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# Tests on Tin-Base and Lead-Base Bearing Metals

by

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## FOREWORD

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The objects of the researches and other activities of the Council are to discover and develop new industrial applications of tin, to improve the existing products and processes, and to assist tin consumers in overcoming technical difficulties and problems relating to tin.

# BEARING METALS AND LUBRICANTS.

Laboratory: Engineering Department, National Physical Laboratory, under the supervision of Dr. H. J. GOUGH, M.B.E.

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## PREFACE.

There have been many attempts to produce bearing metals of hardened lead in the past and in the case of bearings carrying light loads such bearings have been used with apparent success, although there is little information available as to the friction losses of such bearings compared with the losses from bronze and tin alloy bearings. During the world war the use of lead alloys for heavily loaded bearings rotating at high speeds was attempted in Germany owing to the shortage of tin. This has led to further investigation into the matter in that country and to the production of lead alloys which have been adopted to a considerable extent. The later development has been in the direction of lead alloys containing more than 98 per cent. lead hardened by small quantities of alkali metals such as sodium, calcium and lithium.

It is well known that oleic acid reacts far more readily with lead than with tin and evidence has been brought forward to show that oxidised mineral oils also react more readily with lead than with tin. Such reactions would be expected to produce sludge in oil continuously circulated through a bearing as well as to hasten the wear of the bearing.

This report deals with comparative tests made in a journal friction testing machine with bearings fully lubricated by continuous circulation of the oil. Lead-base and tin-base alloys, hardened with copper and antimony, and also an Alkali metal-Lead alloy obtained from a German source, have been run with various lubricants. The conditions of the materials and tests are fully described and it is shown that under the conditions of the test there is no very marked chemical reaction between the lubricants and the alloys except in the case of lubricants containing free fatty acid used with alloys containing a high percentage of lead. The tests also show that as a general rule the frictional losses and wear of bearings of alloys containing a high percentage of lead are greater than the losses and wear occurring when the bearing metal contains a high percentage of tin.

It therefore appears that tin alloys are superior to lead alloys for bearing purposes and that the latter are useless when it is necessary to use lubricants such as olive oil or sperm oil.

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## INTRODUCTION.

This research was carried out for the Tin Research Sub-Committee of the British Non-Ferrous Metals Research Association with the primary object of ascertaining the comparative chemical action of lubricants upon tin-base and lead-base bearing metals. Sir John Dewrance published (*a*) some results in 1896 showing very rapid solution of pure lead bearing metal in olive oil and Mr. Bowrey in the discussion on Mr. Foord's (*b*) paper before the Royal Aeronautical Society gave some results of the chemical action of mineral oil on a large range of metals. The conditions under which the latter tests were made were not stated, but it would appear that the temperature was very high, since an attempt to reproduce the results, given later in this paper, failed to show any similar action at a temperature of 100° C. The latter temperature may be taken to exceed any temperature generally met with in the circulating system of an internal combustion engine.

The main results of the investigation are to show that except in the case of oils containing free fatty acid the chemical action upon any of the bearing metals employed is of little importance. The measurements of the coefficient of friction and wear of the bushes generally indicate that tin is superior to lead as a base for bearing metal alloys.

(*a*) Machinery Bearings. John Dewrance. Inst. of Civil Engineers, Proceedings, Vol. CXXV. Part III. Page 351, paper No. 2953. 1896.

(*b*) Proceedings. Vol. XXXIII. December 1929. P. 1120. "Lubrication of Aircraft Engines."

# MECHANICAL TESTS.

## TESTING MACHINE EMPLOYED.

The bearings were run on journal bearing testing machines of the type used at the National Physical Laboratory for some years past and somewhat similar in design to that used by Professor Goodman. Fig. 1 shows a general view of the

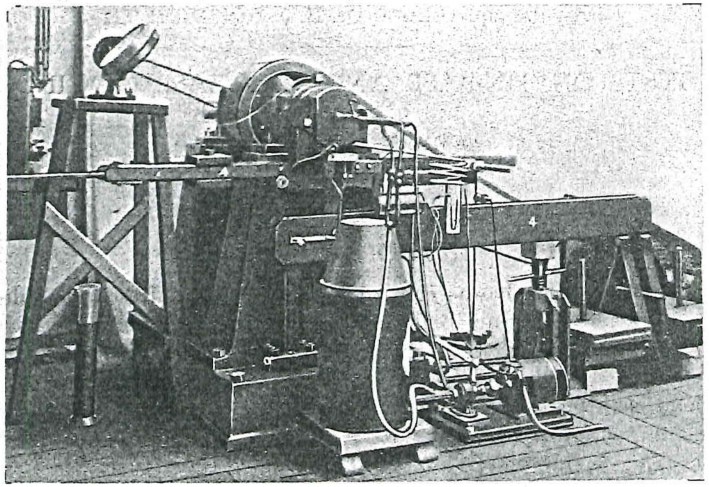

FIG. 1.
General View of Journal Bearing Testing Machine.

machine. It consists of a journal 2 inches in diameter and 3½ inches long formed on the end of a nickel-chrome steel shaft 4 inches in diameter. The shaft is mounted in roller bearing plummer blocks and driven by a belt from an electric motor. The bearing bush 2 inches in diameter by 2¼ inches long is mounted in a cast iron holder with a spherical seating, and the load is applied to the holder by means of a lever and link system as shown in Fig. 2. The friction torque is measured by a load applied to an extension of the horizontal link of the loading system. The load in the scale pan is adjusted until this link is in its normal horizontal position. This adjustment has to be accurately made and a tube containing a pin hole at the eye piece end and a lens and cross wires at the other end is focussed upon a fiducial line upon the arm. The absolute value of the friction torque is estimated from the change in the load on the scale pan required upon reversal of the direction of rotation of the journal. This determination is made when the temperature is constant and sufficiently high



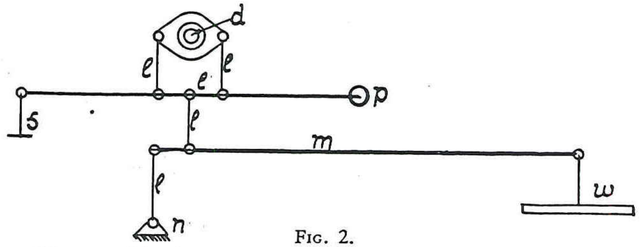


FIG. 2.
Diagram of loading system. (*d*) journal, (*l*) links, (*m*) loading lever. (*n*) anchorage, (*w*) load, (*s*) friction scale pan, (*p*) counter balance.

for the variation of friction with temperature to be small. The friction at other temperatures is calculated from the change in load on the friction scale pan. The method of reversals will not give an accurate value for the friction torque if the relative position of the centre of the journal and the centre of the bush changes on reversal. The determination will not be correct unless the friction is the same in both directions of rotation. Unless the contact surface is symmetrical about the vertical line there is probably a small difference in the friction torques. No attempt is made to correct for these errors since in all cases comparative values have been required, and the conditions of wear under which determinations have been made have been the same for each bush as far as possible.

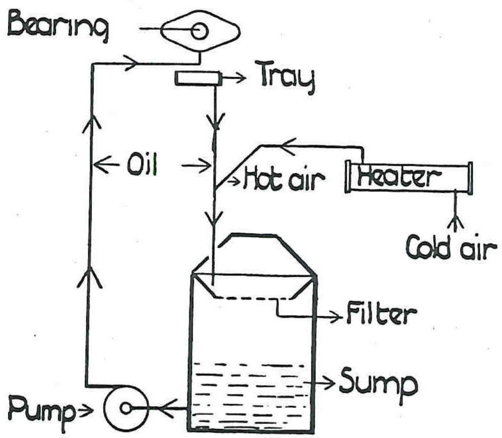


FIG. 3.
Diagram of circulating system.

The oil is circulated by means of an electrically driven pump, feeding the lower side of the bearing which is free from load. After passing through the bearing the oil is collected in a tray, drained off to a gauze filter and returned to the sump. An electric air heater is provided so that hot air can be blown into the oil on its return to the sump in order to increase the rate of oxidation of the oil. The hot air is blown in at a temperature of about 160° C. The circulating system is shown in Fig. 3.

## CONTROL AND MEASUREMENT OF TEMPERATURE.

The journal is bored out 1 inch in diameter for a length of about 4½ inches and a number of ¼ inch holes are drilled from the face of the 4 inch shaft to meet the bored hole (see Fig. 4.) The special gas burner shown is inserted in the bored hole and the products of combustion, diluted with as much air as is necessary to cool them to the desired temperature, pass through the central bore and the inclined holes discharging into the casing surrounding the bearing. The temperature is measured by means of a base metal thermojunction inserted in a tube with a closed end which is screwed tightly into the lining of the bush. The closed end of the tube is just free from the surface of the journal and is in contact with the oil film at the top of the bearing.

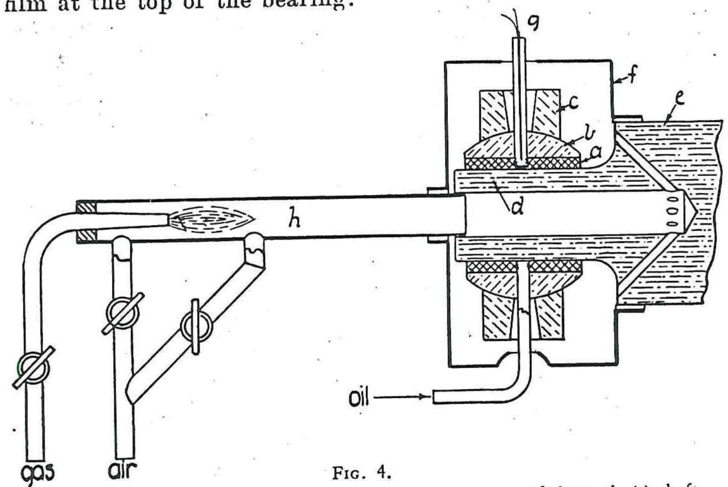


Fig. 4.

Method of heating bearing. (*a*) shell, (*l*) lining, (*c*) holder, (*d*) journal, (*e*) shaft, (*f*) casing, (*g*) thermojunction leads, (*h*) gas heater.

## CONSTRUCTION OF BUSHES.

The spherical steel shell is bored out to 2½ inches diameter and eight small slots are cut in the bore as shown in Fig. 5. The inside is tinned and the white metal run in to a thickness of about ⅜ inch. This is afterwards bored out to the size required. The bushes for these tests have been run by Messrs. Fry's Metal Foundries Ltd. except the bushes of Alkali metal-Lead alloy metal which are described later in this report.



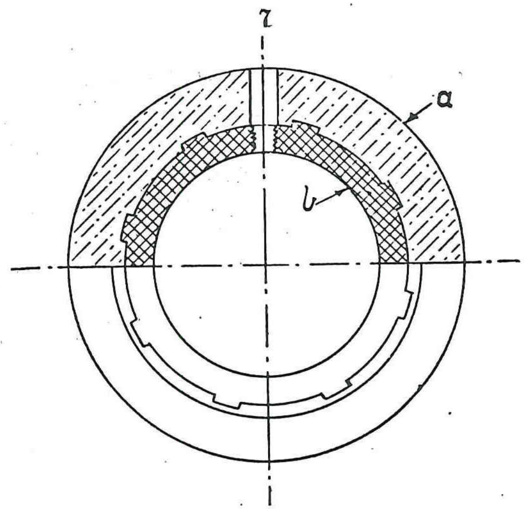


Fig. 5.

Section end view of bush. (*a*) steel shell (*b*) lining.

## METHOD OF TEST.

The tests have been made in the usual manner adopted for comparison tests on oils since the chief object of the investigation was to observe the contamination of the oil. The speed has been kept constant at 1300 r.p.m. (11·4 ft./sec. rubbing speed) and the load has been 1000 lbs. per sq. in. of projected area of the bush except when this load proved to be too great for any particular alloy and was reduced to 800 lbs./sq. in. The machine has been run every week-day for about 8 hours (except on Saturday when the run was about 3½ hours) until a total of 100 hours running has been reached. Throughout this period determinations of the coefficient of friction have been observed and changes in the appearance of the oil have been recorded. Measurements of the bushes have been made at three or four stages of each run.

The average running temperature has been maintained in the neighbourhood of the temperature of minimum friction. It was intended if possible to determine the "seizing" temperature at frequent intervals since deterioration of the oil causes a rapid lowering of the "seizing" temperature in most cases. In the first test, however, on the High Tin bush No. 1, the seizing temperature was 196° C. with castor oil and this temperature caused the metal to flow so that no further test could be made on that bush. At the end of each day's run, therefore, the temperature was gradually raised to a maximum of about 130° C. in order to determine the temperature of minimum friction and to avoid damage to the bush by plastic flow of the metal.

At the conclusion of the 100 hour run a large sample of the oil was pumped into a bottle for chemical and physical examination, care being taken that the oil was not allowed to remain at rest in the sump, which might have caused solid matter to settle out from the oil. The filter and sump were then washed with petrol or paraffin and the solid sludge, if any, separated by means of a centrifuge.

A special series of tests were made on Alkali metal-Lead alloy bushes as described later.

Particulars of the bushes and oils employed are given in Tables I and II.

### TABLE I.

PARTICULARS OF BUSHES.

| No. | Description. | Analysis %. Sn. | Sb. | Pb. | Cu. | Fe. | Na. | Ca. | Li. | Brinell Hardness. |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 & 2,<br>7 & 9,<br>11 | High Tin | 92.4<br>92.6<br>91.6 | 3.7<br>4.1<br>4.0 | 0.5<br>0.25<br>0.5 | 3.3<br>2.9<br>3.8 | .04<br>.03<br>.04 | —<br>—<br>— | —<br>—<br>— | —<br>—<br>— | 21½ |
| 3 & 4 | Medium Tin | 40.2 | 10.7 | 47.6 | 1.4 | .03 | — | — | — | 19 |
| 5 & 6,<br>8,<br>10 | High Lead | 4.9<br>5.1<br>5.2 | 15.3<br>15.0<br>15.2 | 79.8<br>79.9<br>79.6 | .03<br>tr.<br>tr. | .01<br>.02<br>.02 | —<br>—<br>— | —<br>—<br>— | —<br>—<br>— | 21 |
| 16 | 80% Tin ... | 82.0 | 10.9 | 3.1 | 3.8 | — | — | — | — | 22½ |
| 12, 13,<br>14, 15 | Alkali metal-Lead Alloy | — | — | 98.65<br>±.09 | — | — | 0.62<br>±.04 | 0.69<br>±.04 | .04<br>±.01 | 35½ |
| | Bronze ... | 11.8 | — (Phosphorus = 0·3%) | tr. | 87.9 | tr. | — | — | — | 127 |

The analyses of the white metals except Alkali metal-Lead alloy were supplied by Messrs. Fry's Metal Foundries Ltd., being the result of analysis of the metal from the pot from which the bushes were run. The analysis of the Alkali metal-Lead alloy was supplied by the makers. The bronze was analysed at the National Physical Laboratory.

## MEASUREMENTS OF THE COEFFICIENT OF FRICTION AND WEAR OF BUSHES.

### COEFFICIENT OF FRICTION.

During each run of 100 hours observations of the coefficient of friction were made over a range of temperature of 40° to 130° C. on from 14 to 16 days. The friction coefficient was found to vary considerably but the usual change was a reduction in friction during the first few hours, followed by a steady increase especially at 40° C. The change at higher temperatures was in general less marked. There were exceptions to the general rule in the case of the High Lead alloy when lubricated with Mobiloil A. and sperm oil. These



### TABLE II.

PARTICULARS OF OILS.

| Name. | Description and Source. | Spec. Grav. at 25° C. | Viscosity at 25° C. poises. | Acidity as oleic acid. |
|---|---|---|---|---|
| Castor Oil ... | Wakefield's Pure ... | .9587 | 6.44 | 0.81% |
| Mobiloil A.... | Vacuum Oil Co.'s. "Gargoyle" Mobiloil A. ... ... ... | .9132 | 3.00 | 0.09% |
| Castrol AA... | Wakefield's ... ... | .9070 | 2.87 | 0.06% |
| Oleogene M. . | Price's Patent Candle Co., Ltd. ... ... | .9166 | 2.87 | 0.11% |
| Olive Oil ... | Willcox & Co., Ltd., conforming to B.P. specification for pure olive oil ... ... | .9123 | 0.629 | 1.1% |
| Sperm Oil ... | Willcox & Co., Ltd., commercial ... ... | .8823 | 0.324 | 1.4% |

combinations gave a steadily decreasing coefficient of friction at 40° C. as the test proceeded, although the total reduction was small in the case of sperm oil. For purposes of comparison the average value of the coefficient of friction at 40° C. and 70° C. for the first quarter of the run and for the last quarter of the run has been tabulated in Tables III and IV.

### TABLE III.

COEFFICIENT OF FRICTION AT 40° C.

*Load*—1,000 lbs./sq. in. *Speed*—1,300 r.p.m. (11·4 f./sec.).
*Clearance*—8 mils.

| Lubricant. | | Bearing Metal. High Tin. | High Lead. | Bronze. |
|---|---|---|---|---|
| Castor Oil ... ... | at start<br>at end | .0032<br>.0035 | .0040<br>.0052 | .0030<br>.0036 |
| Mobiloil A. ... ... | at start<br>at end | .0028<br>.0038 | .0038<br>.0034 | —<br>— |
| Castrol A.A. ... | at start<br>at end | .0021<br>.0021 | .0018<br>.0018 | —<br>— |
| Oleogene M. ... | at start<br>at end | .0024<br>.0024 | .0025<br>.0028 | —<br>— |
| Olive Oil ... ... | at start<br>at end | .0015<br>.0019 | .0016<br>.0020 | —<br>— |
| Sperm Oil ... ... | at start<br>at end | .00115<br>.0012 | .0017<br>.0016 | —<br>— |

## TABLE IV.

### Coefficient of Friction at 70° C.

*Load*—1,000 lbs./sq. in. *Speed*—1,300 r.p.m. (11·4 f./sec.).
*Clearance*—8 mils.

| Lubricant. | | Bearing Metal. | | |
|---|---|---|---|---|
| | | High Tin. | High Lead. | Bronze. |
| Castor Oil ... ... | at start<br>at end | .0016<br>.0018 | .0019<br>.0024 | .0014<br>.0015 |
| Mobiloil A. ... ... | at start<br>at end | .0011<br>.0013 | .0018<br>.00165 | —<br>— |
| Castrol A.A. ... | at start<br>at end | .00135<br>.00125 | .0012<br>.0012 | —<br>— |
| Oleogene M. ... | at start<br>at end | .0011<br>.00125 | .00126<br>.0014 | —<br>— |
| Olive Oil ... ... | at start<br>at end | .0010<br>.0012 | .0011<br>.00125 | —<br>— |
| Sperm Oil ... ... | at start<br>at end | .00085<br>.0010 | .0012<br>.0012 | —<br>— |

An examination of Tables III and IV will show that the High Lead alloy gives a higher coefficient of friction than the High Tin alloy except in the Castrol A.A. With this lubricant alone of the six chosen does the High Lead alloy give less frictional loss than the High Tin alloy. The results obtained with the Medium Tin alloy with Castor Oil are not given in the above Table because this metal would not stand up to a load of 1000 lbs./sq. in. and was run at 800 lbs./sq. in. The coefficient of friction at any particular temperature is therefore higher due to the lower loading. Some of the results obtained with this metal are used for comparison with Alkali metal-Lead alloy.

### Wear of the Bushes.

All the bushes were bored 8 mils larger in diameter than the diameter of the journal. During the first part of the run the vertical diameter increased somewhat rapidly as the arc of contact was formed. The rate of wear was very much less after the arc of contact was formed. In some cases a small reduction in the horizontal diameter occurred due to flow of the metal and flow also occurs in the axial direction on the upper side of the bush. The former amounted in some cases to a little over one mil and the latter varies from 0·2 to 1·1 mils. Measurements of the white metal bushes before and after test showed a reduction in the volume of metal very much greater than that which could be accounted for by the total metal found in the oil, so that an appreciable increase of



density due to the load was indicated. The measured increases in vertical diameter are given in Table V. The bushes run with olive and sperm oils had already been run with Oleogene M and Mobiloil A respectively. The arc of contact had therefore been formed before the commencement of the second runs and the wear was very much smaller, as would be expected.

## TABLE V.

### Wear of Bushes in Mils.

| Lubricant. | Bearing Metal. | | | | | |
|---|---|---|---|---|---|---|
| | High Tin. | | | High Lead. | | |
| | Bush No. | Hours of running. | Wear. | Bush No. | Hours of running. | Wear. |
| Castor Oil. ... | 1 | 12<br>37½ | 3.8<br>7.0 | 5 | 12<br>44½ | 5.5<br>7.1 |
| | 2 | 42½<br>62 | 4.2<br>4.2 | | 101½ | 8.4 |
| Mobiloil A ... | 7 | 11<br>79½<br>100½ | 3.6<br>4.0<br>4.0 | 6 | 12<br>43<br>82<br>106 | 5.4<br>6.1<br>6.8<br>6.8 |
| Sperm Oil ... | 7 | 34<br>100 | 0<br>0 | 6 | 34<br>103 | 0.3<br>0.6 |
| Castrol A.A. ... | 11 | 10<br>42<br>79<br>99 | 2.3<br>2.6<br>2.8<br>3.1 | 10 | 18<br>42<br>77½<br>100 | 2.3<br>2.4<br>2.4<br>2.5 |
| Oleogene M. ... | 9 | 16<br>40<br>82<br>104 | 2.8<br>3.0<br>3.2<br>3.2 | 8 | 16<br>47<br>81½<br>104 | 4.2<br>5.1<br>5.2<br>5.3 |
| Olive Oil ... ... | 9 | 35½<br>78<br>103 | 0.5<br>0.5<br>0.5 | 8 | 35½<br>77<br>102 | 0.5<br>0.8<br>0.8 |

Table V shows that the High Lead alloy wears faster than the High Tin alloy except when used with Castrol A.A. in which case the wear is a little less in the case of the High Lead alloy than in the case of the High Tin alloy. The excessive wear of bush No. 1 was due to the temperature having been raised on one occasion to 196° C. after running for 37½ hours. The run was completed by 62 hours run on bush No. 2, care being taken not to exceed a temperature of 140° C. at any time. The wear on the Bronze bush with castor oil was 0·4 mil. after 101½ hours.

## VISUAL EXAMINATION OF OILS.

### Castor Oil.

The oil darkened somewhat during the first 30 hours of the tests but afterwards became a little lighter in colour, without regaining its initial pale colour. In all cases it was clear at the end of the test and there was no appreciable difference in the appearance of the samples from the four different bearings.

### Mobiloil A., Castrol A.A., Oleogene M.

These three oils showed no appreciable change in colour or cloudiness during the test and there was no visible difference in the samples from the High Tin and the High Lead bearings.

### Olive Oil from High Tin Bush.

During the first 20 hours the oil changed in colour from yellow to green. After this period up to 60 hours the colour gradually lost part of the green tint and there was no change in the last 40 hours. No sludge could be separated in the centrifuge. The sump and filter were afterwards washed and 0·45 gram of dried sludge was recovered from the washings.

### Olive Oil from High Lead Bush.

Similar colour changes were observed in this sample but cooled samples became cloudy after 10 hours' running and the cloudiness persisted at higher temperatures at the end of the run. Samples centrifuged from 10 hours upwards showed about 1 per cent. of sludge. The sump and filter were washed and 2·57 grams of dried sludge recovered from the washings.

The green colouration is derived from the action of the oil on the copper circulating pipes. This was verified by pumping the hot oil for 50 hours through the pipe system with the bearing removed.

### Sperm Oil from High Tin Bush.

The original colour of this oil was a pale yellowish green but after 5 hours the green tint was lost. After 35 hours the oil appeared to be slightly cloudy and at the end of the run it was still cloudy and of a dull golden brown colour. A small amount of sludge of a brown colour was recovered from the filter and sump.

### Sperm Oil from High Lead Bush.

The oil turned cloudy after 15 hours of running but did not lose its green tint. The cloudiness increased as the test proceeded and at the end the colour was olive green. A small amount of sludge of grey colour was recovered from the filter and sump.

From the visual examination, therefore, sludge is formed only from olive and sperm oils and in each case more sludge is formed by the High Lead bush than by the High Tin bush.



The detailed examination of the oils is given in the Appendix below.

These tests have shown that the chemical action of castor oil or of the three motor cylinder oils tested is small upon either lead or tin alloys. With olive oil the action on the High Lead alloy containing antimony is much less marked than that observed by Sir John Dewrance on a pure lead bearing. In order to complete the investigation it was therefore considered to be advisable to make some tests upon a lead bearing metal containing 98 per cent. of lead and small quantities of the alkali metals. Such alloys are used to a considerable extent on the Continent and are said to be satisfactory in practice. The British Non-Ferrous Metals Research Association approached the manufacturers of these lead bearing metals in the matter and they kindly loaded some standard shells with the Alkali metal-Lead alloy for these tests.

## TESTS ON AN ALKALI METAL-LEAD ALLOY.

The two bushes referred to above were run, one with Mobiloil A and the other with olive oil. The oils were not oxidised by hot air during these tests. A very few minutes' running showed that 1,000 lbs. per sq. in. was too high a load for this metal and the load was reduced to 800 lbs. per sq. in. These bearings did not run steadily, there being sudden changes in the friction which were probably due to the cracks which were afterwards found to have developed in the metal. Average values of the coefficient of friction at the running temperature are given in Table VI. There were no tests on the High Tin or High Lead alloys with which to compare these figures but the figures for the Medium Tin alloy which was tested at this load with castor oil are given. The corresponding figures for either Mobiloil A or olive oil would be less than those given for castor oil.

### TABLE VI.

| Bearing Metal. | Lubricant. | Coefficient of Friction. Time from start—hours. | | |
|---|---|---|---|---|
| | | 10 | 50 | 90 |
| Medium Tin Alloy (3) | Castor Oil | ·0022 at 80° C. | ·0033 at 80° C. | ·0038 at 80° C. |
| Alkali Metal-Lead Alloy (13) | Mobiloil A. | ·0029 at 72° C. | ·0036 at 81° C. | ·0035 at 82° C. |
| Alkali Metal-Lead Alloy (12) | Olive Oil | ·0058 at 85° C. | ·0043 at 76° C. | ·0065 at 84° C. |

The test on the Alkali metal-Lead alloy and olive oil was abandoned after 97 hours because the cracks which had started to develop after 30 hours had increased to such an extent that friction determinations could not be made. An examination of bush No. 13 showed that very fine cracks had developed but that they were much less marked than in No. 12 both in number and in size. There was no visible change in the Mobiloil A during the test but the olive oil behaved similarly to the previous sample test with the High Lead alloy, but to a more marked degree. There was a considerable amount of sludge collected from the sump and filter. That the chemical action had been great was also shown by the increase in the size of the bush, which was 6·4 mils larger in horizontal diameter and 28·2 mils larger in vertical diameter.

## COMPARISON BETWEEN ALKALI METAL-LEAD ALLOY AND 80 PER CENT. TIN ALLOY.

The last test confirmed the action of olive oil on a bush containing a large percentage of lead but the formation of cracks in bush No. 13 did not confirm the published results of tests of this metal. A further bush was obtained from the maker as well as a number of thick rings of the metal. For comparison tests a shell was lined with a commercial quality of tin bearing metal containing about 80 per cent. Tin by Messrs. Fry's Metal Foundries Ltd. Comparative tests were made upon these by running them at various loads until they reached a steady temperature and observing the coefficient of friction under these conditions. The results are tabulated in Table VII.

### TABLE VII.

*Speed*—1,300 r.p.m. (11·4 f./sec.). *Initial Clearance*—8 mils.
*Lubricant*—Mobiloil A.

| | ALKALI METAL-LEAD ALLOY. BUSH No. 14. | | | 80% TIN ALLOY. BUSH No. 16. | | |
|---|---|---|---|---|---|---|
| Load. lb./sq. in. | Temp. °C. | Temp. °C. above air. | Coeff. of friction. | Temp. °C. | Temp °C. above air. | Coeff. of friction. |
| 127 | 45 | 23 | ·0081 | 45½ | 25½ | ·0092 |
| 255 | 49 | 27½ | ·0041 | 46½ | 24½ | ·0045 |
| 510 | 59 | 39 | ·0024 | 57 | 36 | ·0025 |
| 1020 | 65½ | 45½ | ·0015 | 61 | 38 | ·0015 |
| 1530 | 74 to 84 | 54 to 67 | ·0036 to ·0048 | 75 | 54 | ·0012 |
| 2040 | — | — | — | 88 | 70 | ·0010 |
| 2550 | — | — | — | 90 | 69½ | ·0010 |



During the test at 1,530 lbs./sq. in. the Alkali metal-Lead alloy lining developed cracks similar to those formed in the previous tests and no further tests were made. The Alkali metal-Lead alloy in the form of a ¼ inch lining in a steel shell will not therefore carry as high a load as an 80 per cent. Tin alloy lining of the same nature. The coefficient of friction of the Alkali metal-Lead alloy appears to be lower than that of the Tin alloy at the lowest load and there is no appreciable difference at loads of 255, 510 and 1,020 lbs./sq. in. The observed higher friction of the tin at loads of 255 and 510 lbs./sq. in. is accounted for by the lower actual temperatures of the oil films. An attempt was made to compare the coefficient of friction of the two alloys over a period of 30 hours at a constant load of 900 lbs./sq. in. For this purpose a steel shell was lined by forcing a thick ring of Alkali metal-Lead alloy into it and securing the lining by driving brass keys down the axial grooves in the shell. The lining was then bored out to the required size. The comparative tests were made upon the 80 per cent. Tin alloy bush which had the arc of contact formed in the test just recorded. The first part of the test on the new Alkali metal-Lead alloy bush would not be comparable since the arc of contact was in progress of formation. The comparison was rendered more unsatisfactory by an unforeseen phenomenon caused by undue compression of the Alkali metal-Lead alloy in forcing it into the steel shell. As a result of this the bore of the bush became smaller as the test proceeded. In spite of the wear associated with the formation of the arc of contact the vertical diameter was reduced by 0·6 mil after 30 hours while the horizontal diameter measured 1·1 mil less than the initial measurement. The shapes and sizes of the two bushes were not similar therefore, during the test. The initial and final dimensions are given in Table VIII and the observed coefficient of friction in Table IX.

### TABLE VIII.

Dimensions of bushes and journal.
*Inches.*

| | Alkali Metal-Lead Alloy | | 80% Tin Alloy | |
|---|---|---|---|---|
| | at start | at end | at start | at end |
| Diameter of journal ... | 2·0070 | 2·0070 | 2·0070 | 2·0070 |
| Horizontal diameter of bush ... ... ... | 2·0148 | 2·0137 | 2·0144 | 2·0148 |
| Vertical diameter of bush ... ... ... | 2·0150 | 2·0144 | 2·0172 | 2·0173 |

## TABLE IX.

Coefficient of Friction.

*Load*—900 lbs./sq. in. *Speed*—1,300 r.p.m. (11·4 f./sec.).
*Lubricant*—Mobiloil A.

| Time of running hours | Alkali Metal-Lead Alloy | | | | 80% Tin Alloy | | | |
|---|---|---|---|---|---|---|---|---|
| | 40° C. | 60° C. | 80° C. | 100° C. | 40° C. | 60° C. | 80° C. | 100° C. |
| 10 | ·0021 | ·0013$_5$ | ·0011 | ·0011 | ·0024 | ·0013$_5$ | ·0009 | ·0008 |
| 20 | ·0023$_5$ | ·0015 | ·0011 | ·0011 | ·0024$_5$ | ·0015 | ·0010 | ·0008 |
| 30 | ·0024 | ·0015 | ·0012 | ·0013$_5$ | ·0025 | ·0015$_5$ | ·0010 | ·0008 |

The Alkali metal-Lead alloy appears to give a lower coefficient of friction up to 65° C., but above this temperature the 80 per cent. Tin alloy gives lower friction values than the Alkali metal-Lead alloy. This result is not conclusive, however, owing to the want of similarity between the bushes.

A final comparison was made by machining out the two bushes to a circular form, thus giving the somewhat high initial clearance of 0·016 in. but producing bushes of exactly similar form. During this machining the Alkali metal-Lead alloy showed signs of recovery from its compressed state, but by

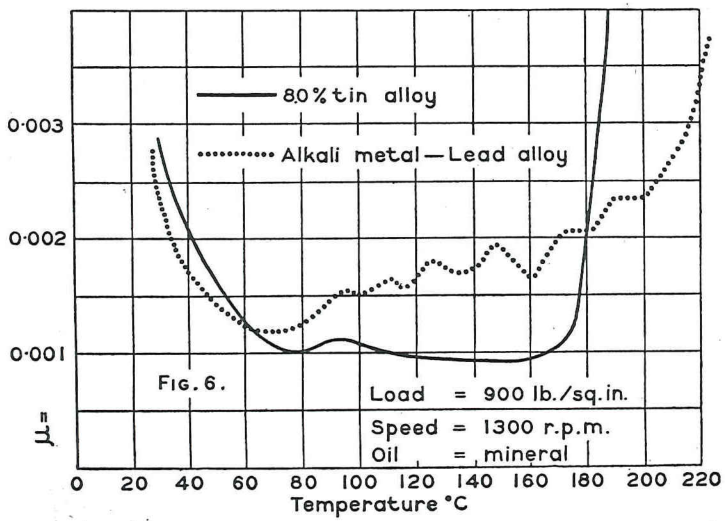


Fig. 6.

Comparison of 80% tin alloy and Alkali metal-Lead Alloy. Curves of Coefficient of Friction plotted against Temperature.



allowing time for recovery after the initial cuts it appeared eventually to reach a condition of stability before the final machining was finished. These two bushes were then given a run of about 10 hours at a load of 900 lbs. per sq. in. and a speed of 1,300 r.p.m., at a temperature of 75° C. for the Tin alloy and 65° C. for the Alkali metal-Lead alloy. They were then measured again and a complete run was made up to seizing temperature on each bush. The curves of coefficient of friction plotted to temperature are given in Fig. 6. The dimensions of the bushes are given in Table X. The seizing temperature and temperature of minimum friction are given in Table XI.

## TABLE X.

Dimensions of Alkali Metal-Lead Alloy and 80 per Cent. Tin Alloy Bushes.

Diameter of Journal=2·0070 ins.

| | Alkali Metal—Lead Alloy. | | 80% Tin Alloy. | |
|---|---|---|---|---|
| | Vertical dia. ins. | Horizontal dia. ins. | Vertical dia. ins. | Horizontal dia. ins. |
| At start ... ... | 2·0230 | 2·0228 | 2·0228 | 2·0226 |
| After 4 hours ... | 2·0230 | 2·0229 | 2·0239 | 2·0213 |
| After 14 hours ... | 2·0232 | 2·0228 | 2·0244 | 2·0214 |
| End of test ... | 2·0163 | 2·0156 | 2·022 to 2·027 * | 2·0126 * |

* Accurate measurements could not be made since globules of molten metal had run round the journal.

## TABLE XI.

| | Coefficient of Friction. | | | | Temperature ° C. | |
|---|---|---|---|---|---|---|
| | At 40° C. | At 70° C. | At 100° C. | Minimum. | At Minimum. | At Seizure. |
| Alkali metal—Lead Alloy | ·0017 | ·0012 | ·0015 | ·0012 | 70 | over 233 |
| 80% Tin Alloy | ·0021 | ·0010$_5$ | ·0011 | ·0009 | 150 | 187 |

The changes in shape are shown in Table X, and it will be seen that during the "running in" the Alkali metal-Lead alloy changed little, whereas the 80 per cent. Tin alloy increased considerably in vertical diameter but decreased in horizontal diameter. At the end of the test the Alkali metal-Lead alloy was flowing at 233° C. but did not actually melt, while the 80 per cent. Tin alloy melted in places at 187° C. The curves shown in Fig. 6 verify the conclusion drawn from the previous test that up to 65° C. Alkali metal-Lead alloy gives less friction than the 80 per cent. Tin alloy. At higher temperatures up to 180° C. the 80 per cent. Tin alloy shows lower friction losses than Alkali metal-Lead alloy.

The conclusion drawn from these tests is that Alkali metal-Lead alloy is unsuited for loads exceeding 900 lbs. per sq. in., whereas the 80 per cent. Tin alloy runs quite satisfactorily up to a load of 2,500 lbs./sq. in.

The Alkali metal-Lead alloy gives lower friction loss than the 80 per cent. Tin alloy up to 65° C. at loads up to 900 lbs./sq. in. (probably due to its greater hardness) but higher friction losses than 80 per cent. Tin alloy above this temperature. These results do not confirm previously published comparisons between "Lurgi"-metal and Tin alloys. In the book by J. Czochralski and G. Welter (*c*) tables are given which show "Lurgi"-metal to be superior to Tin alloy bearing metals at all loads. These tests were probably made upon ring lubricated bearings, but full details are not given. In opposition to this, M. Armbruster (*d*) records tests showing a lead alloy of the nature of the one used in these tests to be quite useless in comparison with a high tin alloy under the conditions of his tests. The loading appears to have been 770 lbs./sq. in., a little less than that used in the test recorded above, but the speed of rubbing was very much higher, namely 43 f./sec. Under these conditions the lead alloy showed an increase in friction moment from 19 to 38 in 22 minutes, after which it remained constant for some minutes. The Tin alloy on the other-hand gave a friction moment varying between 5 and 8 in the same units over a period of 60 minutes.

The results obtained during this investigation indicate that an Alkali metal-Lead alloy will run satisfactorily at moderate loads and temperatures when lubricated with mineral oil or compounded oil but that the alloy freely dissolves in olive or sperm oils. The general conclusions drawn from the whole investigation are that neither high lead nor high tin alloys are readily attacked by the lubricants in common use such as mineral oil, compounded mineral oil and castor oil, but that generally speaking a higher friction loss will occur with a high lead alloy than with a high tin alloy.

(*c*) "Lagermetalle und Ihre Technologische Bewertung." Springer. Berlin.

(*d*) Deutsche Motor-Zeitschrift. October 1929. Vol. 6. P. 504.



## *APPENDIX.*

## DETAILED EXAMINATION OF OILS.

As mentioned in the description of the method of test, samples of oil were taken from the circulating system at the end of each of the 100 hour runs. The specific gravities and viscosities of these samples were determined and compared with those of the unused oils. Chemical tests were also applied in most cases in order to obtain data regarding the quantities of metallic compounds present in solution or in suspension.

The following table gives particulars of the various samples of oil, together with notes as to their appearance after standing for two months in the Winchesters in which they had been collected: general notes of the changes visible during and at the end of the run have already been made in Part I.

### TABLE XII.

| Ref. No. | Oil | Treatment | Colour | Sediment |
|---|---|---|---|---|
| 1 | Castor | As received. | | |
| 2 | | 100 hrs. in bushes 1 & 2 (92% tin). | Unchanged. | None. |
| 3 | | 100 hrs. in bush 5 (80% lead). | Appreciably darker. | do. |
| 4 | | 100 hrs. in bush 3 (40% tin). | Orange and cloudy. | do. |
| 5 | | 100 hrs. in bronze bush T.B.5. | Orange, clear. | Grey, slight. |
| 6 | Mobiloil A. | As received. | | |
| 7 | | 100 hrs. in bush 6 (80% lead). | Unchanged. | Slight. |
| 8 | | 100 hrs. in bush 7 (92% tin). | do. | do. |
| 20 | | 100 hrs. in bush 13 (Alkali metal-Lead alloy). | do. | Moderate. |
| 9 | Oleogene M. | As received. | | |
| 10 | | 100 hrs. in bush 8 (80% lead). | Unchanged. | None. |
| 11 | | 100 hrs. in bush 9 (92% tin). | do. | Very slight. |
| 12 | Castrol A.A. | As received. | | |
| 13 | | 100 hrs. in bush 10 (80% lead). | Unchanged. | Inappreciable. |
| 14 | | 100 hrs. in bush 11 (92% tin). | do. | do. |
| 21 | Olive | As received. | | |
| 15 | | 100 hrs. in bush 8 (80% lead). | Turbid. | Grey, heavy. |
| 16 | | 100 hrs. in bush 9 (92% tin). | Amber. | Inappreciable. |
| 19 | | 100 hrs. in bush 12 (Alkali metal-Lead alloy). | Orange. | White, heavy. |
| 23 | | 50 hrs. through copper pipes only. | Greenish. | Green. |
| 22 | Sperm | As received. | | |
| 17 | | 100 hrs. in bush 6 (80% lead). | Cloudy. | Grey, moderate. |
| 18 | | 100 hrs. in bush 7 (92% tin). | Slightly cloudy. | None. |

## PHYSICAL PROPERTIES.

Specific gravities, relative to water at 25° C. were determined by means of a 50 ml. specific gravity bottle. Viscosities were measured in a U-tube viscometer (No. 3 of British Engineering Standards Specification 188, 1929) which had been calibrated by means of sugar solution. All tests were made in a thermostat of which the temperature remained constant at 25° C. within 0·01° C. Some of the used oils were cloudy and some showed sedimentation on standing, but as the measurements were intended merely to give an indication of change, the oils were not filtered: the gravities and viscosities recorded are probably higher in these cases than would have been found after filtration. The values obtained are shown in Table XIII.

The increases in specific gravity and in viscosity of the used, as compared with the unused, oils afford some measure of the extent of oxidation which has occurred owing to the exposure of the hot oils to air during the runs. In almost every instance the viscosity increases progressively with increase in specific gravity. The changes are small in the case of the mineral oils but are more marked in the fatty oils, olive oil being the most affected. The mineral matter suspended in samples 15 and 19 does not appear to increase the time of flow through the viscometer, since the comparatively clear sample 16 gives an even longer time: it is, therefore, probable that the increased viscosity of these samples is due to dissolved lead salts.

### TABLE XIII.

| Oil. | Ref. No. | Specific gravity $S^{25° C.}_{25° C.}$ | Viscosity at 25° C., poises. |
|---|---|---|---|
| Castor ... ... | 1 | 0·95873 | 6·44 |
| | 2 | 0·96063 | 7·28 |
| | 3 | 0·96050 | 7·26 |
| | 4 | 0·96082 | 7·40 |
| | 5 | 0·96141 | 7·43 |
| Mobiloil A. ... | 6 | 0·91322 | 3·00 |
| | 7 | 0·91374 | 3·04 |
| | 8 | 0·91417 | 3·11 |
| | 20 | 0·91471 | 3·17 |
| Oleogene M. ... | 9 | 0·91657 | 2·87 |
| | 10 | 0·91680 | 2·95 |
| | 11 | 0·91682 | 2·96 |
| Castrol A.A. ... | 12 | 0·90699 | 2·87 |
| | 13 | 0·90749 | 2·95 |
| | 14 | 0·90735 | 2·94 |
| Olive ... ... | 21 | 0·91226 | 0·629 |
| | 15 | 0·92709 | 1·174 |
| | 16 | 0·92780 | 1·254 |
| | 19* | 0·93029 | 1·092 |
| | 23 | 0 91307 | 0·660 |
| Sperm ... ... | 22 | 0·88229 | 0·324 |
| | 17 | 0·89492 | 0·472 |
| | 18 | 0·89424 | 0·486 |

* After more thorough agitation this sample gave 0·93087, 1·096.



## ESTIMATION OF MINERAL MATTER.

In some of the fatty oil samples it was obvious that appreciable attack of the bush had occurred. The mineral oil samples were not examined in detail from this point of view; ash determinations on oils 7 and 8 showed residues of only 0·0011 per cent. and 0·0018 per cent. respectively. Since lead is likely to be lost during the ashing process an extraction method was worked out for use with the fatty oil samples. Samples of about 100 ml. were diluted with an equal volume of ether and extracted three times in a separating funnel with a mixture of 25 ml. of dilute hydrochloric acid (twice normal) with 100 ml. of nearly boiling water, the hot water being added gradually with shaking so as to avoid undue losses of ether. The extracts were combined, filtered from suspended oil, boiled to remove ether and then evaporated to fuming with sulphuric acid: after separation of the lead as sulphate, tin and antimony were precipitated in weakly acid solution with sulphuretted hydrogen and the copper in the ignited precipitate was determined colorimetrically by the ferro cyanide method. Iron was estimated in the filtrate by precipitation as hydroxide.

In the case of castor oil it was demonstrated that two extractions with hot dilute acid were sufficient to remove at least 90 per cent. of the lead present when the castor oil contained 1 per cent. of its weight of lead oleate in solution. In the case of the oil siphoned off from sample 19, eight extractions had to be made before a negative test with sulphuretted hydrogen could be obtained on a portion of the extract.

Except in the case of sample 19, where the sediment was so considerable and so slimy after a few days' standing that mixing appeared impracticable, the analyses were made without any attempt to distinguish between compounds present in solution and those in suspension, the quantity required being poured off after vigorous agitation. From sample 19 the turbid oil was siphoned off and the sediment washed out of the bottle with benzene on to a filter where it was further washed and dried: the weight so obtained was 8·5 gm. and analysis showed it to contain 54 per cent. of its weight of lead and 0·32 per cent. of iron; since the total volume of the sample was about 2 litres the lead content tabulated below for sample 19 should be increased by some 0·2 per cent. The unused olive and sperm oil gave no residue when the acid extracts were evaporated to dryness: the percentage contents found in the other determinations made are shown in Table XIV.

### TABLE XIV.

| Oil | Ref. No. | Lead | Tin (plus Antimony) | Copper | Iron |
|---|---|---|---|---|---|
| Castor | 2 | 0·0005 | 0·0017 | 0·0013 | 0·0015 |
| | 3 | 0·0009 | 0·0007 | 0·0030 | 0·0008 |
| | 4 | 0·0025 | nd | 0.0015 | nd |
| Olive | 15 | 0·14 | 0·0034 | 0·0042 | 0·0021 |
| | 16 | 0·014 | 0·0036 | 0·0021 | trace |
| | 19 | 0·59 | nd | nd | 0·037 |
| | 23 | nil | nil | 0·0066 | 0·0014 |
| Sperm | 17 | 0·15 | 0·0023 | 0·0062 | 0·0011 |
| | 18 | 0·013 | 0·0005 | 0·0013 | trace |

nd = not determined.

The high lead contents found when olive and sperm oils were used in 80 per cent. lead bushes (samples 15 and 17) are the most noticeable feature of this table: the maximum tin content is only 0·0036 per cent. (olive oil in 92 per cent. tin bush). Sample 23 was obtained from a run which was made in order to verify the source of the copper contamination: the fact that the rate of solution of copper was much higher than in an actual test is to be explained either by differences of temperature and oxygen solubility (the average temperature for sample 15 was 68° C., while for sample 23 it was 55° C.) or by the unfortunate circumstance that the steel pump normally used was replaced in this case by one containing brass. The iron content of sample 19 cannot be ascribed to the wear of the journal, which was only of the order of 1/17 of that necessary to give so high a percentage: apart from possible imperfections in the lead lining of the sump, there was also present an iron baffle plate in the oil return circuit where corrosion may have occurred.

## EXAMINATION OF SLUDGES.

The sludges mentioned in Part I as having been collected from the filter and sump of the testing machine were examined by transferring them with the aid of petrol to filter papers of known dry weight, washing them free from paraffin and oil and weighing. Estimations of the lead content were then made, with the following results.

### TABLE XV.

| Accompanying oil sample. | Source of sludge. | Weight of sludge gm. | Lead content gm. |
|---|---|---|---|
| 15 (olive) | sump & filter | 1·228 | 0·469 |
| 16 " | sump & filter | 0·061 | 0·017 |
| 19 " | sump & filter | 1·87 | 0·562 * |
| 17 (sperm) | filter | 0·410 | 0·0097 |
| | sump | 2·33 | — |
| | sump walls | 2·79 † | 0·315 |
| 18 " | filter | 0·209 | 0·008 |
| | sump | 0·345 | 0·039 |

* There were also found 0·001 gm. tin, 0·004 gm. copper, 0·026 gm. iron.

† Not entirely free from oil: this sample was scraped from the sump, which was lead lined, hence the lead content may be too high: tin present = 0·004 gm.

## OTHER CHEMICAL TESTS.

The acidities of some of the samples were determined for comparison with the values obtained for the unused oils. The acidity (calculated as percentage of oleic acid) of Mobiloil A increased from 0·09 per cent. to 0·11 per cent. during the run in the Alkali metal-Lead alloy bush (sample 20). The values for the olive oil samples were:—

| Sample 21 (new). | 15 (High lead bush). | 16 (High tin bush). | 19 (Alkali metal-Lead alloy bush). |
|---|---|---|---|
| Acidity 1·1% | 1·0% | 1·4% | 0·7% |

The sperm oil samples gave the following results:—

| Sample 22 (new). | 17 (High lead bush). | 18 (High tin bush). |
|---|---|---|
| Acidity 1·4% | 2·6% | 2·9% |



It may be noted that the acidity is the lower, the greater the extent of the chemical attack on the bush. The normal effect of oxidation during the use of the oil would be to increase the acidity: this is shown in samples 16 and 18. Oxidation tends also to reduce the proportion of unsaturated organic compounds, as measured by the iodine number of the oils. The iodine number (Wijs's method) of the new olive oil No. 21 was 84·8: after use in the Alkali metal-Lead alloy bush (sample No. 19) the iodine number had fallen to 75·4.

The sediment separating from the olive oil used in contact with bushes containing high proportions of lead might be expected to be essentially lead oleate: the lead contents shown in Table XV for the sludges accompanying samples 15 and 19 are somewhat higher than required by the formula for the normal oleate (27 per cent. lead). It has already been mentioned that the heavy sediment from sample 19 contained 54 per cent. of lead; some of this material was extracted with ether in a Soxhlet apparatus to remove adherent oil (and most of the lead oleate probably) and was then shaken with ether and hydrochloric acid to set free the organic acid: the waxy residue obtained on evaporation melted at about 50° C. and had an iodine number of 70. It is thus evident that acids less unsaturated than oleic acid were present: the high lead content indicates that a basic rather than a normal salt constitutes the bulk of the sediment.

## RATE OF SOLUTION OF BEARING METALS IN MINERAL OILS AND CASTOR OIL.

In an attempt to obtain data for comparison with those of Bowrey, to which reference has been made in the introduction, 50 gm. of turnings from two bushes were placed in a beaker and covered with about 200 ml. of oil: oxygen was blown through the mixture for 30-40 hours, while the temperature was maintained at 100° C. Finally the turnings were washed free from oil with benzole and reweighed. Turnings from bush No. 6 (80 per cent. lead) were so treated with Mobiloil A and Oleogene M, and turnings from bush No. 11 (92 per cent. tin) with castor oil and Oleogene M.: in no case was there any loss in weight greater than the error of the measurements (0·01 gm.): the tin base turnings with castor oil actually increased in weight by 0·06 gm. In view of the smallness of the attack indicated by these tests, no further measurements were made on the same lines.

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