possess an unstable type foam passed specification requirements although the foaming tendency of the fluid could stand some improvement.

In general, MLO 54-645, passes all MIL-H-8446 specification laboratory tests which include, besides the above, the following: pour point, spontaneous ignition temperature, neutralization number, low temperature stability and vapor pressure. The fluid properties which are marginal with respect to specification requirements are viscosity at -65°F, oxidation resistance and foaming tendency. The low temperature viscosity can be improved in a new batch whereas the other two properties may be improved by more development work towards a better blend. The important point about MLO 54-645 remains that the addition of diester to MLO 8200 improved an important property (rubber compatibility) whereas it only slightly affected viscosity and oxidation resistance. This improvement makes MLO 54-645 a better all around fluid when compared to the MLO 8200 for the -65 to 400°F temperature range.

Although MLO 54-645 passed the specification hydrolytic stability test at 200°F, this fluid does not possess great hydrolytic stability at higher temperatures. At 400°F, and in the presence of 6 percent water, this high temperature hydraulic fluid underwent hydrolysis to form an insoluble mass within four hours. Tests with smaller percentages of water showed that the fluid property changes increase with increasing amount of water, whereas the threshold of hydrolysis remained the same for each water concentration. The evaluation of other silicate ester fluids similar in physical and chemical properties to MLO 54-645, indicate that hydrolysis is a general problem of the presently available fluids.

It should be mentioned that the silicates represent a class of compounds that are inherently by structure susceptive to a certain degree of hydrolysis. From past experience with the silicate fluids, it was discovered that even slight concentrations of water over a period of time brought about hydrolytic instability of a fluid that formerly met the requirements of MIL-H-8446 specification test. This indicates that the present specification test may not simulate such conditions and it may therefore be necessary to modify or even substitute a different test in Specification MIL-H-8446. The high temperature hydrolytic stability of MLO 54-645 may be improved to a certain degree with inhibitors but the greatest improvement will probably be achieved through structural changes of the base fluid.

The results from the laboratory tests at 400°F and mock-up tests indicate that special precautions should be observed when handling and using MLO 54-645 to prevent water from contaminating the fluid. Initial purging of the system with N_2 before filling with the fluid will decrease the possibility of getting water into the fluid.

The results from the Shell 4-Ball Wear Test indicate that MLO 54-645 is as good a lubricant at 167°F as Specification MIL-O-5606 mineral oil, whereas the lubricity of MLO 54-645 is not as good at 400°F as a MIL-O-5606 fluid is at 167°F. However, the difference in lubricity of the two fluids, when they are compared at their respective operating temperatures, may not be too significant considering the light loads that are experienced in hydraulic systems. The results from the Shell 4-Ball Extreme Pressure Tester indicate that MLO 54-645 has good load carrying ability at room temperature.

Although the spontaneous ignition temperature of MLO 54-645 is above 700°F at atmospheric pressure, this ignition temperature falls to 510°F when the fluid is sprayed from pressures greater than 750 psig. against a pyrex glass surface. Special safety precautions should be observed when operating MLO 54-645 at high temperatures and pressures to prevent harmful fires. This drop in ignition temperature with increase in injection pressure is present in other silicate and diester fluids tested and seems to be a structural phenomenon of the molecule.

TABLE I

COMPOSITION ON MLO 54-645

A. In Terms % of MLO 8200 Blend

MLO 8200 fluid blend	84.69 Wt %
Di(2-ethyl hexyl) sebacate	14.72 Wt %
Dioctyldiphenylamine	0.413 Wt %
Quinizarin	0.007 Wt %
Total	100.000

B. In Terms of Basic Compounds

Hexa (2-ethyl butoxy) disiloxane	79.073 Wt %
Silicone XF 371	4.073 Wt %
Di(2-ethyl hexyl) sebacate	14.720 Wt %
p,p'Dioctyldiphenylamine	2.110 Wt %
Quinizarin	0.024 Wt %
Total	100.000

TABLE II

PHYSICAL AND CHEMICAL PROPERTIES OF MLO 54-645 COMPARED TO REQUIREMENTS FOR SPECIFICATION MIL-H-8446

Tests	MLO 54-645	Present Specification MIL-H-8446 Requirements
1. Viscosity, cs, at °F		
400°F	2.5	2.5 min
210°F	9.2	
100°F	26.5	
-65°F	2605	2500 max
2. Flash Point, °F	390°F	
3. Five Point, °F	450°F	
4. Pour Point, °F	below -75	-75 max
5. Spontaneous Ignition Temperature, °F	770	700 min
6. Neutralization Number, $\frac{\text{mg KOH}}{\text{gm oil}}$	0.0	0.2 max
7. Specific Gravity, gm/cc,		
60°F	.920	
130°F	.906	
250°F	.865	
325°F	.834	
8. Evaporation, %, (6 1/2 hours at 400°F)	7.9	
9. Low Temperature Stability 72 hrs. at -65°F	no gelation or separation	no gelation or separation

TABLE II (CONT'D)

Tests	MLO 54-645	Present Specification MIL-H-8446 Requirements
10. Foaming, 200°F		
Total volume of foam and oil, ml	600	600 max
Collapse time, seconds	480	600 max
11. Rubber Compatibility at 250°F, 70 hrs.		
% Rubber Swell (Standard "R" Stock)	23	25±5
at 400°F, 168 hrs. closed system,		
%Rubber Swell (453-26C elastomer)	22.1	
Tensile, lb/in^2	650	
% elongation	85	
Hardness, Shore "A"	63	
Brittle Point, °F	-57	
12. Oxidation-Corrosion at 400°F, 72 hrs.		
Air Rate = 5 liters/hr		
Copper-weight change (mg.cm^2)	0.2	±0.4
-Appearance	red discoloration	no pitting or etching
Aluminum-weight change (mg/cm^2)	0.0	±0.2
-Appearance	no change	no pitting or etching
Steel-weight change (mg/cm^2)	0.0	±0.2
-Appearance	blue color	no pitting or etching
Silver-weight change (mg/cm^2)	0.0	±0.2
-Appearance	no change	no pitting or etching
% Viscosity change at 210°F	-25	±20
Acid number increase	+0.7	0.5

TABLE II (CONT'D)

Tests	MLO 54-645	Present Specification MIL-H-8446 Requirements
Oil Appearance	Dark but clear of solids	
13. Hydrolytic Stability at 200°F, 48 hrs, 25 wt % water		
copper-wt change (mg/cm^2)	+.004	0.5 max
-Appearance	stain	no etching
acid number-oil layer change	0.0	0.5 max
-water layer	0.0	0.5 max
% Viscosity change at 210°F	-3.3	±20
% Insolubles	.07	0.5 max
at 400°F, 24 hrs, 0.5 wt % water		
copper-wt change (mg/cm^2)	-0.71	
-Appearance	slight stain	
Neutralization Number Increase	0.24	
% Insolubles	.003	
% Viscosity Change at 210°F	-23	
at 400°F, 24 hrs, 1 wt % water		
copper-wt change (mg/cm^2)	-0.49	
-Appearance	slight stain	
Neutralization Number Increase	0.0	
% Insolubles	.012	
% Viscosity change at 210°F	-28	
Breakpoint	4 hrs.	
at 400°F, 24 hrs, 2 wt % water		
copper-wt change (mg/cm^2)	+0.43	

TABLE II (CONT'D)

Tests	MLO 54-645	Present Specification MIL-H-8446 Requirements
-Appearance	blue stain	
Neutralization Number Increase	0.47	
%Insolubles	.023	
% Viscosity Change at 210°F	-34	
Breakpoint	4 hrs.	
at 400°F, 24 hrs, 5 wt % water		
copper-wt change (mg/cm^2)	+0.49	
-Appearance	dark stain	
Neutralization Number Increase	0.50	
% Insolubles	.490	
% Viscosity change at 210°F	-58	
Breakpoint	5 hrs.	
at 400°F, 12 hrs, 6 wt % water		
% Insolubles	Gel	
Breakpoint	4 hrs.	
14. Thermal Stability (Closed tubes)		
at 400°F, 200 hrs.		
% Viscosity change (210°F)	-19	
Neutralization Number Increase	0.0	
Insolubles	none	
at 550°F, 10 hrs.		
% Viscosity change (210°F)	-52	
Neutralization Number Increase	0.0	
at 550°F, 24 hrs.		
% Viscosity change (210°F)	-64	
Neutralization Number Increase	0.0	
15. Vapor Pressure, mm Hg, at		
350°F	0.67	
400°F	2.8	5 max

TABLE II (CONT'D)

Tests	MLO 54-645	Present Specification MIL-H-8446 Requirements
16. Lubricity:		
Shell 4-Ball Wear Test		
(75°C, 1200 rpm, 2 hrs.)		Similar to
Wear Scar Diameter, mm,		MIL-0-5606
at loads of		
4 kg	0.34	0.24
10 kg	0.42	0.26
40 kg	0.62	0.86
(400°F, 1200 rpm, 2 hrs.)		
Wear Scar diameter, mm,		
at load of		
10 kg	1.03	
Shell 4-Ball Extreme Pressure Test		
(1 minute, room temperature, steel on steel)		
Seizure Point, kg	80	
Weld Point, kg	130	
17. Heat Capacity, BTU/lb/°F, at 400°F	.768	

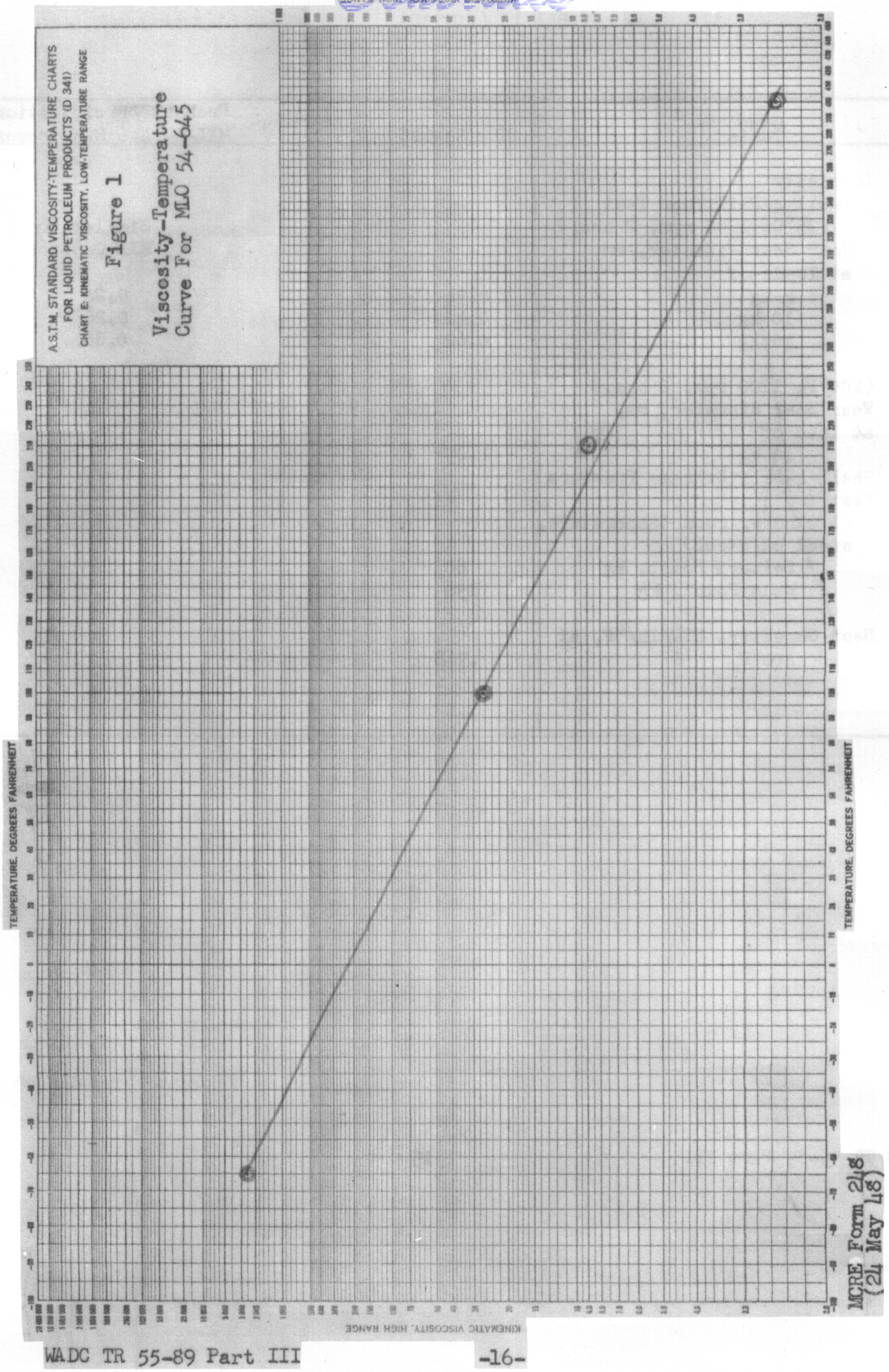

Figure 1

Viscosity-Temperature Curve For MLO 54-645

MCRE Form 248
(24 May 48)

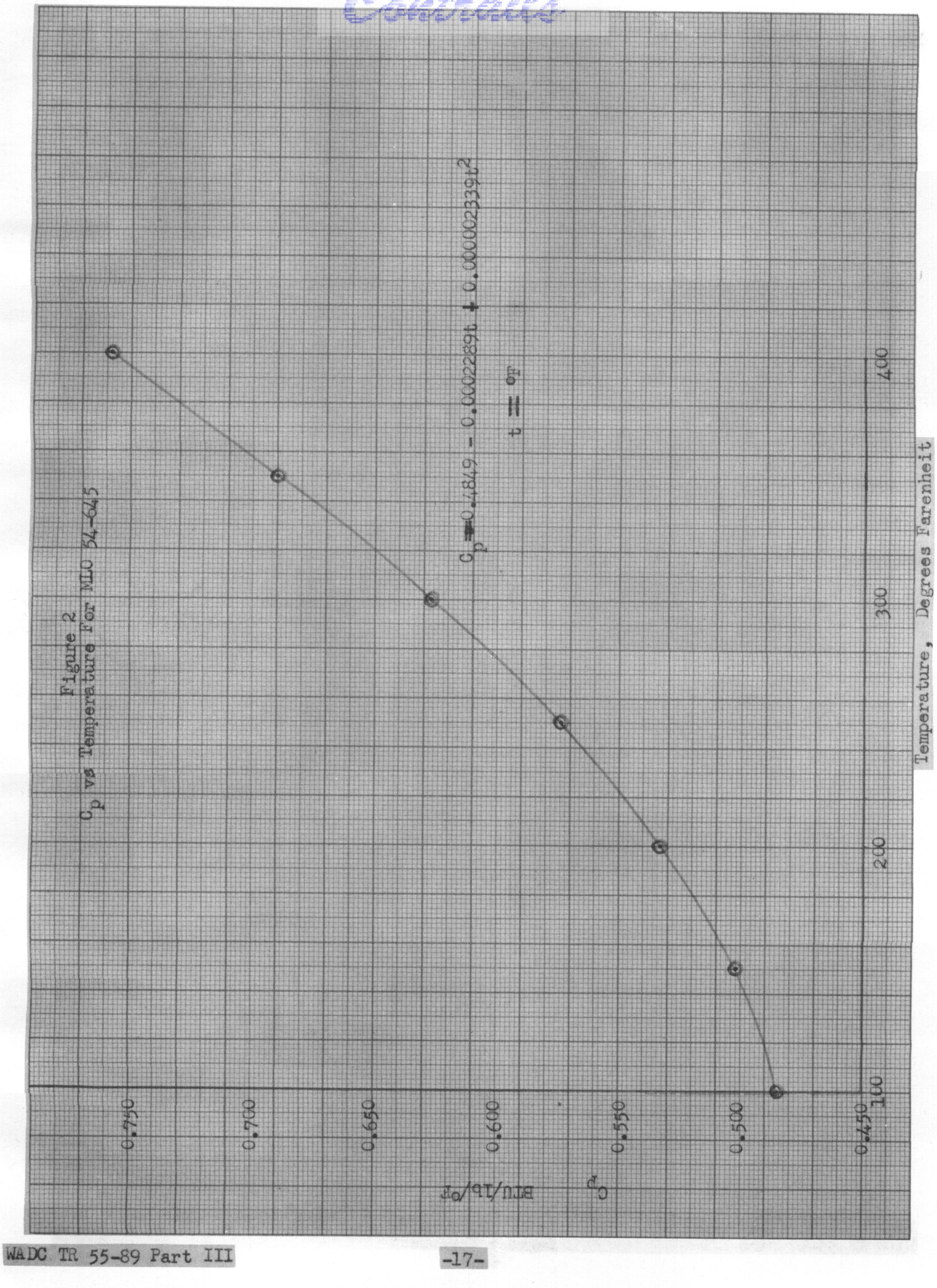

Figure 2
C_p vs Temperature For MLO 54-645

Figure 3

Minimum Spontaneous Ignition Temperatures of MLO 54-645 In Air at One Atmosphere Pressure as a Function of Diesel Injecter Pressure