[redacted]

DECLASSIFIED

May 1945

NRL Report No. P-2530
NRL Problem No. P-51


NAVAL RESEARCH LABORATORY
Anacostia Station
Washington 20, D. C.

CHEMISTRY DIVISION
Lubrication Section



DECLASSIFIED by NRL Contract
Declassification Team
Date: 9 SEP 2016
Reviewer's name(s): H. DO, P. HANNA
Declassification authority: NAVY DECLASS GUIDE, 11 DEC 2012, PGS 6-7, PARA 3(2)


Report on

# INVESTIGATION OF SILICONE POLYMER FLUIDS - PART V, PERFORMANCE AS HYDRAULIC FLUIDS IN PISTON PUMPS

BY


Vincent G. Fitzsimmons
Deets L. Pickett
Richard O. Militz, Lt. USNR


FR-2530

Report No. P-2530 UNCLASSIFIED
Problem No. P-51

[redacted]


DISTRIBUTION STATEMENT A APPLIES
Further distribution authorized by
UNLIMITED only.


Approved by:

W. A. Zisman, Head Lubrication Section

P. Borgstrom, Superintendent
Chemistry Division

A. H. Van Keuren, Rear Admiral USN
Director, Naval Research Laboratory

Number of Pages:

Text: 7
Tables: 2
Plates 7


DECLASSIFIED: By authority of 5000A January 1958
Entered by: E. Bliss Code 2027


[redacted]

UNCLASSIFIED

sbg

DECLASSIFIED

DECLASSIFIED

# TABLE OF CONTENTS



[redacted]

DECLASSIFIED

DECLASSIFIED


## ABSTRACT

This report concerns progress of the investigation of this Laboratory on the use of "silicone" fluids or dimethyl polysiloxanes for non-inflammable hydraulic fluids. In NRL report No. P-2481 of March 1945 the performance in gear pumps was described. It is shown herein that the silicone fluids tested also may be used with success as hydraulic fluids in Vickers piston pumps provided certain types of bearing surfaces are altered. The requisite mechanical changes are simple and inexpensive.

In NRL report No. P-2499 of April 1945 it was proved that the silicone fluid is a very unsatisfactory lubricant for loaded surfaces of steel sliding on steel, while for steel sliding on bronze surfaces it is a good lubricant. It is shown here that the same conclusions relative to steel sliding on steel or bronze are reached from Vickers piston pump tests. The failure to lubricate the piston pumps occurred at the universal link and knuckle bearings, the only lubricated parts where loaded surfaces of steel sliding on steel occurred. When bronze knuckles were substituted for steel, it was found that the pump was in reasonably good condition after more than 600 hours of operation at 1500 pounds per square inch.

The formation of gel was found to be considerable when steel on steel bearings were used, but appeared to be very much less when bronze to steel bearings were substituted.


[redacted]

DECLASSIFIED

DECLASSIFIED

## I. INTRODUCTION

### A. Authorization

1. On 19 October 1942 a letter from the Bureau of Ships JJ14(350) authorized this Laboratory to investigate the application of organo-silicon polymer fluids to naval lubrication problems. Further research was authorized in Bureau of Ordnance Project Order No. 40227 of 22 June 1944 on the use of silicones as non-inflammable hydraulic fluids for gun control systems and recoil fluids. In Project Order No. 337/45 of 30 October 1944 the Bureau of Aeronautics authorized the development of non-inflammable fluids for use in aircraft hydraulic systems.

### B. Statement of Problem

2. Research reported in NRL Report No. P-2481 of March 1945 (ref. 5) and NRL Report No. P-2499 of April 1945 (ref. 6) revealed that the dimethyl silicone polymer fluids could not adequately lubricate loaded sliding surfaces of steel on cast iron or steel. The presence of loaded surfaces of steel sliding on steel in the Vickers piston pumps and motors, as well as the common use of these units in aircraft hydraulic systems, made it desirable to supplement the tests already completed on hydraulic gear pumps by a study of the behavior of silicone fluids operating in such piston pumps.

### C. Known Facts Bearing on Problem

3. Previous research on silicones by this Laboratory (ref. 1, 2, and 3) showed that these fluids were most promising for use as non-inflammable hydraulic oils. A later report (ref. 5) on gear pump tests revealed the fluids would be of value where loaded steel surfaces sliding on cast iron were not present, where properly fabricated O rings were used and where it was possible to employ a tight enough hydraulic system to prevent excessive leakage of these fluids.

4. From this information, together with other data obtained from research reported on silicones in journal bearings (ref. c) and experiments to be reported shortly involving a technique developed for the study of the lubrication possibilities of silicone fluids in conjunction with various bearing metal combinations, it was possible to predict certain changes in piston pump design that would permit such pumps to operate satisfactorily with silicone fluids.

## II. MATERIALS TESTED

5. The silicone fluid tested was made to the specification of this Laboratory by the Dow Corning Corporation and belonged



[redacted]

DECLASSIFIED

DECLASSIFIED

to their 500 series. The manufacturer's identification number was 369-56-36. The viscosities over the range of temperature of interest were found to be:

| Temp. $^{\circ}$F | Visc. cs. |
|---|---|
| 210 | 29.76 |
| 130 | 55.64 |
| 100 | 73.53 |
| 32 | 170 |
| 0 | 275 |
| -20 | 390 |
| -40 | 600 |

The high viscosity of this fluid at 100$^{\circ}$F was feasible because of the low temperature coefficient of viscosity of the fluid. The advantage obtained was that the tendency to leak out of the system was minimized by using the highest possible viscosity without exceeding a reasonable maximum viscosity at -40$^{\circ}$F of around 500 cs. Due to the fact that analytical results and gear pump tests revealed that the General Electric and the Dow Corning series 500 fluid acted chemically identically, in order to save time only the Dow Corning fluid was investigated in these tests in Vickers pumps.

6. The reference petroleum hydraulic fluid tested was made in accordance with specifications AN-VV-O-366B by the Socony Vacuum Company for the Sperry Corporation. The viscosity-temperature characteristics were found to be:

| Temp. $^{\circ}$F | Visc. cs. |
|---|---|
| 210 | 5.16 |
| 130 | 10.08 |
| 100 | 14.08 |
| 32 | 41.62 |
| 0 | 90.25 |
| -40 | 406.4 |

## III. EXPERIMENTAL EQUIPMENT AND TEST TECHNIQUE

### A. Description of Test Equipment

7. A photograph of the hydraulic system used is shown on Plate 1. The reservoir "A" was made of copper and was designed to produce a long liquid path within the sump from inlet to outlet in order to facilitate deaeration. The capacity of the entire system was three gallons and of that volume 2½ gallons was retained in the sump. "T" was a thermometer used for reservoir temperature measurements. The line "C" was 5/8" O.D., .035" wall copper tubing. "D" was a flexible steel-rubber hose



[redacted]

DECLASSIFIED

DECLASSIFIED

with 13/32" I.D. Army Navy specification No. AN-863-8-21. All other tubing was 1/2" O.D., .035" wall copper. Standard 24ST aluminum alloy or equivalent AN type flow fittings were used throughout.

8. The pump "E" was a Vickers piston pump aircraft type, constant delivery piston pump, Model No. PF-2713-10 normally containing a hardened steel universal connecting link and four steel knuckles. In run VP2 the steel knuckles were replaced by a new set made of copper-base alloy of 80% copper, 10% lead and 10% tin. The driving motor used, "F", was a G.E. type K, frame 225, 220 and 440 volts, 3 phase, rated at 5 H.P. at 3600 RPM. Pressure was controlled by a Vickers No. C167E relief valve "H". The gauge "I" was used on the high pressure side of the valve. This was a Lonergan gauge with a range of 0 to 3000 psi. Gauge "J" was used to measure the pressure drop across the relief valve and gauge "K" was to measure the pressure drop across the filter "L". This filter was either a Purolator aircraft line type using a paper element impregnated with what is reported to be a phenol formaldehyde resin or a Skinner aircraft instrument type filter using a paper disc element enclosed in a cloth sheath.

9. The hydraulic fluid was cooled in the apparatus "M" which consisted of 20 feet of 3/8" copper tubing inserted in 20 feet of 3/4" copper tubing and then coiled. The test fluid passed through the space between inner and outer tubes and a flow of cooling water passed through the inner 3/8" tube. The device "N1" was a Fenwal thermoswitch which was connected with the driving motor control, the purpose being to shut off the driving motor if the temperature of the hydraulic fluid exceeded the desired temperature. This device was in the nature of a safety shut off in case of water failure to the cooler. The device "$N_2$" was also a Fenwal thermoswitch which controlled the sump oil temperature through a solenoid "O" in the water supply line to the cooler.

10. The test fluid then passed through "P", a Fisher and Porter rotameter, stable-vis type 12 P No. 7. This device measures rate of flow from 0 to 5 GPM. On top of the rotometer a Minneapolis-Honeywell Pressuretrol (Q) was installed. This was a safety device to switch off the device if for any reason the pump failed to deliver fluid. This device was caused to operate by the slight back pressure in the rotometer which was generally in the region of 1 or 2 psi, and when this pressure was not present the switch moved to the "off" position, thereby breaking the circuit to the drive motor. The fluid left the rotometer through line "R" which entered the side of the reservoir at the top and then directed the flow against the side of the container. This caused the test fluid to take a circular path to the pump inlet. thus allowing any entrapped air bubbles



[redacted]

DECLASSIFIED

the greatest possible time to escape to the surface. The liquid velocity was not sufficient to cause the fluid to vortex in the reservoir.

B. <u>Technique</u>

11. The entire hydraulic system was thoroughly cleaned with unleaded 62 octane gasoline and air dried by forcing a blast of clean air through the system before the start of each run. Samples of the test fluid were taken at the start of the run, each time the pump was stopped to check the wear, and at the end of the run. All samples were checked for the viscosity at 100°F. Filter elements were carefully examined at the end of each run for deposits of material separated from the fluid. A new element was used for each run.

12. Pump performance was characterized by observations of flow rate at the beginning and end of each run, appearance of metallic particles in the test fluid or in the filter, and condition of the working parts as evidenced by weight losses, appearance and fit. Due to the size and mass of the working components as well as the presence of many crevices impossible to clean perfectly, measurements of weight losses were not considered practicable for observing wear.

IV. BEHAVIOR OF OIL IN PISTON PUMPS

13. The petroleum hydraulic oil made according to specification AN-VV-O-366b is commonly used in aircraft while that made according to Navy Ordnance specification OS-2943 is used to a considerable extent in ordnance ship equipment. Vickers piston pumps are built for aircraft and ship use and range from five to several hundred horsepower. Because of considerations of size and laboratory convenience, use was made of the aircraft Vickers piston pump.

14. This Vickers piston pump contains a hardened steel universal link on which are pivoted on steel pins four hardened steel knuckles (Plate 2). This assembly serves to connect the drive shaft to the offset bronze cylinder block (Plate 3). As a result of this offset, each rotation of the pump causes the steel knuckles to rotate 20 degrees around the steel pins of the universal link. A hole drilled through the length of the universal link is the main source of lubricant flow to these bearing surfaces. The flow of force feed lubricant is therefore very limited.

15. A 300 hour test run at 1500 psi and 180°F sump temperature was made on this fluid in order to provide comparison data. Measurements were taken after 100, 200, and 300 hours of continuous



[redacted]

DECLASSIFIED

operation, and are presented in Table I. The appearance of the universal link, knuckles and cylinder can be seen in Plate 2, while the cylinder block alone is shown in Plate 3. The wear rates with the petroleum reference fluid were so low as to be negligible. The general pump condition remained excellent throughout the test. The oil remained clear although appreciable darkening in color was observed. The viscosity decreased with pumping, presumably caused mainly by shear breakdown of the polyacryloid thickener. The viscosity decrease in 5000 cycles at 1500 psi was approximately 24%, and as usual the rate of viscosity breakdown rapidly became less after the first 5000 cycles.

16. Using the silicone hydraulic fluid it was found that after 65 hours in one run and 80 hours in another the pump failed. In the first case it failed through seizure and in the second case through fracturing of the universal link. Much before failure occurred the oil darkened with dispersed particles of steel. The surfaces of the pins and knuckles were so worn that their diameters changed by approximately one-half of the original values (Plate 4). Enough gel and finely divided metal was created to accumulate in the filters and increase the pressure drop across the filter by 8.7 pounds per square inch. Pump failure was directly due to the excessive wear in these members, which allowed the piston connecting rods to strike the sides of the cylinders (see cylinder block of Plate 5) either causing seizure or breaking the universal link completely.

17. In a report of the General Electric Company (ref. 4) a similar failure of the universal link was described, but it was attributed to fatigue of the universal joint after 304 hours of operation. Their successful operation of the pump for even 304 hours is believed due to the fact that fluid was delivered to their pumps under 50 to 100 psi pressure. Since the universal link and knuckles are lubricated only by the fluid which leaks past the pump valve plate and pistons, this positive pressure may have permitted leakage sufficient to lubricate hydrodynamically and also to cool these bearings enough to prevent rapid wear at the steel on steel loaded bearing surfaces.

18. A new technique has been devised by this Laboratory whereby it has been possible to evaluate the lubrication properties of silicone fluids when applied to any combination of two metals. These experiments which will be reported in the near future demonstrate that while steel sliding on steel bearings are not adequately lubricated by dimethyl silicones, steel sliding against bronze appeared satisfactory. Since pump failures in previous tests had invariably been caused by the extreme wear of the steel universal link and knuckles, it was believed that substituting bronze for the original steel knuckles might permit silicone fluids to be used in the pumps. A set of four such knuckles was accordingly made and installed in a new pump and



[redacted]

DECLASSIFIED

DECLASSIFIED

tested for 50 hours. No appreciable wear was apparent after this time; hence the test was continued for a total of 650 hours. The results are recorded in Table II. Wear rates were not excessive and the general condition of the pump was good. The silicone fluid remained clear for the entire test and no change was observed in the viscosity.

19. Hence, the use of steel pins and bronze knuckles improved the lubrication characteristics so much as to permit the silicone fluid to be a practicable hydraulic fluid in this type of pump. However, it has not been established here that steel pins and bronze knuckles are the best possible arrangement. Other combinations of metals will be reported shortly which will deserve consideration by those interested in necessary changes of design for silicone lubricated hydraulic systems.

## V. GEL FORMATION IN SILICONE HYDRAULIC FLUIDS

20. Gel formation was at no time a problem during this work, but its existence was very evident in those tests where finely divided metal was developed during the deterioration of the loaded steel-on-steel bearings. Tests in which bronze on steel bearings were used were notable in the apparent absence of gel. It is possible, however, that gel was more visible in those fluids containing finely divided metal in suspension due to particles of metal sticking to the transparent gel. However, no significant clogging of the filter was observed during operation with bronze knuckles. An accumulation of gel was present around the universal link bearings in all silicone tests; however, the fact that these points were exposed to a very small flow of fluid would indicate that any gel generated would have little chance of being circulated through the system.



[redacted]

DECLASSIFIED

DECLASSIFIED

## VI. CONCLUSIONS

21. It may be concluded from the foregoing data that dimethyl silicone fluids may be used profitably up to 180°F and 1500 psi in Vickers piston pumps provided certain steel on steel loaded bearing surfaces are replaced by bronze on steel. Even after that change the lubrication value of silicone fluid was not quite equal to that of Navy petroleum hydraulic fluid made according to specification AN-VV-O-366b; however, viscosity shear breakdown was appreciable in the petroleum oil and practically nil in the silicone fluid. Gel formation, while occurring, did not appear of importance in the tests with bronze knuckles.

## VII. RECOMMENDATIONS

22. (a) It is recommended that dimethyl silicone fluids should not be used in Vickers piston pumps as now constructed. However, a slight modification of the universal link mechanism can be readily made which will permit successful operation with this new fluid.

(b) Should commercial and naval use of this silicone fluid in Vickers piston pumps and motors be contemplated, it is recommended that before changing the steel knuckles to bronze, consideration be given to other combinations of metals to achieve the best freedom from wear. Numerous combinations of promise will be reported in the near future.

(c) Hydraulic pumps or motors of other designs may not wear well if used with this silicone fluid. However, a similar analysis to that presented here of the sliding loaded bearing surfaces should permit location of possible sources of trouble and a decision as to the necessary changes of design. It is believed that through such a procedure any hydraulic system can be modified to permit successful operation with the dimethyl silicone fluids.

## VIII. ACKNOWLEDGMENTS

23. Assistance of Lt. G. L. Potter and Lt. J. Kendall of the Bureau of Aeronautics in expediting delivery of equipment is much appreciated. Viscosity data were obtained through the cooperation of Mr. Charles M. Murphy, Jr. and Miss Helen Fobes of this Section.



[redacted]

DECLASSIFIED

DECLASSIFIED

## BIBLIOGRAPHY


1. NRL Report No. P-2165 of September 1943 entitled "The Laboratory Evaluation of Hydraulic Oils - Part I, Methods for Inflammability Test".

2. NRL Report No. P-2227 of January 1944 entitled "Investigation of Silicone Polymer Fluids - Part II, Chemical and Physical Properties of Importance in connection with their Uses as Lubricants or Hydraulic Fluids".

3. NRL Report No. P-2308 of September 1944 entitled "The Laboratory Evaluation of Hydraulic Oils - Part II, New Fluids having Improved Inflammability Characteristics".

4. General Electric Company report of December 1943 entitled "Silicone Oils - Part III. Hydraulic Service Tests" by D. F. Wilcock.

5. NRL Report No. P-2481 of March 1945 entitled "Investigation of Silicone Polymer Fluids - Part III, Performance as Hydraulic Fluids in Gear Pumps".

6. NRL Report No. P-2499 of April 1945 entitled "Investigation of Silicone Polymer Fluids - Part IV, The Performance Characteristics in a Unilaterally Loaded Journal Bearing".


[redacted]

DECLASSIFIED

DECLASSIFIED

## Table I

Results of Piston Pump Tests on Petroleum Oil Prepared according to Specification AN-VV-O-366b
(Test temperature at sump 180°F)

| | Start | After 100 hrs. | After 200 hrs. | After 300 hrs. |
|---|---|---|---|---|
| Test pressure (psi) | 1500 | 1500 | 1500 | 1500 |
| Pressure drop across relief valve (psi) | 1450 | 1450 | 1450 | 1450 |
| Flow rate GMM | 2.94 | 2.68 | 2.85 | 2.84 |
| Approx. number of cycles | 0 | 5360. | 11390. | 16450. |
| Visc. cs. at 100°F | 14.27 | 10.73 | 9.637 | 9.58 |
| Percent visc. change | 0 | 24.8 | 32.4 | 32.9 |
| Filter type used | Skinner | Skinner | Skinner | Skinner |
| Appearance of oil | Clear red | Clear red | Clear red | Clear red |

[redacted]

DECLASSIFIED

DECLASSIFIED

## Table II

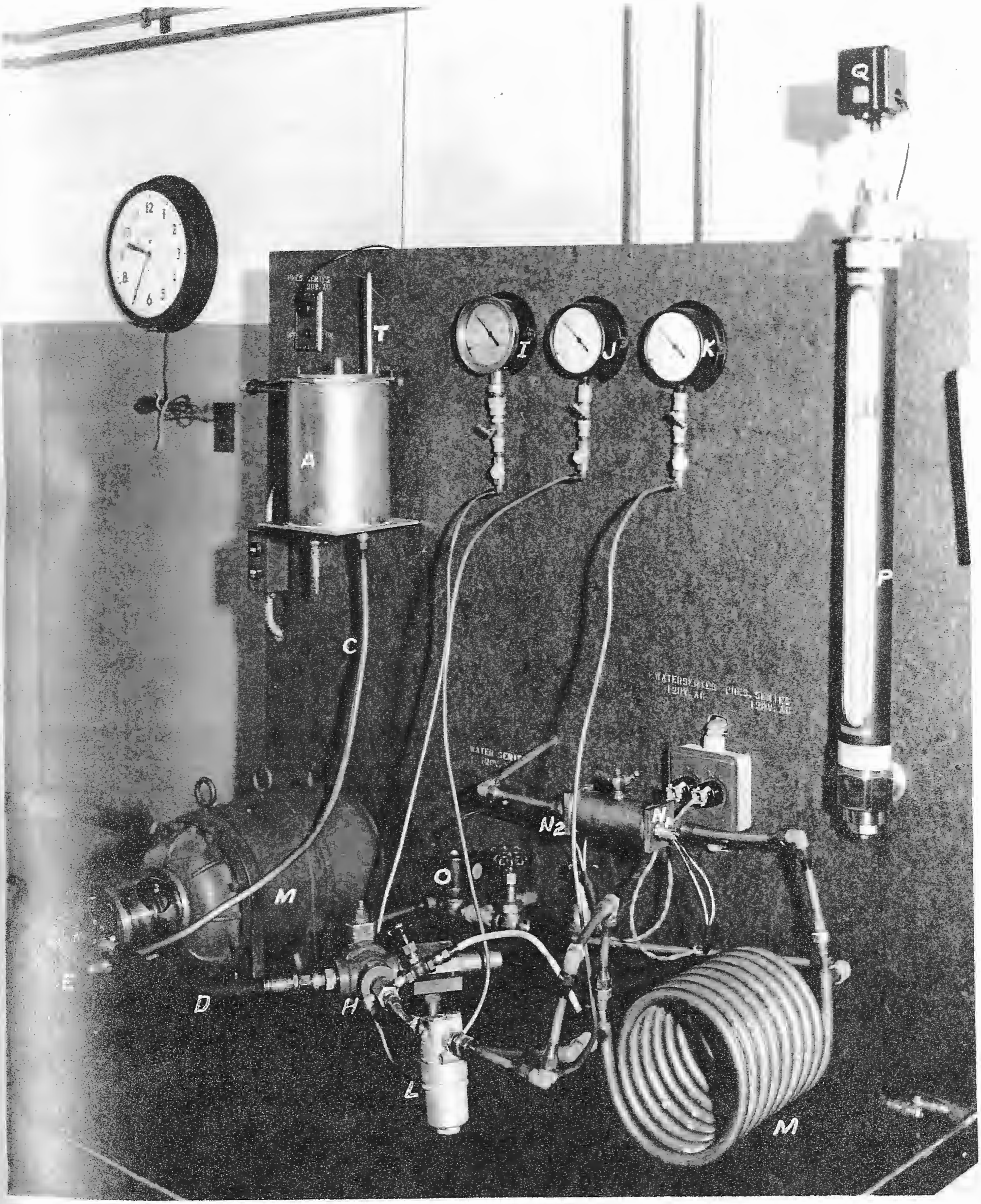
### Piston Pump Tests as Silicone Hydraulic Fluid

| | Run $F_1$ (Steel knuckles) | Run VPI (Steel knuckles) | Run $VP_2$ (Bronze knuckles) |
|---|---|---|---|
| Time in hours | 65 | 80 | 650 |
| Sump temp. °F | 140 | 100 | 180 |
| PSI high | 1500 | 1500 | 1500 |
| PSI low | 190 | 75 | 64 |
| Flow GPM: | | | |
| Start | 3.18 | 2.7 | 3.4 |
| Finish | 0 | 0 | 2.99 |
| Cycles approximately | 1908 | 4500 | 38900 |
| Visc. cs. at 100°F | | | |
| Start: | 71.11 | 71.11 | 71.11 |
| Finish | 73.22 | 71.28 | 73.67 |
| Percent change | + 0.3 | nil | + 0.36 |
| Filter type | Skinner | Purolator aircraft | Purolator aircraft |
| Appearance after run | Cloudy gray | Cloudy gray | Clear, light amber |

[redacted]

DECLASSIFIED

DECLASSIFIED




HYDRAULIC TEST SET-UP USED

DECLASSIFIED

DECLASSIFIED

UNIVERSAL LINK, STEEL KNUCKLE, AND BRONZE CYLINDER AFTER
300 HOURS OPERATION WITH PETROLEUM FLUID

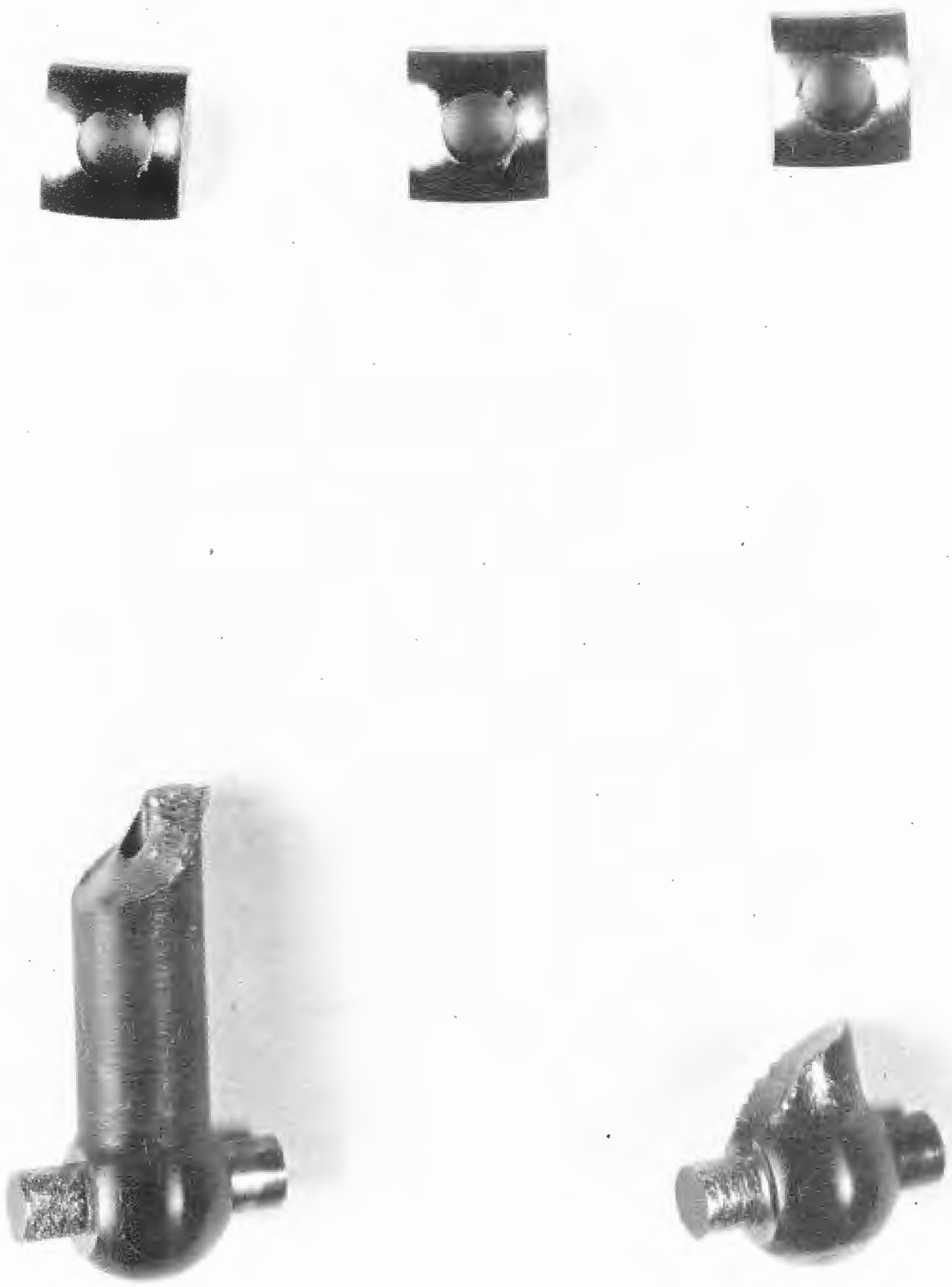
DECLASSIFIED

DECLASSIFIED

BRONZE PUMP CYLINDER BLOCK AFTER 300 HOURS OPERATION WITH PETROLEUM FLUID

DECLASSIFIED

DECLASSIFIED

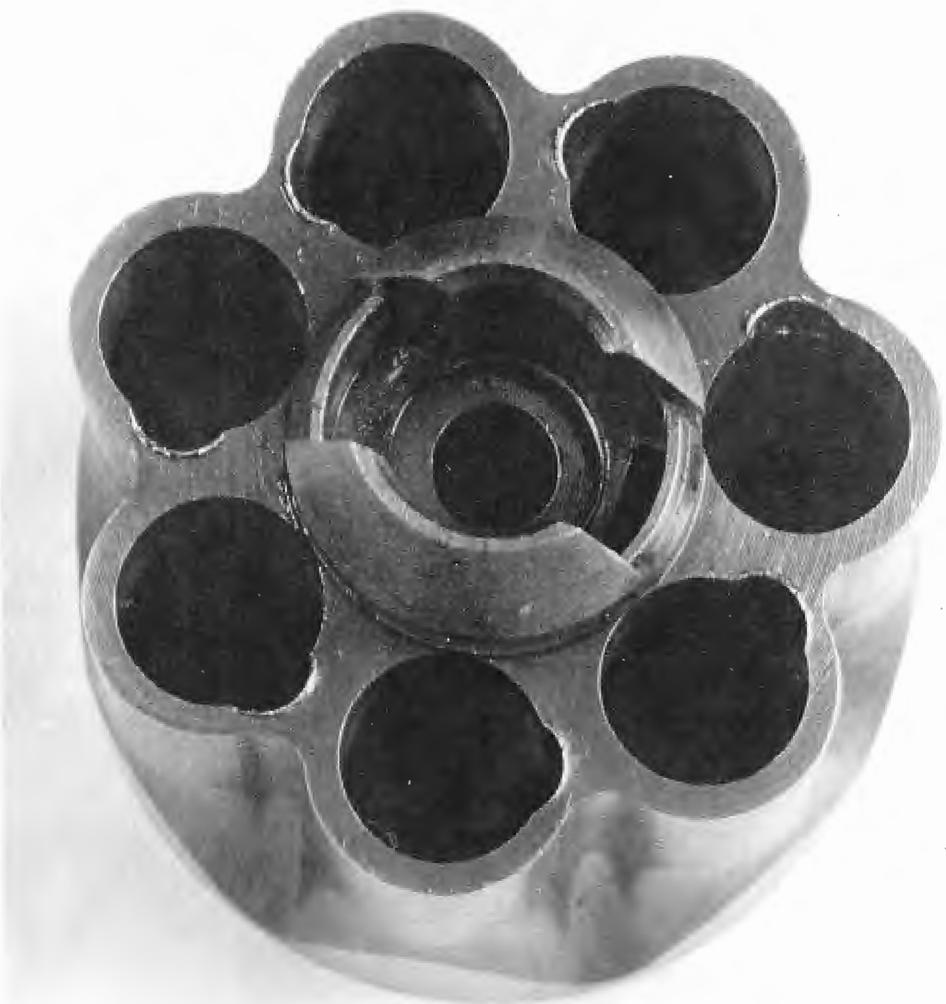


DECLASSIFIED

UNIVERSAL LINK AND STEEL KNUCKLES AFTER 80 HOURS OPERATION
IN SILICONE FLUID (RUN VPL)

PLATE 4

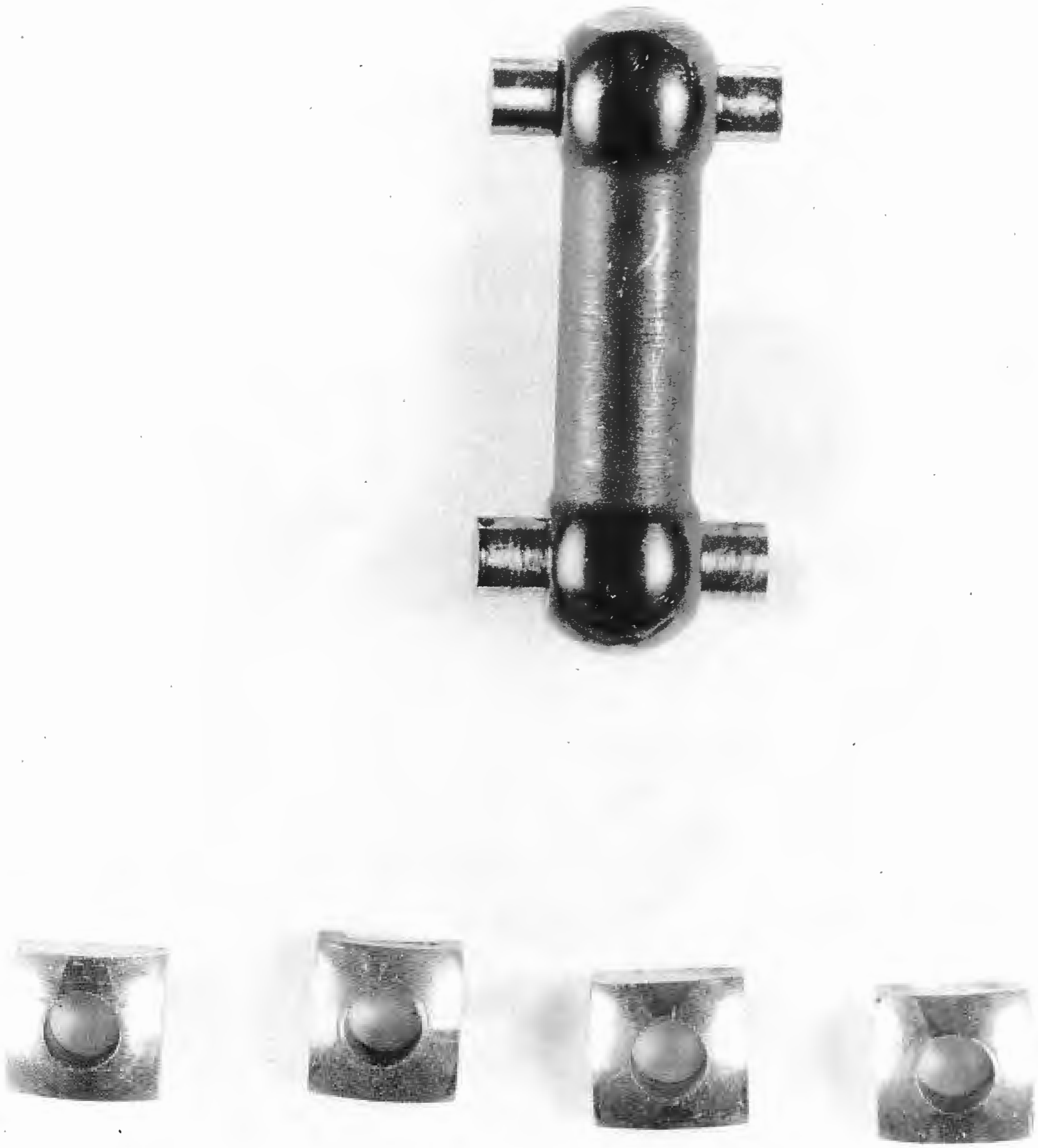
DECLASSIFIED



BRONZE PUMP CYLINDER BLOCK AFTER 80 HOURS OPERATION IN SILICONE FLUID (RUN VP1)

DECLASSIFIED

DECLASSIFIED



UNIVERSAL LINK, BRONZE KNUCKLES AFTER 650 HOURS OPERATION
IN SILICONE FLUID (RUN VP2)

DECLASSIFIED

DECLASSIFIED

BRONZE PUMP CYLINDER BLOCK AFTER 650 HOURS OPERATION IN SILICONE FLUID (RUN VP2)

DECLASSIFIED