THE EFFECT OF METALS ON THE DETERIORATION OF STEAM-TURBINE OILS

by

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I - INTRODUCTION

From the viewpoint of the engineer the basic essentials of steam-turbine oils are durability and reliability. It must reliably perform its functions as a lubricant and coolent over long periods of time. Industrial units are often operated for a week or more and central station units are frequently run for several months, and even as long as a year without a shutdown. To have to shutdown a large high-efficiency unit because of lubricating oil trouble and carry the load on smaller less-efficient units is, in most instances, very expensive.

While performing these services the oil is subjected to severe operating conditions that are brought about by subjecting the oil to detrimental influences. Several factors, apart from the oil itself that tend to cause turbine oil to deteriorate are: (a) water, (b) heat, (c) air, (d) solid impurities, (e) electric action, (f) constant agitation, and (g) some metals. These factors individually and collectively tend to bring about emulsification, sludge formation, and foaming.

Water, particulary in industrial units, is probably the most prevalent of all impurities. A mechanical mixture of oil and water forms an emulsion, which may separate readily if the oil is a carefully refined mineral oil, and if it is permitted to remain quiet for a considerable period of time. A pure emulsion is probably not harmful, but emulsions tend to collect and hold impurities, that accelerate oxidation and sludge formation.

Lubricating oils are complex chemical compounds consisting chiefly of hydrogen and carbon that are united chemically to form organic compounds known as hydrocarbons. Oxidation is the chemical combination of these compounds with oxygen. Air supplies the necessary oxygen for oxidation; heat renders the oil more susceptible to chemical change; metals and solid impurities act as catalytic agents to hasten the action; and agitation further accelerates oxidation by intimately mixing the oil, air and impurities. The rate of oxidation depends upon the extent to which these detrimental influences are present, and upon the ability of the oil to resist such action.

When lubricating oil oxidizes a variety of complex products are formed; the chief ones are believed to be various alcohols, ketones, aldehydes, esters, organic acids, and metallic soaps. In practice, these products are variously referred to as varnish and lacquer, and are usually divided into two classes; namely, those soluble and those insoluble in oil at the operating temperature.

Soluble products are not deposited in the parts of the system that are at normal operating temperature, but some may be deposited on the cold surfaces of the cooling coils, interfering with heat transfer, and in other parts of the system where the oil is quiet and the temperature is below normal.

Insoluble oxidized hydrocarbons may be carried with the oil in circulation and tend to settle and form deposits in coolers, strainers, bearing housings, oil pipes and passages, and particularly in reservoirs. Such deposits tend to reduce the heat transfer in the oil coolers, clog the oil systems, and in severe cases may cause complete stoppage of the oil flow to the bearings.

The accumulation of oxidized hydrocarbons, whether soluble or insoluble in oil at operating temperatures, impairs the resistance of the oil to emulsification.

All deposits in turbine circulating systems are commonly known as sludge, but chemically sludge is percipitated oxidized hydrocarbons. This so-called sludge may be a relatively dry punk-like deposit, which consists mainly of oxidized hydrocarbons, or it may be a slimy, liver-like mass, consisting of emulsions of oxidized hydrocarbons, other impurities, and a large quantity of otherwise good oil. Sludge in general does not form suddenly, but only after the oil has been in prolonged service. The formation of sludge, therefore, is usually due to a gradual change in the condition of the oil, brought about by oxidation, by the accumulation of emulsions and oxidized hydrocarbons tending to break down the stability of the oil.

Accumulations of sludge in oil pipes, passages, and cooler impair the circulation of the oil and cause high oil and bearing temperatures, which accelerate oxidation. Sludge also has a detrimental effect upon the operation of the hydraulic type of governor gear. It causes this type of governor gear to operate sluggishly, and even render it inoperative in extreme cases.

The deterioration of turbine oils, then, is affected by several factors. This study was made of only one of these factors; namely, the effect of metals on oil deterioration. This factor, however, has not received the attention that it probably merits, hence very little scientific information is available on the subject.

II - OBJECT OF THE INVESTIGATION

This study was made for the purpose of obtaining some accurate and concrete data on the effects of several metals, common to steam-turbine lubricating systems, on the deterioration of three commercial steam-turbine oils.

III - REVIEW OF LITERATURE

A search of the literature indicates that Waters was the first to call attention to the effect of metals on the deterioration of oils (1). In a paper published in 1911 he gave the results obtained when two pure mineral oils were heated in the presence of several metals. He used tubes 20 mm. in diameter and 105 mm. long made from ordinary brass, cold-rolled steel, 0.8 per cent carbon steel, vanadium steel, chrome steel and cast iron. Five gram samples of the oil were heated at 482° F for three hours in each of the tubes. No air was forced into the samples, but the tubes were open to the atmosphere.

He was interested in the amount of insoluble sludge and varnish formed and made no other inspections. The amount of insoluble material was determined by adding 25 cc of petroleum ether to the oxidation products and allowing the mixture to settle for 22 hours. The insoluble material was then filtered and weighed. The amount of varnish deposited was determined by weighing the tubes before and after removing the varnish.

Cold rolled steel and brass were increasingly effective in producing insoluble in oil B. The other metals had no more effect than glass on the oil. Insoluble was formed from oil C in an increasing amount by chrome vanadium steel and brass. Cast iron gave less insoluble than glass. Vanadium steel and cold-rolled steel were not tested with this oil. In all cases the varnish formed was less with metal tubes than it was with glass.

In 1921 Waters made additional tests (2). This time instead of using metal containers, he placed strips of metal in the samples of oil and heated the oil and metal to 482°F for two hours in glass Erlenmyer flasks. The metal strips were 11 by 72 mm and from 0.2 to 0.6 mm thick. These strips were polished with fine emery cloth, washed with water and dried, prior to using. The amount of oil used in each test was ten grams.

Results of these tests show that zinc and aluminium cause no increase in quantity of precipitate formed; that steel, cast iron, nickel and cobalt cause slight acceleration and that phosphor-bronze, brass and copper greatly accelerate the rate of oxidation.

An iron tank called a "sludge accelerator" was designed in 1924 by Funk for the purpose of determining the sludge and emulsion characteristics of turbine oils (3). The oil, at a temperature of 212°F, was circulated through an iron tank in the presence of air and water. The purpose of this work was primarily for devising a suitable test for turbine oils rather than determining the effect of the metal, air or water on the oil. This test is now known as the "Funk" test.

Rogers and Miller did some noteworthy work in 1926 (4). They tested several turbine oils in the presence of copper and iron and attempted to correlate the sludging rate of the oil with the results obtained from the same oils in actual service.

In these tests 500 ml. of oil were heated in a water bath at 210°F. Samples of oil were withdrawn at intervals of 48 hours and inspected for acidity and demulsibility. Oxygen at the rate of two or three bubbles per second was passed through the oil.

Preliminary tests were conducted for 300 hours with copper and iron. The final tests were made with iron alone and were conducted for 500 hours. The iron used in each test was a piece of 18-gage iron wire 40 inches long.

Oxidation was accelerated somewhat by iron and still more by copper. The Herschel demulsibility values dropped rapidly. One oil showed no sludge until after 300 hours and the other none until after 500 hours.

The summary given by the writers was: "The deterioration which turbine oils undergo in service is due to oxidation. Two types of oxidation products are formed: (1) asphalic material insoluble in the oil. (2) Free acids soluble in the oil. The latter in the presence of water form insoluble soaps in contact with metals such as iron and copper."

Dornte and Ferguson investigated, in 1936, the effect of copper, iron, tin, and lead on the oxygen absorption of different oils. (5) They found that the rate of absorption in all cases gradually decreased with time, possibly because the constituents of the oil were being oxidized and gradually decreasing in quantity. In all investigations, also, the rate of oxidation was not increased to any appreciable degree by increasing the ratio of metal surface to oil. Copper increased the rate of oxidation 20 times, iron three times and tin and lead doubled the rate of oxidation.

Haringhuiren and Was made several tests with copper, tin and lead in 1937. (6). They heated 50 ml. samples of oil contained in glass basins to 207°F for 1350 hours.

They found that the viscosity, surface tension and acidity of the oils were not influenced by the metals. Copper stimulated sludge formation and tin and lead acted as anti-oxidents. The amount of sludge formed depended on the amount of aromatic compounds in the oils. They investigated the corrosion by an optical method and found that copper was strongly affected; that tin and lead were protected by a film of reaction products. The amount of sludge formed was determined by filtering the oil and weighing the sludge.

In 1937 Weiland made a series of tests on several different oils at different temperatures(7). These tests were conducted at temperatures from 250° to 350°F. Most of the oils showed very little change when tested at the lower temperature, whereas at the higher temperature the rate of oxidation was, in some instances, excessive and the behavior of a few of the oils was erratic. The most logical and consistent results were obtained from the tests made at 300°F.

Blends of fatty and mineral oils were relatively stable for a while then deterioration increased rapidly. Mixed-base oils showed medium oxidation numbers and oxidation tended to become constant. Paraffin base and solvent extraction oils gave very low oxidation numbers and became stable at low oxidation numbers.

Farmer studied the catalytic effect of several metals on turbine oils last year (8). He heated 400 ml. of oil in the presence of metals to 212°F. Ten liters of air per hour was bubled through the oil. Samples of oil were withdrawn every 100 hours and inspected for acidity, viscosity, percipitation number and color. The samples used for viscosity and color were returned to the tubes and only a small amount was lost each time. In his tests he used several turbine oils and two metals; namely, iron and brass.

His preliminary work showed that Admiralty metal did not have much effect on the rate of oxidation. Brass accelerated oxidation three times as fast as iron, but one oil was unaffected by brass. Brass and iron in the same sample of oil oxidized it more rapidly than brass alone.

A good oil may not be oxidized much by this test in less than 1000 hours. An oil that will remain unchanged for 300 hours in the "Funk" test with brass added to the iron and water was found to be very stable.

Some tests have been made recently at the Gulf Oil Corporation laboratory (9). Each oil sample with ten per cent of water added was contained in cylinderical tanks of two gallons capacity, and constructed of aluminum, steel and stainless steel. Pumps and short lengths of connecting pipes were of steel or iron. The oil and water mixture was maintained at a temperature of 195° to 200° F, and circulated at a rate of several gallons per minute, being picked up at the base of the tank and returned at a point just below the oil level. Oxygen was supplied at the inlet of the circulating gear pump at a rate of five liters per hour; the gas was vented from each tank through an opening in the cover. Oil samples were taken periodically for inspections of acidity and steam-emulsion number.

A number of representative turbine oils were tested over a period of months, all of which showed similar influences of the effect of the various metals. However, the useful life of the several oils varied widely. The indicated useful life of the oils in the presence of alumnium is 46 per cent greater than in the presence of steel, and about 50 per cent greater than in the presence of stainless steel.

Weiland extended his work in 1939. (10) He found that the presence of metals in the oil sample during oxidation has a variable effect and is quite alarming with some internal-combustion engine lubricating oils. However, he made no tests with steam-turbine oils. One oil was far superior to all other oils in resisting the catalytic action of copper, but no information was given regarding the behavior of the same oil in the presence of any other metals. Some oils were oxidized in the presence of a strip of metal cut from an aluminum alloy piston. This alloy caused the oils to deteriorate faster but not as fast as copper.

The results of previous work then indicate that copper, lead, tin, brass and zinc are most effective in promoting acid and sludge formation. Iron, nickel and aluminum slightly accelerate oxidation. However, not all investigators agree regarding the action of some metals. Haringhuizen and Was found tin and lead to be anti-oxidizing, whereas Dornte found lead second and tin last in promoting oxidation.

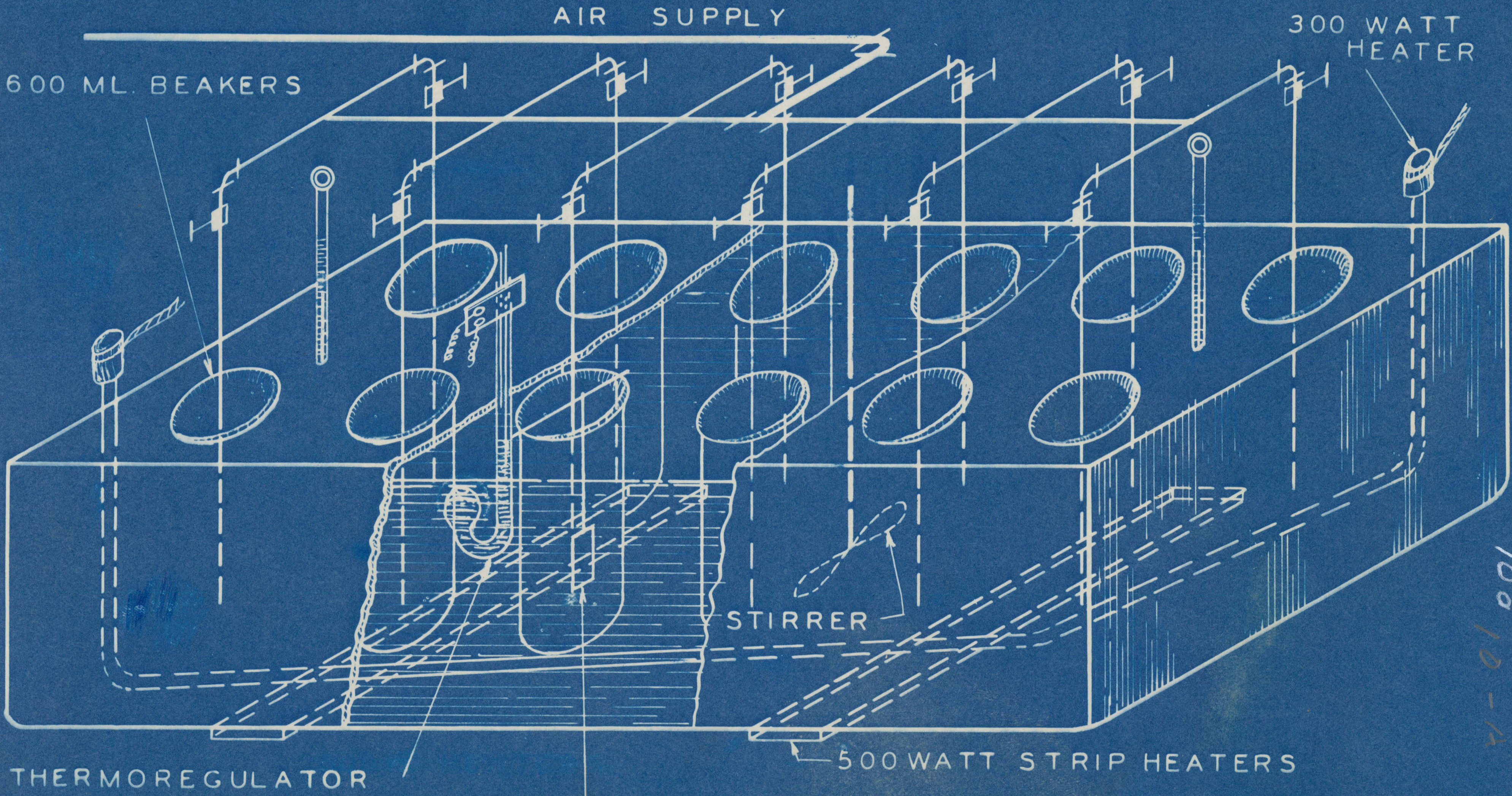

FIG. 1.— OIL SENSITIVITY APPARATUS

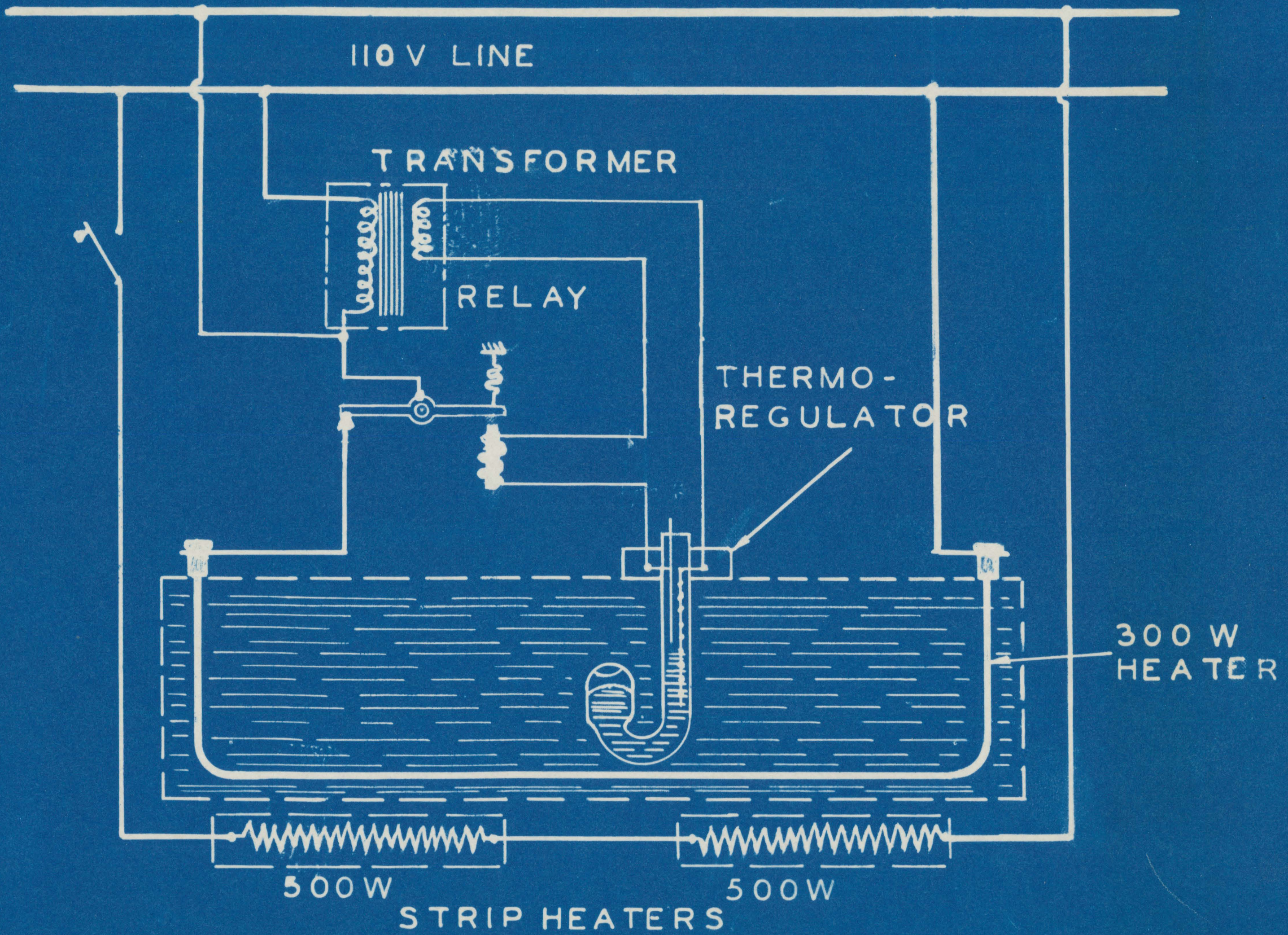

FIG. 2. -ELECTRIC HEATING CIRCUIT

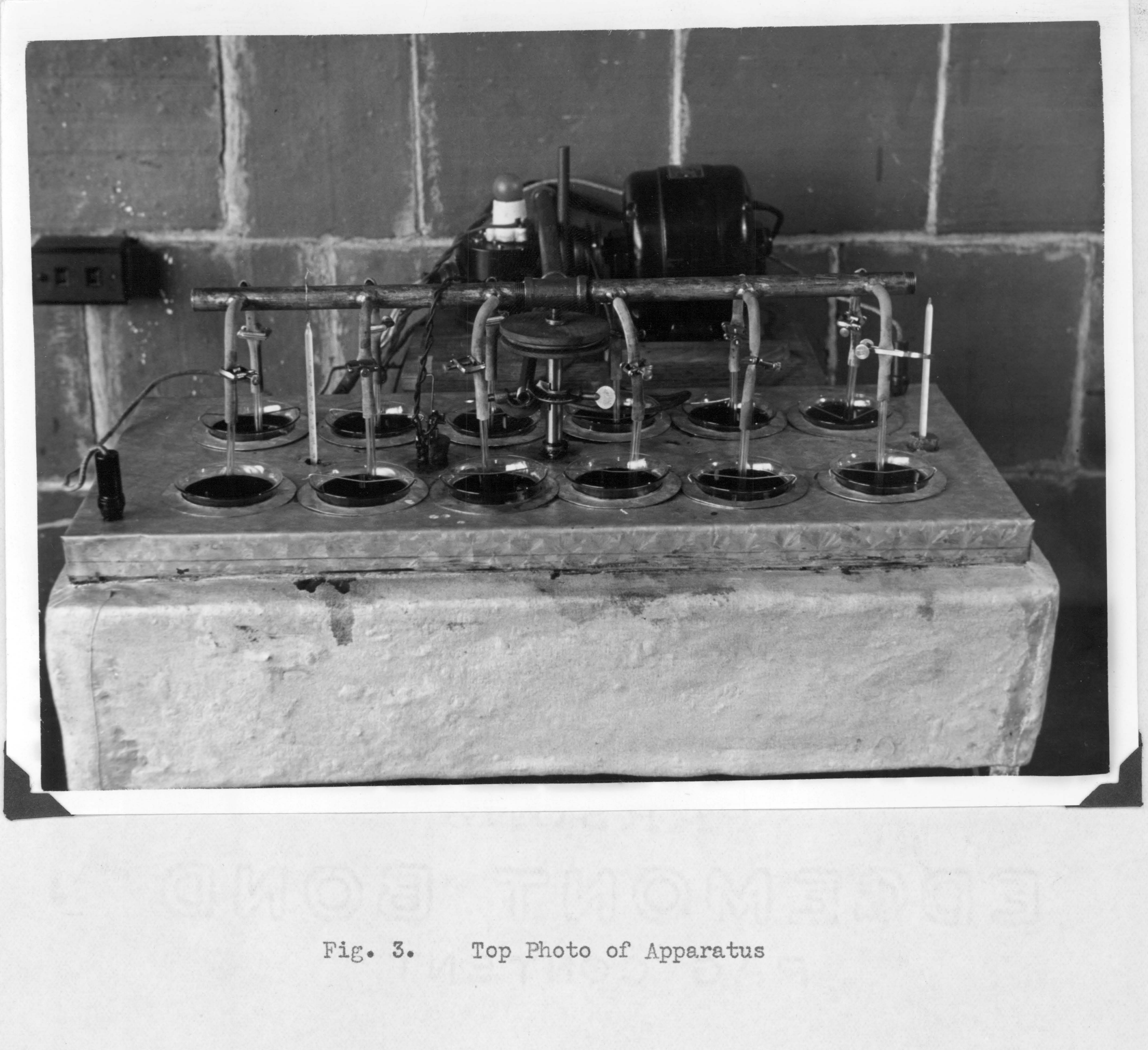

Fig. 3. Top Photo of Apparatus

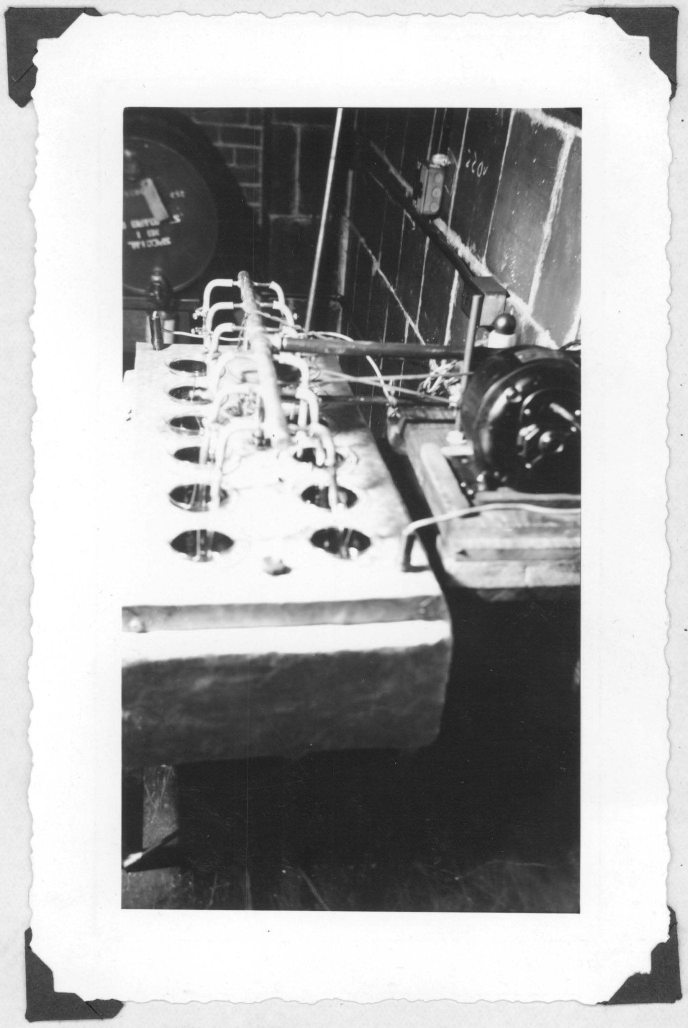

Fig. 4. End Photo of Apparatus

IV - THE INVESTIGATION

Apparatus: The apparatus used for this investigation was constructed in the Mechanical Laboratory of the Virginia Polytechnic Institute. It consisted essentially of an "oil bath", electric heaters, an agitator for the heat transfer medium, test oils, metal samples, and 600 ml. beakers, as shown in Fig. 1.

The oil bath was a rectangular box constructed of galvanized sheet steel, 32 inches long by 14 inches wide and nine inches deep. 12 two three-fourth inch diameter holes were cut in the top to hold the beakers that contained the oil and metal samples. Two 500-watt strip electric heaters were placed under the bath and one 300-watt immersion heater was installed inside the bath. The latter heater was controlled by a thermoregulator as shown in Fig. 2. The oil bath was placed on a steel stand and the sides, ends, and bottom were covered with one and one-half inches of magnesia insulation. Two holes were cut in the top, one in each end, for the thermometers. The tank was then filled with used oil to a point such that the level was one inch below the top.

The temperature of the bath was maintained at a constant temperature by a Precision Temperature Regulator, which consisted of a mercury thermostatic control and a 115-volt, five ampere relay as shown in Fig. 2. The temperature control was connected to the 300-watt immersion heater.

The agitating apparatus for the bath is shown in Fig. 3. It was a propeller mounted on a shaft, which extended into the oil bath four inches. It was mounted on top of and in the center of the oil bath, and was driven by a one-quarter horsepower electric motor at a speed sufficient to hold the temperature constant within three degrees Fahrenheit in all the samples.

Air was supplied from an outside source and distributed to the oil and metal samples through a distribution system as shown in Fig. 1. This system was mounted directly above the oil bath and the distributing manifold consisted of a piece of three-fourth inch pipe having closed ends and extending the entire length of the bath. Twelve holes were drilled in the pipe and short pieces of one-fourth inch copper tubing were soldered over the holes. The holes were drilled so that after assembly of the apparatus they were directly over the beakers containing the oil samples. Glass tubes were placed in the beakers and rubber tubing was used to connect the glass tubes to the copper tubes in the distribution pipe. Valves were placed in the lines for controlling the flow of air to the oil samples.

The containers for the oil samples were standard 600 ml. Pyrex glass high form beakers.

Materials: The bearing metals used were all metals made by the Federal-Mogul Corporation, Detroit, Michigan. Two samples 0.10 in. thick and 1.0625 in. in diameter were used in each oil sample. The total exposed area was approximately 2.44 square inches.

Metal No. 5 was a lead-bronze bearing material containing 39.5 per cent lead, 68.5 per cent copper, and 2.0 per cent nickel.

Metal No. 6 was Babbitt and is known as the Society of Automotive Engineers' No. 10 Babbitt. The composition of this material was 89.0

per cent tin, 0.25 per cent lead, 3.7 per cent copper, and 7.3 per cent antimony.

Metal No. 8 was a cadmium-silver bearing material of 97.45 per cent cadmium, 2.25 per cent silver, and 0.30 per cent copper.

Metal No. 9 contained 83.5 per cent lead, 10.0 per cent antimony, 6.0 per cent tin, and 0.5 per cent copper.

Metal No. 10 was cadmium-nickel bearing alloy containing 98.5 per cent cadmium and 1.5 per cent nickel.

The remaining metals were all sheet materials. All samples of these metals were cut two inches long and one inch wide. Each sample was of uniform thickness, but the thickness varied from one-thirty second to three-thirty seconds of an inch for the different metals. One sample was used in each oil sample, except in the cases where two metals were used in the same oil sample. In such cases one sample of each metal was used. The exposed area of each sample was approximately 2.38 square inches.

The lead was chemical lead of 99.93 per cent lead, and 0.07 per cent copper.

The copper was a commercial grade of soft sheet copper.

The composition of the Monel metal was 68.0 per cent nickel, 27.0 per cent copper, and iron, magnesium, silicon and carbon 5.0 per cent.

The zinc was 99.25 per cent zinc, 0.25 per cent lead, and 0.40 per cent cadmium.

The composition of the alumnium was within the following limits: copper, 3.6 to 4.7 per cent; magnesium, 1.25 to 1.75; mangenese, 0.3 to 0.9 per cent; and a minimum of 92.0 per cent aluminum. It was commercial sheet material and is classified as 24-S grey plate half hard as is widely used in the aviation industry.

The steel was ordinary hot rolled, low carbon sheet.

The tin used was a high-grade alloy, which is used for making electric light reflectors, but its composition could not be obtained.

The brass was a commercial grade of sheet brass but the composition of it could not be secured.

Method of Conducting tests: The metals were cut to the dimensions previously given, then cleaned and weighed. They were not polished because it was desired to simulate actual conditions as closely as possible. The object in cleaning them was to remove any tarnish or foreign material from the metal. By so doing the catalytic effect on the oil would be that of the metal and not that of some oxide of the metal, or some other unknown substance.

The oil samples of 400 ml. each were poured into the 600 ml. beakers and a small wire was fastened across the top of each beaker from which the metal sample was suspended into the oil by a cotton thread.

Two or three bubbles of air per second were passed through the oil to accelerate oxidation. No attempt was made to determine the amount of air supplied to the oil samples. Other investigators have found that the consumption of oxygen was relatively slow and the rate of oxidation is not a function of the amount of oxygen supplied as long as there is an excess of oxygen (4, 5).

Test No. 1 was run with each oil and with three metals. Each oil was, also, tested without a metal to give a basis for comparison. The test was started at 200°F. but after the oil was oxidized for 264 hours at this temperature it showed very little change and the temperature was then increased to 275°F. The test was ended after 106 hours at this temperature.

Test No. 2 was conducted at 275°F for 200 hours. At the end of this period the blank oils (oils without metals) showed that oxidation had progressed as far as it did in the first test.

Tests Nos. 3 and 4 were conducted as was No. 2: however, blanks of oils containing no metal were included in each test, thus giving a check on the correlation between the different runs.

After the oils were oxidized, laboratory inspections were performed on each sample to determine the extent of oxidation. The following American Society for Testing Materials methods of testing were followed:

1. Standard Method of Test for Viscosity by means of the Saybolt Viscosimeter. (D88-38)

2. Tentative Method of Test for Neutralization Number of Petroleum Products and Lubricants. (D188-27T)

3. Standard Method of Test for Precipitation Number of Lubricating Oils. (D91-39)

4. Standard Method of Test for Gravity of Petroleum Products by Means of the Hydrometer. (D287-39)

The colors of the oils were determined by a Tag-Robinson instrument and are designated as Tag-Robinson Numbers.

Oil A (Gargolyle D.T.E. Light) is a straight mineral oil made by the Socony-Vacuum Oil Company. The properties as given by the manufacturer are as follows:

Specific gravity	0.885	
Pour point	5.	deg. F.
Flash point	385.	" "
Fire point	440.	" "
Viscosity at 100°F.	148 to 155 S.U. S.	

Viscosity at 130°F.	85	S.U.S.
Viscosity at 210°F.	42	"
Color (Lovibond scale)	1	

Oil B (Gulforest A) is a straight mineral oil made by the Gulf Oil Corporation. They list the properties as follows:

Specific gravity	0.863	
Pour point	0.	deg. F.
Flash point	395.	" "
Fire point	460.	" "
Viscosity at 100°F.	150.	S.U.S.
Viscosity at 130°F.	85.	"
Viscosity at 210°F.	43.	"
Color (N.P.A. scale)	1.	
Carbon-residue	0.01	per cent
Neutralization number	neutral	
Oxidation number (Sligh)	4.0	
Demulsibility at 130°F.	1620.	

Oil C (Teresso 43) is made by the Standard Oil Company of New Jersey. It is straight mineral oil to which a special oxidation inhibitor has been added. The properties as given by the manufacturer are as follows:

Specific gravity	0.855
Viscosity at 100° F.	166.
Color (Tag-Robinson)	14.
Neutralization number	neutral
Precipitation number	0.

16a

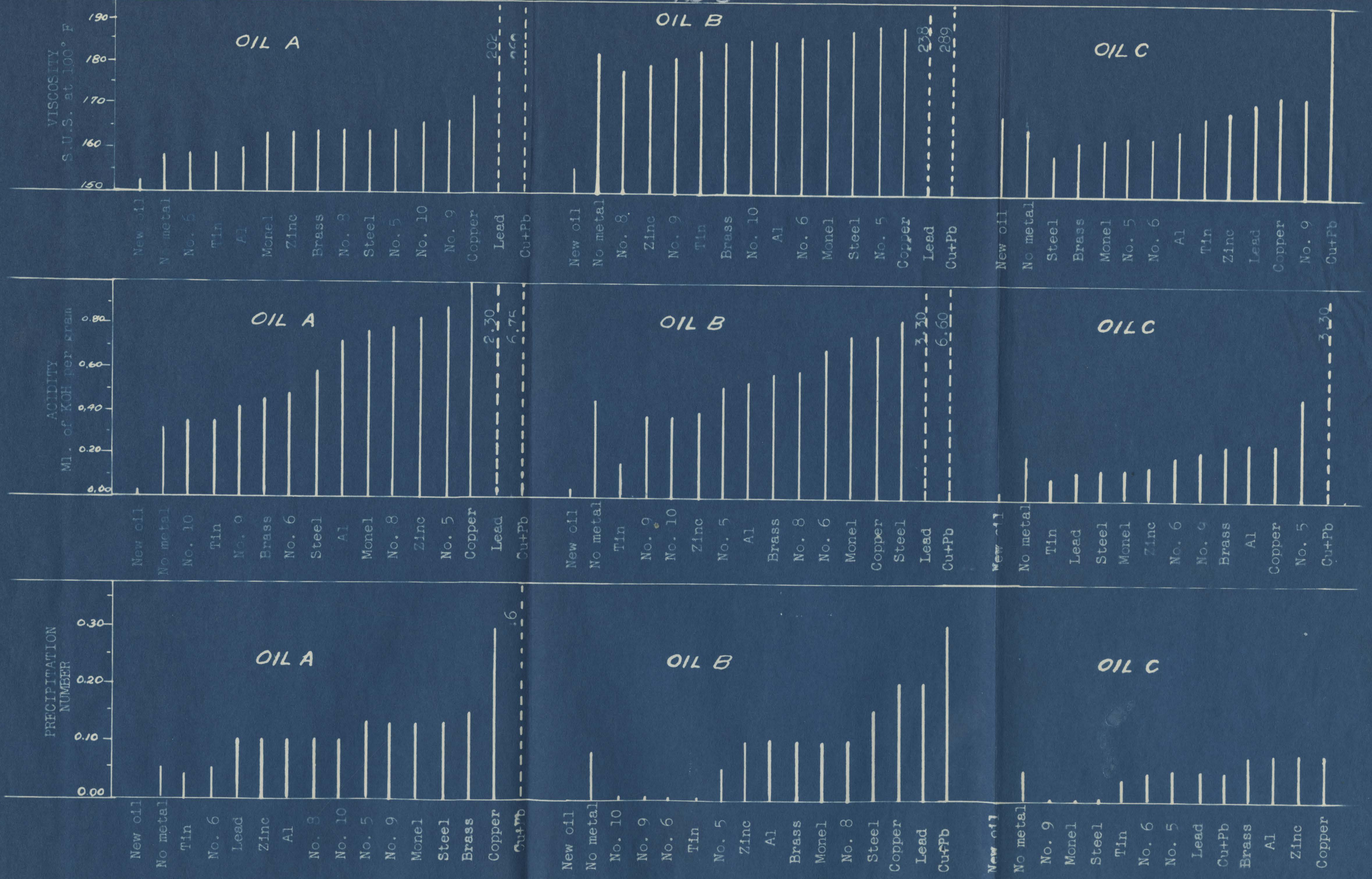

FIG. 6. GRAPHICAL REPRESENTATION OF LABORATORY INSPECTIONS

TABLE I. SUMMARY OF RESULTS OF LABORATORY INSPECTIONS

Metal	Viscosity S.U.S. at 100°F			Acidity Ml of KOH per gm			Precipitation Number			Color Number Tag-Robinson			Specific Gravity		
	Oil A	Oil B	Oil C	Oil A	Oil B	Oil C	Oil A	Oil B	Oil C	Oil A	Oil B	Oil C	Oil A	Oil B	Oil C
New oil	152.4	156.0	168.8	0.02	0.04	0.03	0.00	0.00	0.00	17.25*	23.50*	13.75*	0.877	0.861	0.854
No metal	159.7	182.8	164.2	0.32	0.42	0.20	0.05	0.08	0.05	12.00	8.75	15.00*	0.877	0.865	0.856
Copper+Lead	260.0	289.0	196.2	6.75	6.60	3.30	0.60	0.30	0.05	8.00	8.75	10.25	0.899	0.883	0.870
Copper	172.9	189.8	173.6	1.00	0.77	0.26	0.30	0.20	0.08	8.00	9.20	10.50	0.880	0.866	0.860
Lead	202.0	238.0	172.0	2.30	3.30	0.13	0.10	0.20	0.05	9.00	8.40	13.15	0.887	0.877	0.859
Zinc	164.0	180.0	170.5	0.83	0.40	0.15	0.10	0.10	0.08	9.00	9.00	11.00	0.880	0.886	0.860
Steel	165.0	187.5	159.8	0.58	0.83	0.13	0.13	0.15	trace	8.75	8.40	13.75	0.880	0.867	0.857
Aluminum	160.7	185.8	165.2	0.72	0.55	0.25	0.10	0.10	0.08	8.50	9.00	9.00	0.880	0.867	0.857
Brass	164.8	185.2	162.3	0.45	0.58	0.25	0.15	0.10	0.08	8.40	9.25	10.00	0.878	0.867	0.857
Monel	163.6	186.5	162.8	0.75	0.75	0.13	0.13	0.10	trace	8.50	8.65	14.00	0.879	0.864	0.857
Tin	159.4	183.6	167.8	0.35	0.16	0.09	0.03	trace	0.03	9.15	9.20	12.20	0.878	0.862	0.856
Metal No. 5	163.5	188.8	164.0	0.88	0.53	0.48	0.13	0.05	0.05	8.50	9.00	11.00	0.880	0.864	0.856
Metal No. 6	158.5	186.0	164.0	0.48	0.70	0.20	0.05	trace	0.05	9.00	8.75	11.25	0.880	0.865	0.857
Metal No. 8	164.8	178.5	-----	0.78	0.60	----	0.10	0.10	----	8.75	8.50	-----	0.880	0.866	-----
Metal No. 9	166.2	181.5	173.8	0.43	0.38	0.23	0.13	trace	trace	8.50	9.50	13.00	0.879	0.863	0.858
Metal No. 10	166.8	185.5	-----	0.35	0.38	----	0.10	trace	----	8.90	9.25	-----	0.878	0.863	-----

DESCRIPTION OF METALS

Aluminum.	24-S grey plate (half hard). Min Al 92.0% Cu 3.6-4.7 %, Mg 1.25-1.75 %, Mn 0.3-0.9 %.
Copper.	Commercial soft copper.
Monel.	Ni 68.0 %, Cu 27.0 %, Fe, Mg, Si, and C 5.0 %
Zinc.	Zn 99.25 %, Pb 0.25 %, Cd 0.40 %.
Lead.	Chemical lead. Pb 99.93 %, Cu 0.07 %.
Tin.	Commercial grade composition unknown.
Brass.	Composition unknown.
Steel.	Hot rolled sheet steel.
Metal No. 5.	Pb 39.5 %, Cu 68.5 %, Ni 2.0%.
Metal No. 6.	S.A.E. No. 10 Babbitt. Sn 89.0 %, Cu 37.0 % Sb 7.3 %, Pb 0.25 %.
Metal No. 8.	Cd 97.45 %, Ag 2.25 %, Cu 0.30 %.
Metal No. 9.	Sn 6.0 %, Pb 83.5 %, Cu 0.5 %, Sb 10.0 %.
Metal No. 10.	Cd 98.5 %, Ni 1.5 %.

* Note: Samples not marked have been diluted with kerosene. 85 Ml of kerosene and 15 Ml of oil as specified by A. S. T. M.

V - DISCUSSION OF RESULTS

Viscosity: The values of all blanks were averaged and are used as a basis for comparison. All other values are for one test only and it would be impossible to say that the same results would be obtained from another similar test, but the results for the blanks are in close agreement and it seems reasonable to conclude that, generally speaking, the other results would be very close to an average value for several tests.

As shown in Table I and Fig. 6, Oil A had the lowest viscosity of any of the new oils, being 152.5 Saybolt universal seconds. After it was oxidized with no metal present there was an increase in viscosity of seven seconds. Metal No. 6, Babbitt, and tin gave viscosity values just a little less than that for the blank. This would indicate that at least they would not cause much increase in viscosity and possibly would be anti-oxidizing, considering viscosity alone. Metal No. 9, which is mostly lead, and Metal No. 10, which is 98.5 per cent cadmium, caused the viscosity to increase approximately seven seconds above the blank. Copper increased it about 13 seconds. Lead and the copper-lead combination caused the greatest increase in viscosity, especially the last named, which caused an increase of 100 seconds.

New Oil B had a slightly higher viscosity than Oil A, and its viscosity was increased when oxidized with no metal more than the viscosity of Oil A was with most of the metals. Heating alone increased the viscosity of Oil B 27 seconds. Zinc and No. 8 metal showed definite anti-oxidizing properties. With the exception of lead and the combination of copper-lead none of the metals increased the viscosity more than seven seconds above the blank. Lead and copper-lead, as was the case with Oil A, caused the greatest increase in viscosity.

The results of the inspections of Oil C are quire different from those of the other oils. It had the highest initial viscosity of the three oils, but when oxidized with no metal the viscosity was lowered about four seconds. Steel, Monel metal, and brass showed anti-oxidizing properties. The samples containing tin, zinc, and metals Nos. 5 and 6 showed lower viscosities after oxidation than the original oil. Copper and lead caused very little increase, being five and three seconds respectively. The copper-lead combination caused a much greater change but was only 28 seconds higher than the new oil.

In general, the effect of the metals on the viscosity of Oils A and B was very much the same. The oils were not, however, affected the same by any single metal and the order of the change was not the same. The only metal that held the same position was the copper-lead combination. It caused the viscosity to be increased the largest amount with all the oils. Lead held the same position with oils A and B but was replaced by the lead alloy bearing metal No. 9 in Oil C. Oil B showed a greater increase in viscosity when oxidized than the other two oils, but as a whole was affected less by the catalytic action of the metals than the other oils.

Acidity: The acidity of the new oils was, as it should be, very low. The neutralization number of Oil A was increased from 0.02 to 0.32 when it was oxidized without a metal present. Tin and metal No. 10 caused the acidity to be increased slightly above the blank value. The value for both metals was 0.35. These are the only metals that caused the acidity to be increased the same amount. Nine of the samples had neutralization numbers between 0.35 and 1.00. Copper gave a value of 1.00. Lead was second in promoting acidity with a neutralization number of 2.30, and the copper-lead combination was first with a value of 6.75. Tin, copper, lead, and the copper-lead combination were the only metals promoting acidity in the same order that they increased the viscosity.

Oil B had an initial neutralization number of 0.04, and this value was increased to 0.42 in the blank. Tin caused the acidity to be increased to 0.16. This value is much less than that for the blank and indicates that tin is anti-oxidizing with respect to acidity. Zinc and metals Nos. 9 and 10 gave values a little below the value for the blank. The largest amount of acid was produced by the copper-lead combination. Lead was next in line but instead of copper being third, as was the case with Oil A, it was replaced by steel with this oil. Lead and the copper-lead combination were the only metals that correlated acid formation with increase in viscosity.

The neutralization number of new Oil C was 0.03 and in the blank it was increased to 0.20. Tin, lead, zinc, steel and Monel did not cause the acidity to be increased as much as it was in the blank. The only metal to cause a large increase was the copper-lead combination, but the neutralization number with this combination was only about one half as high with this oil as it was with the other two oils. The copper-lead bearing metal No. 5 affected this oil more than it did the other oils, and was second to the copper-lead combination in producing acidity. The same position was occupied by lead in the case of Oils A and B. With the exception of the copper-lead combination there is no correlation between acidity and viscosity.

All three of the oils were oxidized the most with the combination of copper-lead. With this one exception there is no correlation whatever between the three oils. Tin is low with all three, but does not hold the same position all the way through, and is not the same with any two oils. Oils A and B gave high values with lead and Oil C was extremely low with this metal. With the exception of the copper-lead combination and metal No. 5 all the metals formed less acid than was formed in the blanks of the other oils. The copper-lead combination and lead with Oils A and B are the only oils that gave any correlation between viscosity and acidity. Oil B gave viscosity values much higher than either of the others but the acidity values were very much in line with those for Oil A.

Precipitation Number: The precipitation number of all the new oils was zero. The precipitation of Oil A blank was 0.05. Tin was anti-oxidizing with respect to Oil A and caused less sludge than the blank, and metal No. 6 showed the same value as the blank. Lead, zinc, aluminum, and metals Nos. 8 and 10 doubled the amount of sludge that was formed in the blank. Monel metal, steel, and metals Nos. 5 and 9 increased the precipitation number to 0.13. Brass was next, and by itself, in sludge producing properties, giving a value of 0.15. Next to the largest amount of sludge was produced by copper; namely, 0.30; twice as much as brass. The sample containing the copper-lead combination showed the largest amount of precipitate and was 0.60. Lead was not consistent with the results of the previously discussed inspections. In those it was next to the copper-lead combination. With respect to precipitation number, however, it was replaced by copper. The copper-lead combination was the only one that retained the same relative position for the three inspections. In all cases it ranked first, promoting the largest amount of sludge.

The blank of Oil B had a precipitation number of 0.08. Four of the samples, tin, metals Nos. 5, 9 and 10 showed only a trace of sludge. Metal No. 5 produced less sludge than the blank and metal No. 6 caused a slight increase above the blank. These results indicate that as far as sludging is concerned this oil is virtually unaffected by the catalytic action of bearing metals. The precipitation number for the lead and copper samples with Oil B was the same, 0.20. The precipitation number with lead in Oil B was higher than it was with Oil A, but copper was less with Oil B than it was with Oil A. The copper-lead combination caused the highest precipitation number, but it was only one-half of what it was with Oil A. Zinc and metals Nos. 6 and 8 gave the same precipitation number with both Oils A and B. The copper-lead combination produced the most sludge with both oils. This combination and lead, like with Oil A, correlated in that they gave the maximum changes in the viscosity and acidity inspections.

The blank of Oil C produced the same amount of sludge as the blank of Oil A, namely, 0.05. Monel metal, steel, and metal No. 9 showed anti-oxidizing properties by causing only a trace of sludge to be formed. Tin also showed anti-oxidizing characteristics but to a lesser degree than Monel, steel and metal No. 9. Metals Nos. 5 and 6, lead, and the copper-lead combination did not cause any increase above the blank value of 0.05. Brass, aluminum, zinc, and copper gave a precipitation number of 0.08. No correlation was obtained between acidity, viscosity, and precipitation number for this oil. The copper-lead combination, which ranks first in producing maximum changes in all inspections with Oils A and B does not occupy first position in all cases with Oil C. This is not, however, the only irregularity. There is no relation between the precipitation number for this oil and the other two oils. Tin and metal No. 9 consistently gave lower values for all oils than the other metals but were not the same for all three oils, nor did they hold the same position for the three oils.

<u>Specific Gravity:</u> The specific gravity of the three oils varied considerably. For new Oil A it was 0.877, for new Oil B 0.861, and for new Oil C it was 0.854. The gravity of Oil A blank was the same as that of the new oil. None of the metals with the exception of lead and the copper-

lead combination changed the gravity of this oil more than 0.003. Lead increased it from 0.877 to 0.887 and the copper-lead combination increased it to 0.899.

The specific gravity of Oil B blank was 0.865. Tin, Monel, and metals Nos. 5, 9 and 10 didn't increase the gravity as much as it was increased in the blank. Lead increased it from 0.865 to 0.877. The copper-lead combination increased it to 0.883 and zinc raised it to 0.886. The position zinc hold is surprising since it gave low results for the other inspections.

New Oil C had the lowest gravity of the three oils and as a whole was changed less than the others. The value for the blank was 0.856 or 0.002 higher than the new oil. The largest increase was caused by the copper-lead combination. It increased the specific gravity to 0.870. Copper and zinc were next giving a value of 0.860.

Color: The color numbers of the new oils are the actual numbers, but the oxidized oil samples were diluted with 85 per cent by volume of kerosene, because they were too dark to show a color number after oxidation. The new oils were all very light in color. The lightest was Oil B and the darkest Oil C.

Oil A after oxidation was very much darker and when it was diluted the color number was lower than that of the original oil. Copper and the copper-lead combination caused the greatest color change and tin gave the least. There was no appreciable difference in the effect of any of the metals. There were only 1.10 points between the darkest and lightest samples.

The blank of Oil B was as dark and, in some cases, it was darker than some of the samples that contained metals. Lead, steel, Monel, and metal No. 8 caused the color to become darker. The copper-lead combination and metal No. 8 did not cause the color to darken any more than the blank, and the remaining metals showed even less effect on the color of the samples. The least color change was shown by metal No. 9 and the greatest change was caused by lead and steel.

Oil C was the darkest of the original oils, but showed less change and gave higher color numbers than the two other oils. Aluminum caused the greatest change, but the color of the oil sample was not any darker than it was with Oils A and B. Of all the metals Monel caused the least change in color.

Condition of Metals: The appearance of the metals after oxidation is shown in Fig. 5. Some of the metals were coated with a dark protective film by the reaction, especially those which were in Oil C. Some of them were apparently unaffected and showed no visible marks of oxidation. Still others were affected differently and were eaten away and had a bright appearance. The most noticeable change was made by the lead. Oils A and B caused the lead to lose 3.44 and 2.68 per cent by weight respectively. The lead samples were much brighter after oxidation and looked as if they had been acid etched. Oil C caused a dark coating to be deposited on the lead sample, which only lost 0.08 per cent by weight, but the lead in the copper-lead combination with this oil lost 1.75 per cent by weight and was not coated with as dark a film as was the lead sample when it was used alone in the oil. The lead in the other copper-lead combinations lost some weight but did not lose asgreat a percentage as when tested alone.

All the metals were weighed before and after use but, with the exception of the lead, there was no appreciable change and the results were not included in the summary of data.

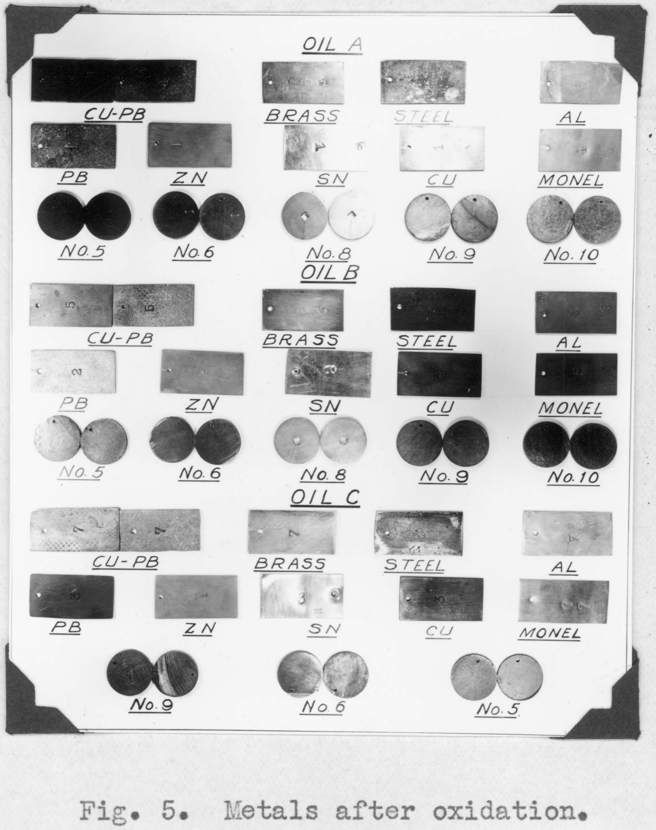

Fig. 5. Metals after oxidation.

VI - CONCLUSIONS

The results of these tests show that the presence of metals has a varing effect on the deterioration of turbine oils. Some metals greatly accelerated oxidation of one oil but had little effect on the rate of deterioration of another oil.

The copper-lead combination had a greater effect on oxidation than any single metal. The results show that two of the oils tested were affected more by the presence of lead than any other single metal, and that copper was next in promoting oxidation.

Oil C contained an oxidation inhibitor, whereas Oils A and B did not contain any additive. The effect of the metals on Oil C in all cases was not as marked as it was on Oils A and B, which indicated that the inhibitor retarded oxidation.

The bearing metal alloys did not increase the oxidation of the oils as much as the constituent metals from which they are alloyed, and the effect of these alloys on the degree of oxidation produced seems to be a function of the percentage of copper and lead in the alloy. This is shown very clearly in Fig. 6.

There is no correlation between the different laboratory inspections for any metal in all the oils. Neither is there any correlation between any one inspection and the three oils.

The results of this investigation indicate that a longer useful life of turbine oils may be secured by the use of metals in oiling systems that have a minimum catalytic effect upon the oil. From these data it is obvious that it would be necessary, however, to establish what particular metals affected any given oil the least.

VII - SUMMARY

Tests were conducted in the Lubrication Laboratory of the Virginia Polytechnic Institute to study the effect of several metals on the deterioration of steam-turbine oils.

A special test apparatus was constructed and three commercial turbine oils were tested in the presence of 14 different metal and metal combinations. Included in this group of metals were five bearing metals, several metals now extensively used in turbine lubricating systems, and several metals that are not at present used in turbine oiling systems.

Oxidation of the oils was accomplished by heating the oil in glass containers at 275°F. for 200 hours, in the presence of the metals. The oil samples were then subjected to laboratory inspections to determine the extent of oxidation.

It was found that in the case of Oil A copper, lead and the copper-lead combination were increasingly effective in increasing the viscosity and acidity. Brass, copper, and copper-lead were increasingly effective in promoting sludge formation.

With Oil B copper, lead, and the coppor-lead combination were increasingly effective in promoting sludge formation and increasing the viscosity. Steel, lead and the copper-lead combination were increasingly effective in producing acidity.

Copper, metal No. 9, and the copper-lead combination were increasingly effective in increasing the viscosity of oil C. Copper, metal No. 5, and copper-lead produced acidity in increasing amounts. Aluminum, zinc, and copper were increasingly effective in promoting sludge formation.

Tin showed the least effect on acidity in the case of all three oils. It caused the lowest sludge formation with oils A and B and was low with Oil C. The viscosity of Oil A was least affected by metal No. 6, of Oil B by metal No. 8, and of Oil C by steel.

VIII - SUGGESTIONS FOR FURTHER STUDY

The following suggestions are offered as possible further research work on the effect of metals in promoting the deterioration of steam-turbine oils. By enlarging the field of the work along the suggested, it is believed that the data would be of greater practical value.

1. Use a larger number of oils of various brands.
2. Increase the number of hours of testing.
3. Use a larger selection of metals and include stainless steel and cast iron in the group.
4. Use more combinations of metals; possibly extending this to include three and four metals.
5. Develop a test in which water could be introduced with the metals.

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