FRICTION & WEAR CHARACTERISTICS OF METAL PAIRS WITH LUBRICANTS HAVING ADDITIVES

A Dissertation
submitted in partial fulfilment of the
requirements for the Degree of
MASTER OF ENGINEERING
in
MACHINE DESIGN

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CERTIFICATE

Certified that the dissertation entitled "FRICTION AND WEAR CHARACTERISTICS OF METAL PAIRS WITH THE LUBRICANTS HAVING ADDITIVES", which is being submitted by Sri J.K. Goyal in partial fulfilment for the award of the Degree of Master of Engineering in MECHANICAL ENGINEERING - MACHINE DESIGN of University of Roorkee is a record of student's own work carried out by him under my own supervision and guidance. The matter embodied in this dissertation has not been submitted for the award of any other Degree or Diploma.

This is further to certify that he has worked for a period of about 8 months from December 1964 to August 1965 for preparing dissertation for Master of Engineering Degree at this University.

Dated: Aug. 28, 1965.

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(J.K. Goyal)

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ABSTRACT

The work presented here comprises of the theoritical background of the effect of additives in lubricants on the wear and friction characteristics of metal pairs and an experimental investigation of various aspects of it.

Two lubricants - SAE-30 and EP- 90 are used along with two additives - lead and chromium soaps in different combinations and proportions. Metal pairs investigated are "mild steel on brass", "mild steel on mild steel" and "brass on brass". The first part deals with the theories and practical importance of the phenomena of friction, wear and lubrication. The second part deals with the experimental investigation.

The results thus obtained have been discussed and conclusions are drawn in the end. Scope of further work is briefly suggested.

C O N T E N T S

INTRODUCTION

Friction studies are complicated since experimental results do not yield very accurate or readily reproducible data and the theories proposed in many cases are not subject to exact experimental verification. One of the best summaries of the theory of friction between solid materials was published by Bowden and Tabor. With an ever increasing power output and capacity, the unit loading and resultant pressure on critical running parts have increased. These higher loads have led to the development of so called concepts of oiliness, film strength, extreme pressure and antiwear agents.

The tests which have been conducted investigate the properties of lubricants and also determine their suitability for various services. An attempt has been made to show the effect of additives in engine and gear oils. In general, friction, wear, and viscosity properties are tested. The results have been analysed in each case and interpreted. A brief description and significance of some of the more important and commonly required properties are also given.

Pairs of mild steel and brass have been used in this study since they are very commonly employed in various industrial applications. The additives used are heavy metal soaps, namely, lead and chromium soaps. The tests have been conducted on a "Timken Wear and Lubricant Testing Machine". Additives are used in order to reduce friction and wear. They form protective coatings and prevent galling, scoring and seizure and also increase adhesiveness of lubricant on metal surfaces.

Friction and wear problems generally encountered in various machines, are overcome by using appropriate lubricating agents. In certain situations, the use of these agents alone may not serve any purpose. However, by using proper additives it becomes quite possible to achieve the desired properties.

FRICTION AND LUBRICATION

FRICTION AND ART OF LUBRICATION

The subject of friction is important in all engineering applications wherever solid surfaces are in contact with each other. Friction, in fact, is the resistance to motion and lubrication is the art of reducing it. It is a common knowledge that lubricating oil is used to keep bearing surfaces apart and thereby permit easy running and reduced wear and tear. This result is brought about by forming a film or layer of oil between bearing surfaces which prevents metallic contact of the parts. The two theories, namely, adhesion theory and interlocking theory, which have been advanced to explain friction, are both tenable. Interlocking of crests and dips seems so obvious that any other explanation appears unnecessary. According to Bowden, friction is essentially the shear strength and adhesion is the tensile strength of the junctions formed at the region of contact. Whether or not this adhesion will in fact be observed, depends primarily on the effect of elastic stresses released when the load is removed.

In fluid film lubrication, lubricant completely separates the moving surfaces during the normal operating conditions. If the layer of fluid does not completely separate the moving surfaces and partial metal to metal contact exists, such a lubrication is termed boundary lubrication. Again, if the extent to which an adsorbed film can prevent metal to metal contact is limited, the boundary film will fail under certain temperature and load conditions, and a direct contact will take place. This condition is called extreme boundary lubrication.

COEFFICIENT OF FRICTION

The coefficient of friction μ is usually defined as the ratio of tangential force F to the normal load N between two solids in relative motion. Thus,

$$\mu = F/N$$

Variables for coefficient of friction may be load, contact area, velocity of slide, time of loading before slide, length of slide, temperature, lubricant viscosity etc. To explain the wide range of coefficient of friction we consider the fundamental mechanism of dry friction. The complete mechanism of dry friction consisted of the following three factors:

1. A mechanical interlocking of surface asperities.
2. A plowing of the surface asperities of the harder of the two metals through the softer.
3. A welding of the surface asperities of the one metal to the other resulting in metallic junctions.

The shear and friction processes are not independent, a fact which will be clear from the coefficient of friction analysis. The satisfactory rules observed for dry friction are:

i) The coefficient of friction μ is independent of the applied load N.

ii) The coefficient of friction μ is independent of apparent area of contact A.

iii) The coefficient of friction is independent of the ambient temperature of metals.

iv) The coefficient of friction is independent of sliding speed.

While these rules represent good approximations under normal conditions of bodies in sliding contact, they may fail completely if conditions are sufficiently abnormal.

Coefficient of friction for effective boundary lubricants lie roughly in the range of 0.02 to 0.1 (compared with clean dry metals, $\mu \approx 0.5$ to 1.5). The variables that influence dry friction also influence boundary friction. Boundary friction may be considered as an extension of dry friction where the additional variables of contamination are recognized and included. The laws of friction are still valid but it can be shown that for most conditions of sliding, some penetration of boundary film occurs. Also, friction depends on the chemical composition of lubricant and/or the reaction between the lubricant and the solid surface.

WEAR THEORY

Among the friction components, shear is generally of major importance but it can be seen that mechanism of metal transfer and wear also explains the shearing component of friction. As defined, wear is the progressive loss of substance from the surface of a body brought about by mechanical action. Wear is the major factor limiting the life and performance of machine components and hence is very important in engineering practice.

Mechanism of metal transfer and wear explains the welding of sheared off peaks to their opponent high spots as a consequence of friction. Metal transfer and wear take place at points of actual contact. The interfaces of high spots that actually make contact are roughned as a result of plastic deformation when they carry normal loads. The mechanical interlocking of these roughned interfaces is the primary cause of metal transfer and wear. Due to mechanical interlocking effect of the roughned interfaces and strain hardening that accompanies plastic deformation, the application of a tangential force will break one of the pair of contacting high spots at certain distance away from the interface rather than at the original interface.

A secondary cause of metal transfer is the adhesion or the diffusion process which takes place during the temperature flash that occurs during breakage. If the adhesive force is very weak and diffusion process is not rapid enough to cause the sheared off peak of the high spot to become a blob of transferred metal, the small pieces of metal sheared can leave as a loose wear particle.

In the operation of a machine, it is essential that the rate of wear of the moving parts be held to a minimum.

Wear, like many other phenomena which take place when a machine is operated, is influenced by the design of machine, the operating conditions, and the lubricating oil. In order to get lubricants which give maximum protection against wear, it is essential to see the effect of additives.

MEASUREMENT OF WEAR

Several methods have been devised by various investigators for the quantitative determination of wear, the most common are those which measure change in weight or dimensions. The weight measurement method is frequently used in the case of small parts which can be weighed on an analytical balance; the dimension measurement may be used for larger parts. In 1940, Williams[1] determined the wear of cylinder rings and that of cylinders by means of a gage capable of measurements to an accuracy of ± .002 mm. An instrument known as McKee gage, developed at the Bureau of Standards is claimed to be even more sensitive[2]. This gage determines wear by measuring change in the length of indentations made prior to the test with a precisely shaped tool.

ADDITIVES

Modern engines and machinery frequently require lubricants which have characteristics superior to those obtained in lubricants derived from petroleum by refining techniques only. The trend of engineering design puts ever increasing demands on the load carrying capacity of lubricants. By the addition of suitable substances, almost any property of an oil can be modified.

Additives are special substances and may be defined as chemical compounds which will either enhance or improve some of the properties which a petroleum product already has or impart new characteristic to it. These are classified in two main divisions:

A) Those which affect some physical characteristics of the lubricant such as viscosity, pour point, foaming etc.

B) Those whose final effect is more chemical in nature and usually more measurable in terms of some performance characteristics. These include oiliness agents, extreme pressure agents, antiwear agents, and other materials.

In order to protect bearing surfaces against seizure and wear, the films formed as a result of chemical action must shear easily or have melting points below those of bearing surfaces. By using proper additives, a film is formed on the metal contacting surfaces due to chemical reaction which has lower shear strength than base metal, thereby reducing friction and preventing welding and seizure when oil film is ruptured. Additives are added to an oil in amounts upto ten percent. A small quantity of these will increase the viscosity of oil and form a structure which minimizes the leakage that occurs with pure oil. Larger quantities of additive will give rise to soft greases.

Additives which reduces friction and wear and prevent galling, scoring, and seizure are chemical compounds containing chlorine, lead, sulphur, aluminium, chromium, and phosphorus. Certain compounds containing zinc are also antiwear agents. Antiwear agents are thought to function through a chemical polishing action which can take place at relatively low temperatures whereas extreme pressure agents require high temperatures (probably localized) to react with the protective coating or film. Fatty acids and fatty alcohols are among the commonly used oiliness agents.

VISCOSITY

The most important property in selecting a lubricant for a particular application is the viscosity. For a bearing operating in the hydrodynamic region at given conditions of load and speed, the viscosity of oil at the film conditions determines the point of operation on "Z N/p" curve and the coefficient of friction. This in turn determines the frictional power loss and heat generation in the bearing and the oil flow rate through the bearing. The viscosity of oil at film temperature should be sufficient to maintain a fluid film, but not so high that frictional losses and heat generation are excessive.

A margin of safety is desirable to ensure that the fluid film is not squeezed out.

There is no simple method for ascertaining the optimum viscosity for any specific mechanism. This knowledge comes from experience and general practice. Selection of viscosity limits is controlled by a number of factors, e.g. temperature, load, method of feed, speed etc.

Generally, low viscosity oils are used for light loads and high speeds and higher viscosity oils for heavier loads and lower speeds. Also with high operating temperatures, comparatively high viscosity oils are required, and with low operating temperatures low viscosity oils are satisfactory.

OILINESS

Oiliness has never been precisely defined or measured. Oiliness is a property which is significant at high pressures and small clearances. The adsorption of an oil film on metal surfaces reduces friction by what has been known for years as oiliness. Oiliness is generally used to indicate the resulting differences in friction when different lubricants are used under the same conditions. Oiliness is the reciprocal of coefficient of friction μ under the conditions of boundary lubrication and is related to the following:

1. Ability to prevent wear.

2. Resistance of oil film being ruptured or displaced.

3. Load carrying abilities.

4. Ability to prevent failure by seizure, galling, or scuffing.

Thus, the term oiliness is intended to convey a thought on something which is difficult to define in scientific terms. A cup of water is not "wet" nor a bottle of oil is "oily" but if a solid be dropped into these liquids, they may become wet or oily. The precise explanation of oiliness term involves considerable knowledge of molecular physics.

A number of machines have been proposed for studying and measuring the property of oiliness, but none have proved entirely reliable from a practical stand point. No standard system has yet been adopted to give numerical values to "oiliness" of lubricants although this would be very desirable.

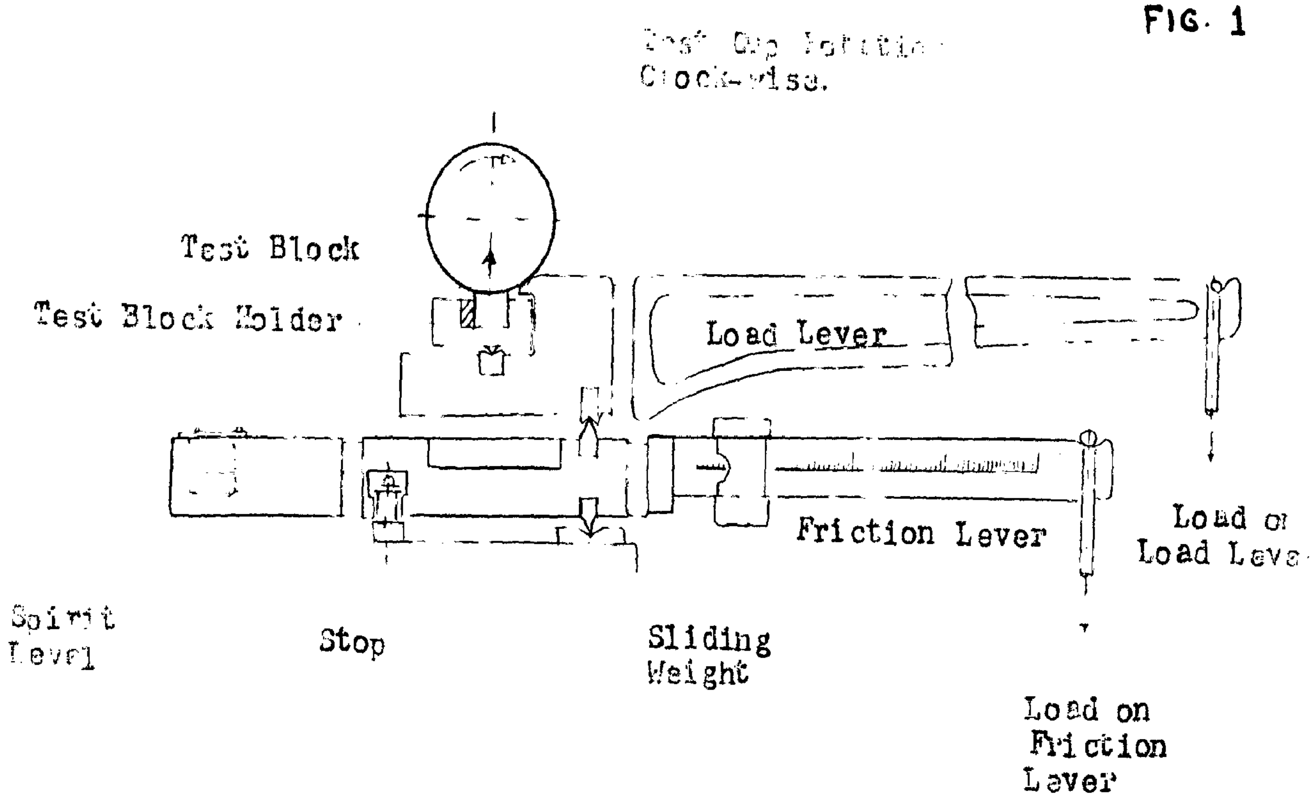
EXPERIMENTAL STUDY

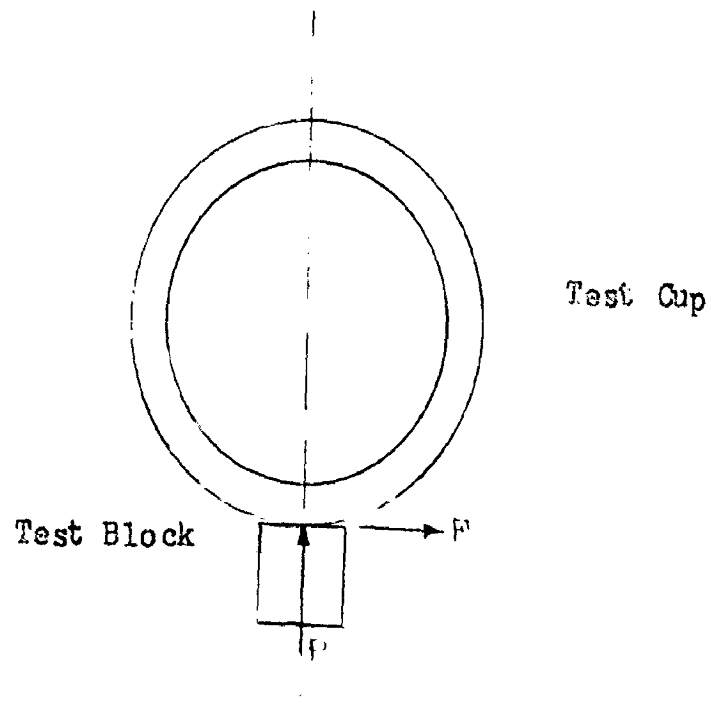
TESTING MACHINE

Timken Wear and Lubricant Testing Machine was used for investigating "Friction and wear characteristics of metal pairs with the lubricants having additives". In this machine, two metal surfaces having a very small contact area are rubbed together in presence of a high normal pressure between them. The applied pressure is increased slowly until seizure occurs and this is found to vary widely with different lubricants. In this machine a circular disc, approximately two inches in diameter, is rotated against a rectangular block, the area of contact being a very narrow band.

The general arrangement of the basic elements of the machine is given in the schematic diagram (Figure 1). It consists of a system of two superimposed levers. The upper or the load lever carries a pivoted holder containing the test block. This test block bears against the test cup being held up by weights suspended from the end of the lever on which the block is carried. The lower or the frictional lever, to which weights are added to balance the frictional forces, is used to obtain a direct reading of friction in terms of weight.. A built-in electric heater below the oil reservoir is used to heat the oil upto 210°F. Oil flows from reservoir by gravity over the test block and is pumped back to the reservoir. The oil pump is engaged or disengaged by actuating a Knob attached to

FIG. 1



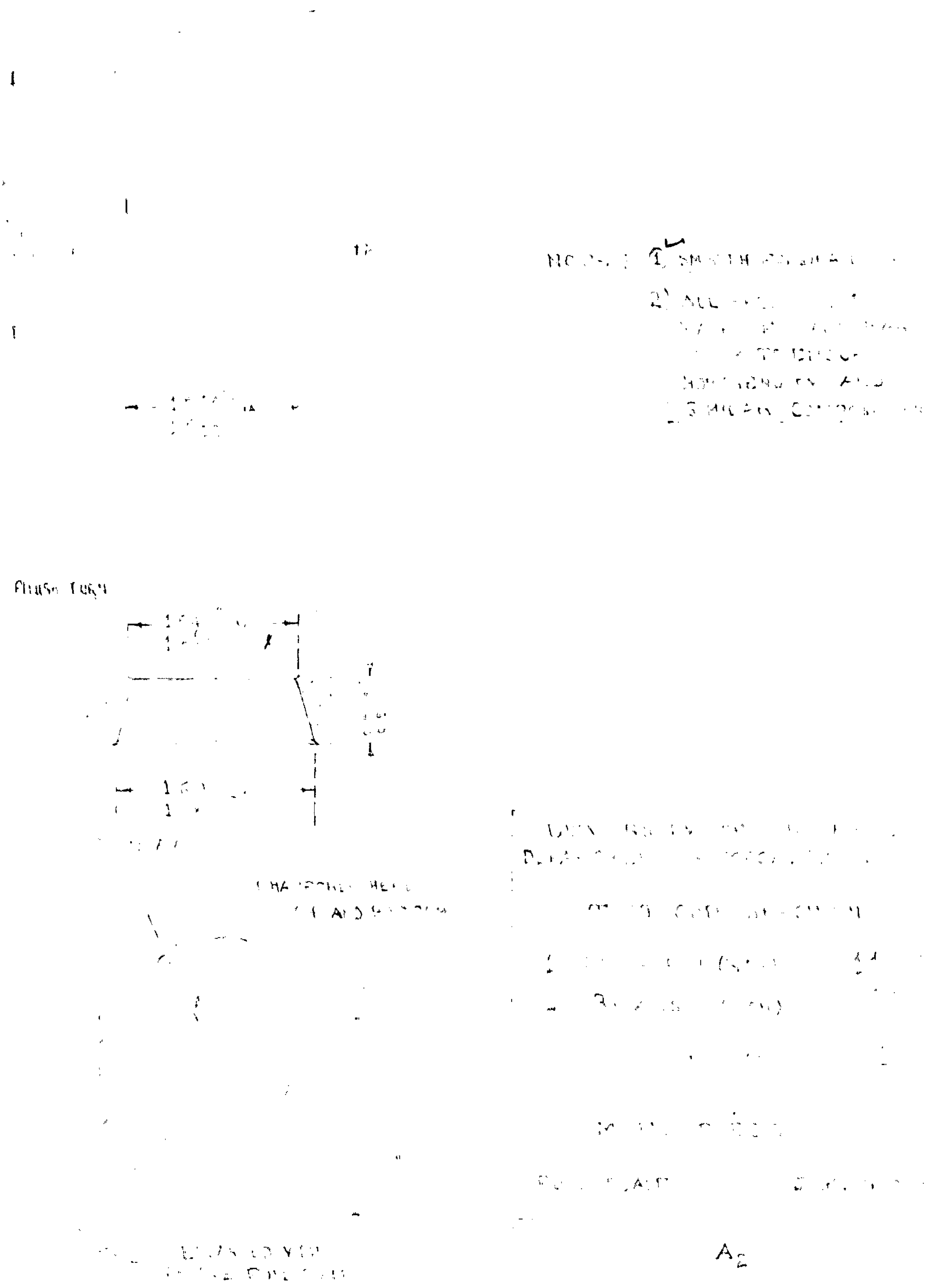


ENLARGED VIEW

Schematic of the Apparatus used for Testing and the System of Forces Acting.

FIG. 2

FIG. 3



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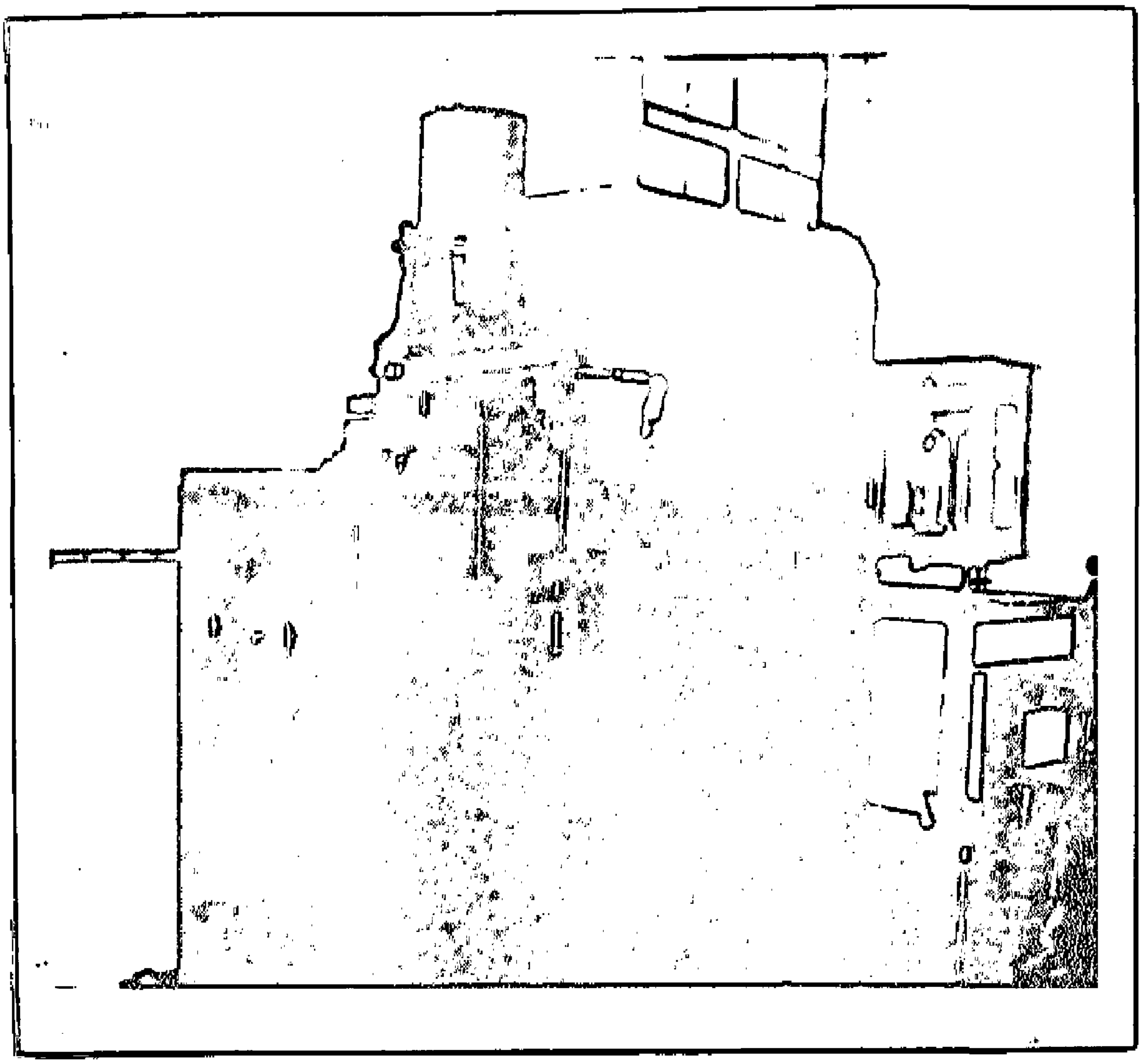


Photographic View of the Timken Wear and Lubricant Testing Machine.

a short lever. A flow valve regulates the flow of lubricant. A small hole in the cover of reservoir is provided for reading the temperature of oil on a thermometer.

The machine is driven by a variable speed motor. The speed can be varied upto 2000 revolutions per minute. There is a spirit level attached at the end of the friction lever which indicates the level of the lever system when it is assembled in position. Other spirit levels are provided to check the level of the machine.

METALS, LUBRICANTS, AND ADDITIVES

The selection of metals is essentially an Engineer's job before passing them to production line. Mild steel and brass, being the most commonly used engineering materials, were selected for investigating the friction and wear characteristics. The above characteristics have been studied to minimize the bad effects, friction and wear, by using a lubricant which will prove best in service.

Lubricating oils selected for the purpose are SAE-30 engine oil and EP-90 gear oil. Additives were added to these oils to improve upon their lubricating properties for reducing friction and wear. Effects of lead and chromium soap, additives were studied. Gear oils are extreme pressure treated oils with high film strength, making them suitable for high temperature conditions. In fact the choice of oil depends on the material, function, and operational speed.

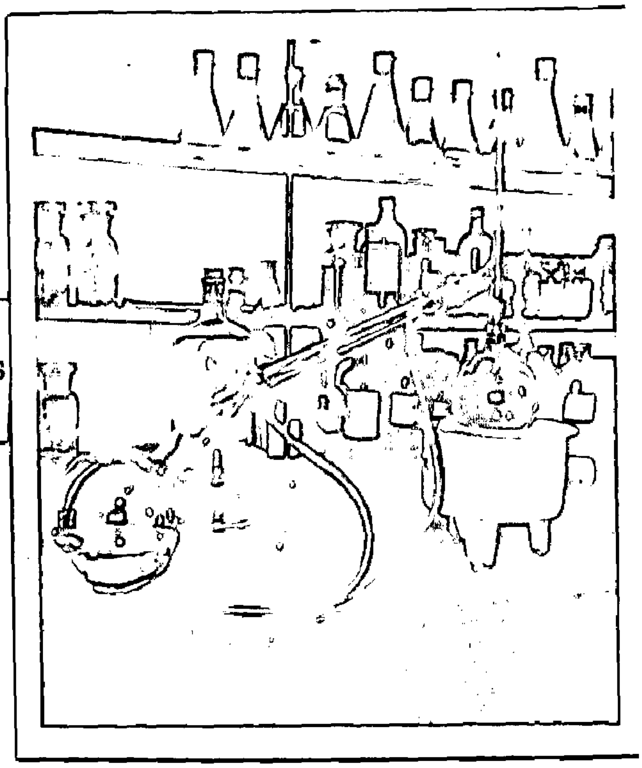
Selection of additives depends upon the lubricating quality we require from the lubricant under existing conditions. As mentioned above, the additives selected are lead and chromium soaps. Lead soap have special uses, because the soap is in solution and it melts on heating. Chromium soap prevents sticking, probably through detergent character. For extreme pressure conditions, lead soap is useful in avoiding sulphur corrosion. Though there are some more additives to be used, but the above two were selected for this investigation.

PREPARATION OF ADDITIVES

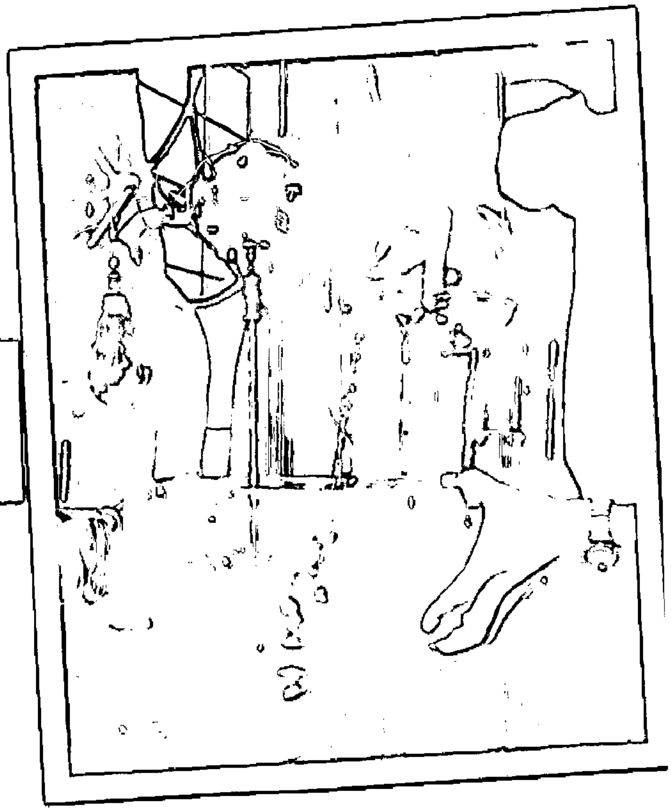
Facilities in the Chemistry Department were used to prepare the lead and chromium soaps. The chemicals required were sodium palmitate, chrome alum, lead acetate, acetone, ether, and absolute alcohol. The chromium soap was prepared by direct metathesis from the corresponding sodium palmitate and chrome alum with constant stirring. The procedure can be summarized in the following steps:

1) Weighing the required amounts of sodium palmitate and chrome alum according to following reaction:

$$6\ Na\ Pal. + K_2\ So_4\ Cr_2\ (So_4)_3\ 24\ H_2O \rightleftharpoons 2\ Cr(Pal.)_3 + 3Na_2\ So_4 + K_2\ So_4 + 24\ H_2O$$



Photograph - showing distillation process



Photograph-showing reaction stage in the preparation of additives.

ii) Dissolving the chrome alum (124.85 grams/liter) and sodium palmitate(208.8 grams/liter) in warm distilled water.

iii) Mixing the above throughly by electric stirrer, which gives a precipitate grey in colour.

iv) Filtering the precipitated chromium palmitate in the buckler funnel and washing with distilled water.

v) Removing the free precipitant and the acid, washing by ethanol and acetone and finally with ether.

The soap thus obtained, was then dried under vacuum.

The lead soap was also prepared by metathesis method, taking lead acetate (110.9 grams/liter) and sodium palmitate (69.6 grams/liter) calculating the amounts by the following chemical equation:

$$\underset{(443.4)}{\text{Pb acetate}} + \underset{(278.4)}{\text{Na Palmitate}} \rightleftharpoons \text{Na acetate} + \text{Pb Palmitate}$$

The lead soap obtained was white in colour.

REQUIRED ACCESSORIES

Following equipment were required for conducting the tests:

1) Chemical balance to weigh the specimens and additives.

2) Acetone and linen cloth to clean the specimens surfaces.

3) Hot plate and flask to dissolve the additives in oils.

4) Fan for cooling the lubricant.

5) Brinell microscope for measuring scar width.

6) Viscometer for measuring viscosities.

TEST GROUPS

The groups of the tests performed are given in the following table:

Group	Metal Pair	Additive	Oil	Total No.of Tests Friction & Wear	Film Strength
1	M.S. on Brass	Lead and	SAE-30	22	12
2	M.S. on M.S.	Chromium	and EP-	22	12
3	Brass on Brass	Soaps	90 Oils	22	12

Different quantities of one of the additives were added in each of the oils, and the viscosity was measured at different temperatures. Similarly test oils with the other additive were also prepared and their viscosity measured.

TEST PROCEDURE

Testing machine was cleaned and brought to correct level. Oil reservoir was filled with equal amounts of prepared lubricants every time. The oil pump clutch was engaged. The test cup and block were cleaned and weighed. Test cup was fitted on machine spindle and test block was placed in its holder. Surfaces of cup and block were smeared fully with the lubricant. The lever system was assembled in position, and checked by built in spirit level at the end of friction lever. The weight carrier was kept in readiness with the required weight fitted on it. Sliding weight on the friction lever was kept at zero initially.

To confirm that the test cup and the block were contacting properly, the machine was turned a few revolutions by hand. The flow valve was opened by same amount each time and machine was started by switching the motor on. The fan, set at suitable position was also started. Speed of the machine was adjusted to the desired value. The weight carrier was mounted on the load lever in position. Friction lever reading was taken when steady temperature was attained. Temperature was checked at different intervals. Test was run for one hour.

After the test, cup and block were again cleaned and weighed. The width of the scar on the test block was measured. The same procedure was adopted throughout for all the tests conducted in this investigation.

TEMPERATURE CONTROL

During the test, the temperature was found to increase considerably at the contacting surfaces. This temperature can be controlled by

i) lowering the speed of machine spindle,

ii) reducing the load on the load lever, and

iii) applying some cooling device.

It was observed that by keeping the speed 500 revolutions per minute, limiting the load below 16 pounds and using an electric fan placed in suitable position and direction for air cooling, the temperature rise was very small.

MIXING ADDITIVES TO OIL

For thorough mixing of the different quantities of additive in oil, an electric heater and one liter capacity flask were used. The weighed quantity of additive was taken and poured in the flask containing about half liter oil. It was then kept on the electric heater and shaked from time to time. After it was completely dissolved, it was added to rest of the reservoir oil (about 2.5 liter) and stirred continually for about half an hour till the temperature fell to 100°F. The required lubricant for the test was thus obtained.

OBSERVATIONS, CALCULATIONS, AND RESULTS

Observations and results are arranged in tabular form (Table Nos. 1-14, Page 21-34). Results have been calculated by using the following formulae:

i) $P = 10(A+C)-2.5(B+R)$

ii) $S = P/WxL$

iii) $\mu = 9.45x(B+R)/10(A+C)-2.5(B+R)$

where A = weight on load lever(L.L.W.)

B = weight on end of friction lever.

C = load lever constant = 1.67 lbs.

P = test force (normal)

R = friction lever sliding weight reading.

S = pressure on test block in lbs. per square inch.

W = width of scar on test block in inches.

L = length of scar on test block in inches=0.5".

μ = coefficient of friction.

(B+R) = friction lever weight (F.L.W.)

SAMPLE CALCULATIONS

$\mu = 9.45x(B+R)/10(A+C)-2.5(B+R)$

$= 9.45(1.02)/10(12+1.67)-2.5(1.02)$

$= 0.0718$ ... ... (Table No. 3, Test No.1) and pressure on test block is:

$$S = P/WxL$$

$$= 10(A+C)-2.5(B+R)/WxL$$

$$= 10(12+1.67)-2.5(1.02)/0.0538x0.5$$

$$= 4992 \text{ p.s.i.}$$

TABLE NO. 1

Test No.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test. gms.	Wt. of Block After Test. gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressure on Block p.s.k.
1.	54.928	54.922	25.607	25.528	6.0	79.0	0.76	6.15	0.0758	0	0.242	783
2.	54.278	54.2746	25.7876	25.7262	3.4	61.4	0.71	5.77	0.0707	8	0.2272	836
3.	54.3326	54.3302	25.7822	25.7446	2.4	37.6	0.54	3.9	0.0535	12	0.1532	1243
4.	54.363	54.3622	25.7432	25.726	0.8	17.2	0.41	3.4	0.0405	16	0.1339	1429
5.	53.7712	53.7706	25.7992	25.7864	0.6	12.8	0.32	3.0	0.0316	20	0.1181	1624
6.	54.672	54.666	25.7856	25.7784	0.6	7.2	0.27	2.7	0.0266	24	0.1064	1804

MILD STEEL ON BRASS : R.P.M. : 500, L.L.W.: 8 lbs., Additive Lead Soap,

Lubricant : SAE - 30 , Maximum Temperature : 101^{o}F, Duration of run : 1 hr.

TABLE NO. 2

est o.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test. gms.	Wt. of Block After Test. gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressure on Block p.s.i.
.	54.928	54.922	25.607	25.528	6.0	79.0	0.76	6.15	0.0758	0	0.2422	786
.	53.8792	53.878	25.7094	25.6544	1.2	55.0	0.56	5.4	0.0555	8	0.2128	896
.	54.2978	54.297	25.6532	25.6256	0.8	27.6	0.48	3.8	0.0474	12	0.1497	1277
.	54.3812	54.3806	25.681	25.6678	0.6	13.2	0.46	2.22	0.0455	16	0.0835	2286
.	53.176	53.1758	25.6672	25.6624	0.2	4.8	0.45	2.04	0.04435	20	0.0803	2382

MILD STEEL ON BRASS:- R.P.M. : 500, L.L.W.: 8 lbs., Additive Chromium Soap,

Lubricant : SAE - 30 , Maximum Temperature : $101^{o}F$, Duration of run : 1 hr.

TABLE NO. 3

Test No.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test gms.	Wt. of Block After Test. gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressure on Block p.s.i.
1.	53.3386	53.336	24.1598	24.1562	2.6	3.6	1.02	1.34	0.0718	0	0.0538	4992
2.	54.328	54.3264	24.3424	24.3396	1.6	2.8	1.035	1.6	0.0729	8	0.063	4266
3.	53.7264	53.7254	24.3396	24.3384	1.0	1.2	1.06	1.5	0.0748	12	0.0591	4545
4.	53.0612	53.0606	24.3384	24.3376	0.6	0.8	1.11	1.3	0.0783	16	0.0512	5238
5.	52.7636	52.7636	24.3376	24.337	-	0.6	1.17	1.3	0.0825	20	0.0512	5226
6.	54.641	54.6406	24.075	24.0748	0.4	0.2	1.225	1.22	0.0867	24	0.048	5572

MILD STEEL ON MILD STEEL :-R.P.M.: 500, L.L.W.: 12 lbs., Additive Lead Soap,

Lubricant : SAE-30 , Maximum Temperature : 104°F, Duration of run : 1 hr.

TABLE NO. 4

est o.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test. gms.	Wt. of Block After Test. gms.	Loss of Wt. in Cup. mgs.	Loss of Wt. in Block. mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressur on Bloc p.s.i.
.	53.3386	53.336	24.1598	24.1562	2.6	3.6	1.02	1.34	0.0718	0	0.0538	4992
.	54.5628	54.5616	24.2294	24.2288	1.2	0.6	1.01	1.18	0.0711	8	0.0464	5803
.	53.8198	53.8190	24.2288	24.2284	0.8	0.4	0.97	1.07	0.0682	12	0.0422	6387
.	54.3624	54.3620	24.2284	24.2282	0.4	0.2	0.89	1.01	0.0626	16	0.0399	6754
.	53.9228	53.9224	24.2604	24.2602	0.4	0.2	0.94	1.12	0.0659	20	0.0442	6106

MILD STEEL ON MILD STEEL:- R.P.M.: 500, L.L.W. : 12 lbs., Additive Chromium Soap,

Lubricant : SAE - 30 , Maximum Temperature : 106°F, Duration of run : 1 hr.

TABLE NO. 5

est o.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test. gms.	Wt. of Block After Test. gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressu on Blc p.s.i
.	58.461	58.2806	25.528	25.5244	180.4	3.6	0.66	2.68	0.0655	0	0.1055	1802
.	58.544	58.3812	25.5244	25.5212	162.8	3.2	0.71	2.64	0.0707	8	0.1039	1826
.	58.437	58.295	25.7846	25.7822	142.0	2.4	0.89	2.57	0.0891	12	0.1011	1869
.	58.255	58.161	25.7446	25.7432	94.0	1.4	0.93	2.5	0.0931	16	0.0985	1917
.	58.1374	58.0552	25.7864	25.7856	82.2	0.8	0.96	2.12	0.0961	20	0.0835	2258
.	58.194	58.1302	25.7784	25.7778	63.8	0.6	0.97	1.9	0.0972	24	0.0749	2516

<u>BRASS ON BRASS</u>:- R.P.M.: 500, L.L.W.: 8 lbs., Additive : Lead Soap,

Lubricant SAE-30 , Maximum Temperature : 102^{o}F, Duration of run : 1 hr.

TABLE NO. 6

Test No.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test. gms.	Wt. of Block After Test. gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressur on Bloc p.s.i.
1.	58.461	58.2806	25.528	25.5244	180.4	3.6	0.66	2.68	0.0655	0	0.1055	1802
2.	57.558	57.437	25.6544	25.6532	121.0	1.2	0.78	1.82	0.0777	8	0.0716	2647
3.	57.350	57.2358	25.6818	25.681	114.2	0.8	0.97	1.64	0.0973	12	0.0646	2916
4.	57.7704	57.674	25.6678	25.6672	96.4	0.6	1.01	1.51	0.0101	16	0.0594	3168
5.	57.6504	57.5768	25.7618	25.7614	73.6	0.4	1.03	1.4	0.0103	20	0.0552	3415

BRASS ON BRASS :- R.P.M.: 500, L.L.W.: 8 lbs., Additive : Chromium Soap,

Lubricant : SAE-30 , Maximum Temperature : 103°F, Duration of run : 1 hr.

TABLE NO. 7

est o.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test. gms.	Wt. of Block After Test gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressure on Block p.s.i.
1.	52.960	52.9582	25.7794	25.7662	1.8	13.2	0.87	3.35	0.0611	0	0.134	2006
2.	54.404	54.4028	25.7646	25.7532	1.2	11.4	0.64	3.23	0.0448	4	0.1284	2098
3.	54.212	54.2112	25.7802	25.7706	0.8	9.6	0.53	3.16	0.037	6	0.1242	2176
4.	54.6998	54.6992	25.7694	25.7632	0.6	6.2	0.48	2.58	0.0334	8	0.1017	2663
5.	54.247	54.2464	25.761	25.7566	0.6	4.4	0.42	2.46	0.0292	10	0.0968	2794
6.	52.4562	52.4556	25.7562	25.752	0.6	4.2	0.41	2.48	0.0285	12	0.0975	2782

MILD STEEL ON BRASS :- R.P.M. : 500, L.L.W. : 12 lbs., Additive : Lead Soap,

Lubricant : EP-90 , Maximum Temperature : 105°F, Duration of run : 1 hr.

TABLE NO. 8

...st ...o.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test. gms.	Wt. of Block After Test. gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressure on Block p.s.i.
.	52.960	52.9582	25.7794	25.7662	1.8	13.2	0.87	3.35	0.0611	0	0.134	2006
.	53.8792	53.878	25.8252	25.8136	1.2	11.6	0.83	2.81	0.0582	4	0.11	2449
.	53.2172	53.2164	25.8122	25.8058	0.8	6.4	0.61	2.50	0.0426	8	0.0985	2744
.	54.0426	54.0424	25.823	25.8188	0.2	4.2	0.52	1.95	0.0363	12	0.0768	3525
.	54.0116	54.0114	25.818	25.8134	0.2	4.6	0.47	1.86	0.0328	16	0.0733	3698

<u>MILD STEEL ON BRASS</u>:- R.P.M. : 500, L.L.W. : 12 lbs., Additive : Chromium Soap

Lubricant : EP-90 , Maximum Temperature: 105^{o}F, Duration of run : 1 hr.

TABLE NO. 9

Test No.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test. gms.	Wt. of Block After Test. gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressure on Block p.s.i.
1.	53.8154	53.8142	24.0748	24.073	1.2	1.8	1.46	1.7	0.0754	0	0.067	5477
2.	53.702	53.7012	24.073	24.0716	0.8	1.4	1.53	1.4	0.079	4	0.0552	6645
3.	53.971	53.9702	24.0716	24.0710	0.8	0.6	1.59	1.26	0.0824	6	0.0496	7396
4.	52.9508	52.9502	24.345	24.3444	0.6	0.6	1.61	1.85	0.0834	8	0.0728	5038
5.	54.6226	54.6224	24.3444	24.3438	0.2	0.6	1.61	1.7	0.0834	10	0.067	5477
6.	54.113	54.1128	24.3438	24.3434	0.2	0.4	1.59	1.5	0.0824	12	0.0591	6263

MILD STEEL ON MILD STEEL :- R.P.M.: 500, L.L.W. : 17 lbs., Additive : Lead Soap,

Lubricant: EP-90 , Maximum Temperature : 109°F, Duration of run : 1 hr.

TABLE NO. 10

est o.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test. gms.	Wt. of Block After Test. gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressure on Block p.s.i.
.	53.8154	53.8142	24.0748	24.073	1.2	1.8	1.46	1.7	0.0754	0	0.067	5477
.	53.751	53.750	24.2602	24.2588	1.0	1.4	1.49	1.52	0.077	4	0.0599	6118
.	53.2454	53.2444	24.2588	24.258	1.0	0.8	1.57	1.43	0.0813	8	0.0567	6463
.	53.9288	53.928	24.0738	24.0732	0.8	0.6	1.59	1.28	0.0818	12	0.0504	7266
.	54.0338	54.033	24.0732	24.0726	0.8	0.6	1.58	1.29	0.0823	16	0.0507	7258

MILD STEEL ON MILD STEEL:- R.P.M.: 500, L.L.W.: 17 lbs., Additive : Chromium Soap,

Lubricant : EP-90 , Maximum Temperature : 108°F, Duration of run : 1 hr.

TABLE NO. 11

Test No.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test. gms.	Wt. of Block After Test. gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressure on Block p.s.i.
1.	58.467	58.4424	25.7662	25.7646	24.6	1.6	0.72	1.6	0.0504	0	0.063	4272
2.	58.2832	58.2656	25.7816	25.7802	17.6	1.4	0.84	1.43	0.0591	4	0.0563	4764
3.	58.3284	58.3136	25.7706	25.7694	16.8	1.2	0.87	1.36	0.0611	6	0.0536	5011
4.	58.8578	58.8424	25.7616	25.761	15.4	0.6	0.92	1.18	0.0648	8	0.0464	5783
5.	57.993	57.9816	25.7566	25.7562	11.4	0.4	1.03	1.10	0.0725	10	0.0433	6188
6.	58.1764	58.1668	25.8556	25.8554	9.6	0.2	1.21	1.12	0.0857	12	0.0442	6075

BRASS ON BRASS:- R.P.M.: 500, L.L.W.: 12 lbs., Additive : Lead Soap,

Lubricant : EP-90 , Maximum Temperature : 103°F, Duration of run : 1 hr.

TABLE NO. 12

Test No.	Wt. of Cup before Test. gms.	Wt. of Cup after Test. gms.	Wt. of Block before Test gms.	Wt. of Block After Test gms.	Loss of Wt. in Cup mgs.	Loss of Wt. in Block mgs.	F.L.W. B+R	W mm.	μ	Additive gms/litre	W inches	Pressure on Block p.s.i.
1.	58.467	58.4424	25.7662	25.7646	24.6	1.6	0.72	1.6	0.0504	0	0.063	4272
2.	57.903	57.8816	25.8136	25.8122	21.4	1.4	0.81	1.73	0.0569	4	0.0681	3954
3.	58.7454	58.7258	25.8242	25.823	19.6	1.2	0.90	1.54	0.0632	8	0.0607	4432
4.	58.2428	58.2252	25.8188	25.818	17.6	0.8	0.93	1.38	0.0653	12	0.0544	4946
5.	58.1024	58.0862	25.9096	25.909	16.2	0.6	0.93	1.23	0.0653	16	0.0484	5554

BRASS ON BRASS:- R.P.M.: 500, L.L.W.: 12 lbs., Additive : Chromium Soap,

Lubricant: EP-90 , Maximum Temperature : 104°F, Duration of run : 1 hr.

TABLE NO. 13

TESTS FOR FILM STRENGTH

Tests	Test Pair	Film Strength lbs.			Lub.	Additive
		Without Additive	Additive 8 gms/ltr.	Additive 16 gms/ltr.		
1-3	M.S. on Brass	26	29	30.5	SAE -30	Lead Soap
4-6	Brass on Brass	28	29	29.5	"	"
7-9	M.S. on M.S.	41	43	44	"	"
10-12	M.S. on Brass	26	27	27.5	SAE -30	Chromium Soap
13-15	Brass on Brass	28	30	31	"	"
16-18	M.S. on M.S.	41	42	43	"	"
19-21	M.S. on Brass	48	49	49	EP-90	Lead Soap
22-24	Brass on Brass	37	39	40	"	"
25-27	M.S. on M.S.	54	54	55	"	"
28-30	M.S. on Brass	48	48	48.5	EP-90	Chromium Soap
31-33	Brass on Brass	37	39.5	41	"	"
34-36	M.S. on M.S.	54	55	55.5	"	"

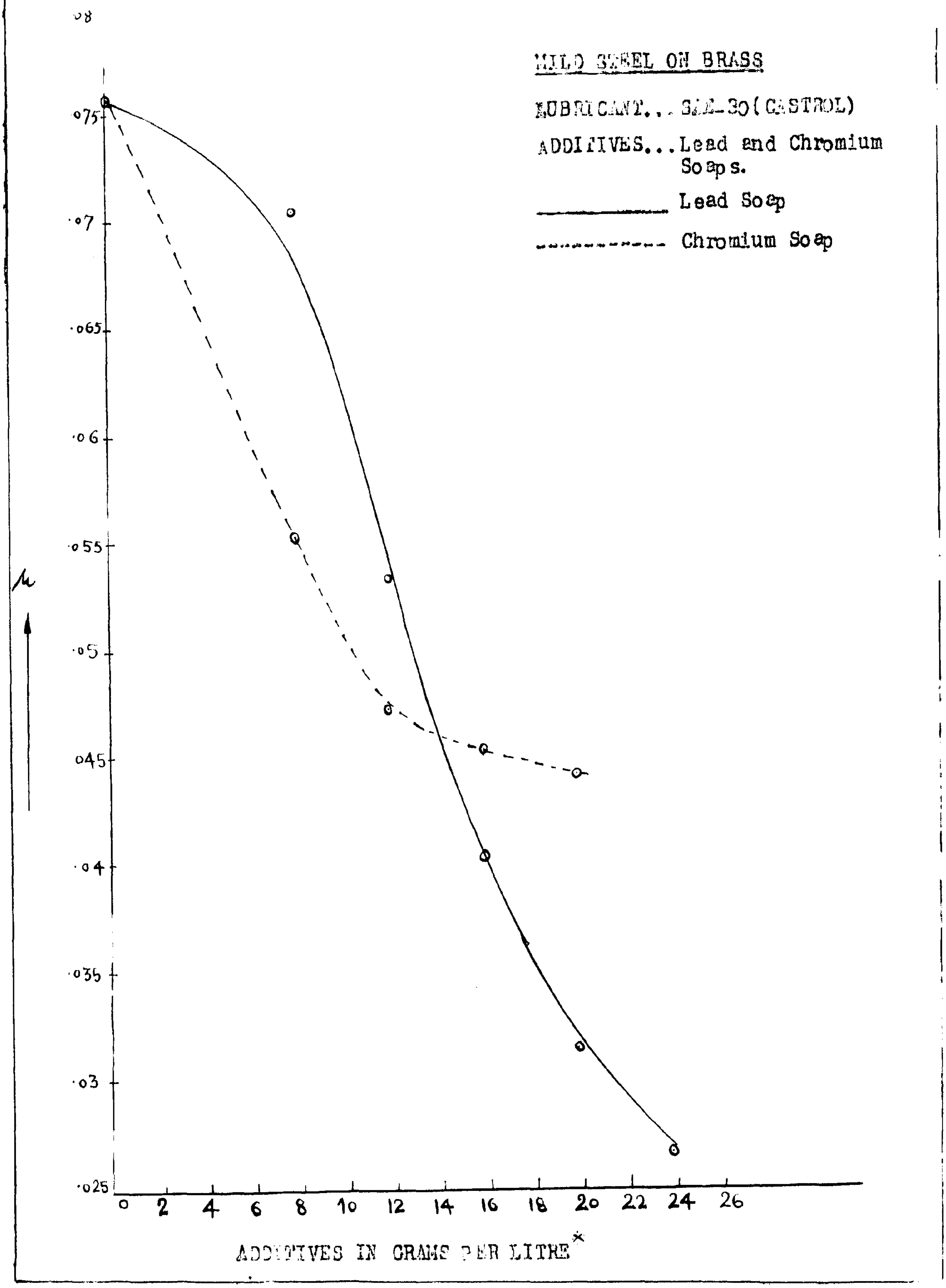
R.P.M. : 800

TABLE NO. 14

VISCOSITY RESULTS

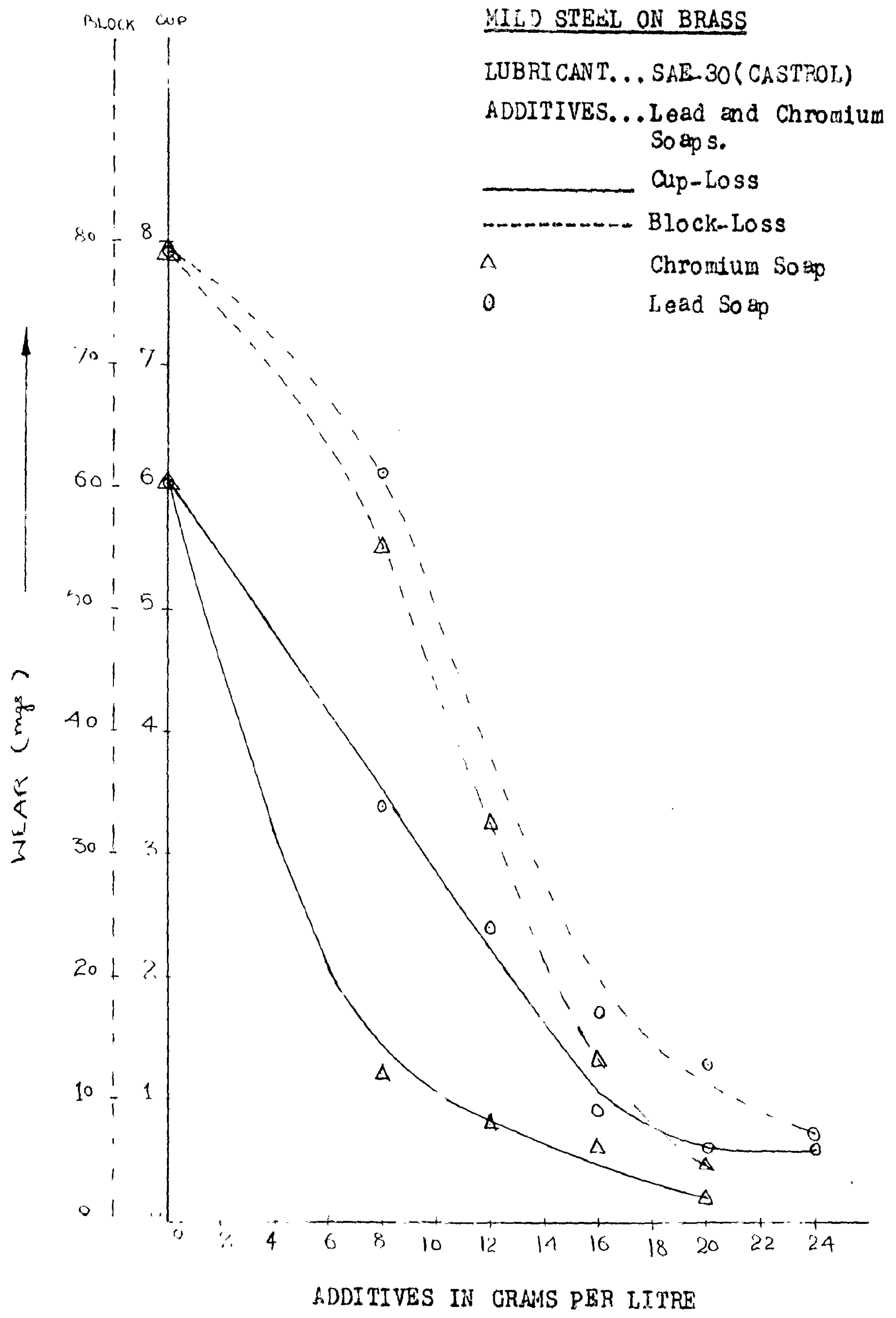
TEMP. °F	VISCOSITY - REDWOOD SECONDS Additive in gms./litre 0	4	8	12	16	LUBRICANT	ADDITIVE
125	295	349	354	359	367	SAE-30	Lead Soap
115	364	413	419	442	454	"	"
105	436	482	493	541	593	"	"
95	554	604	612	655	758	"	"
125	295	306	308	316	322	SAE-30	Chromium Soap
115	364	381	393	407	424	"	"
105	436	472	487	518	546	"	"
95	554	587	604	635	676	"	"
125	467	474	483	494	-	EP-90	Lead Soap
120	543	556	563	575	-	"	"
115	624	641	649	657	-	"	"
105	828	862	883	909	-	"	"
100	987	1037	1054	1091	-	"	"
95	1166	1244	1267	1303	-	"	"
125	467	533	546	564	-	EP-90	Chromium Soap.
115	624	648	657	676	-	"	"
105	828	837	844	852	-	"	"
95	1166	1203	1208	1217	-	"	"

FIG. 4



*Pl. read liter for litre.

FIG. 5



MILD STEEL ON BRASS
LUBRICANT... SAE-30(CASTROL)
ADDITIVES...Lead and Chromium Soaps.
Cup-Loss
Block-Loss
Δ Chromium Soap
O Lead Soap
BLOCK
CUP
WEAR (mgs)
ADDITIVES IN GRAMS PER LITRE

FIG. 6

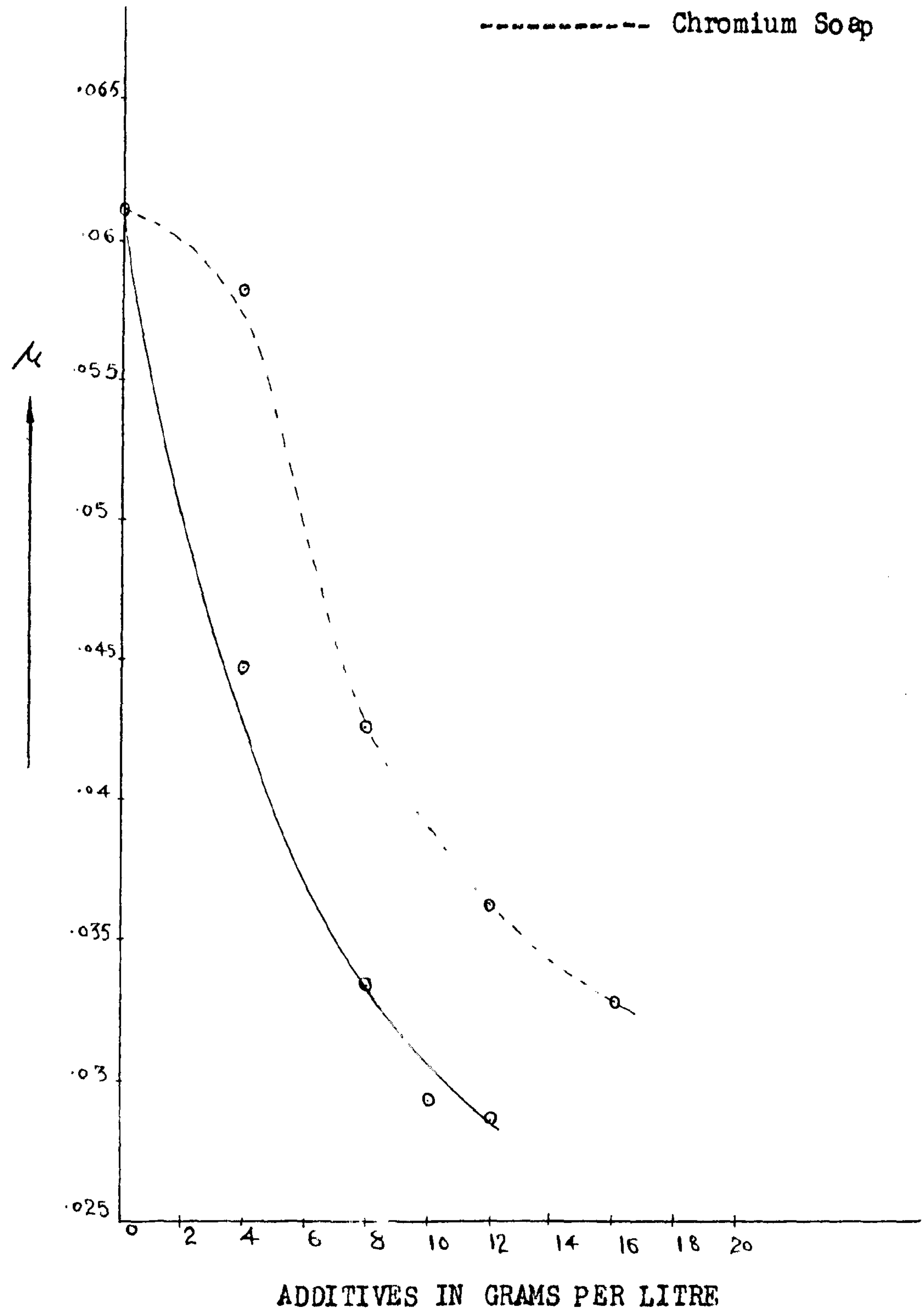
MILD STEEL ON BRASS

LUBRICANT...EP-90(CASTROL)

ADDITIVES...Lead and Chromium Soaps

——————— Lead Soap

- - - - - - - - Chromium Soap



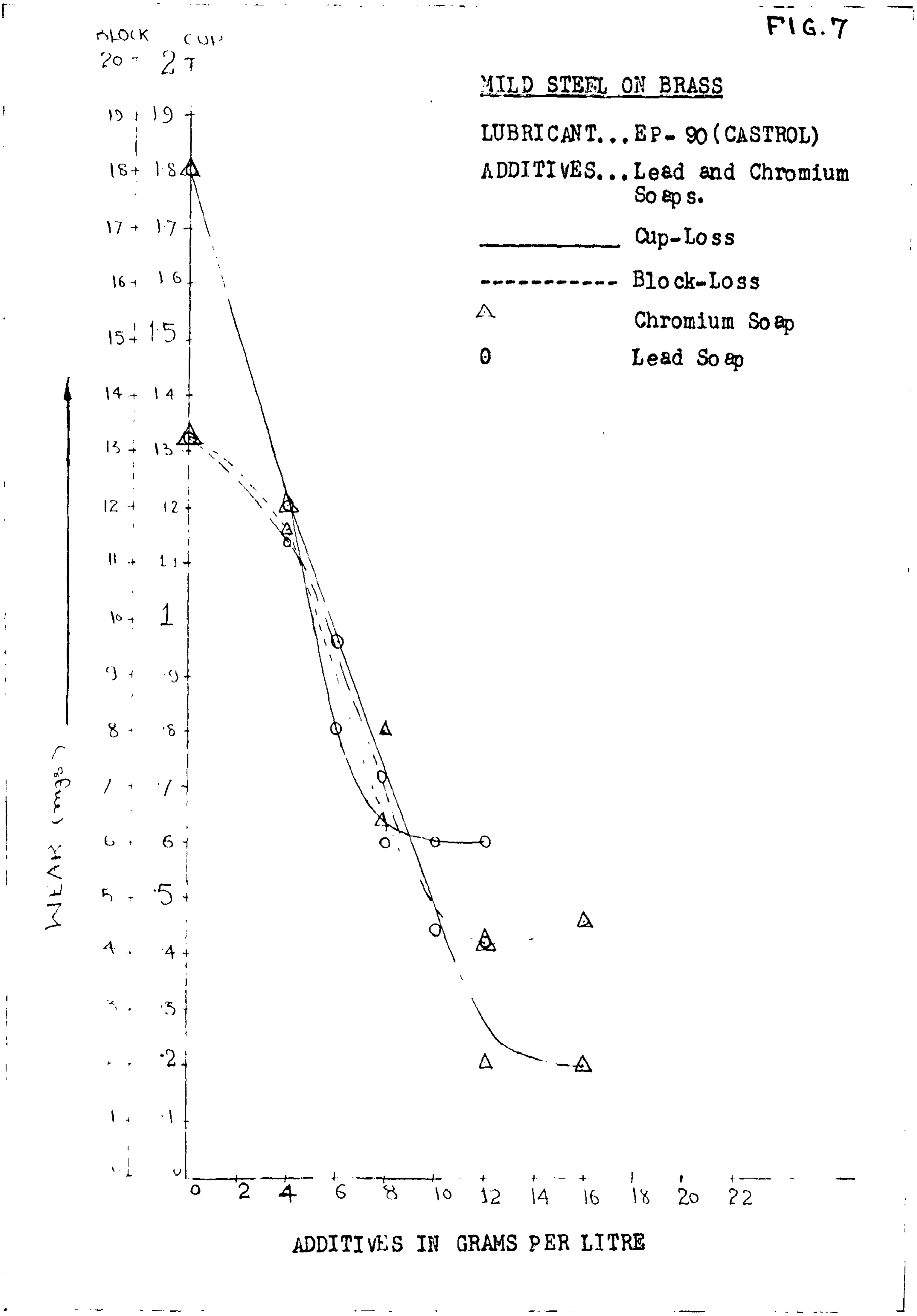


FIG.7
MILD STEEL ON BRASS
LUBRICANT...EP- 90(CASTROL)
ADDITIVES...Lead and Chromium Soaps.
Cup-Loss
Block-Loss
Chromium Soap
Lead Soap
BLOCK
CUP
WEAR (mgs)
0
2
4
6
8
10
12
14
16
18
20
22
ADDITIVES IN GRAMS PER LITRE

FIG. 8

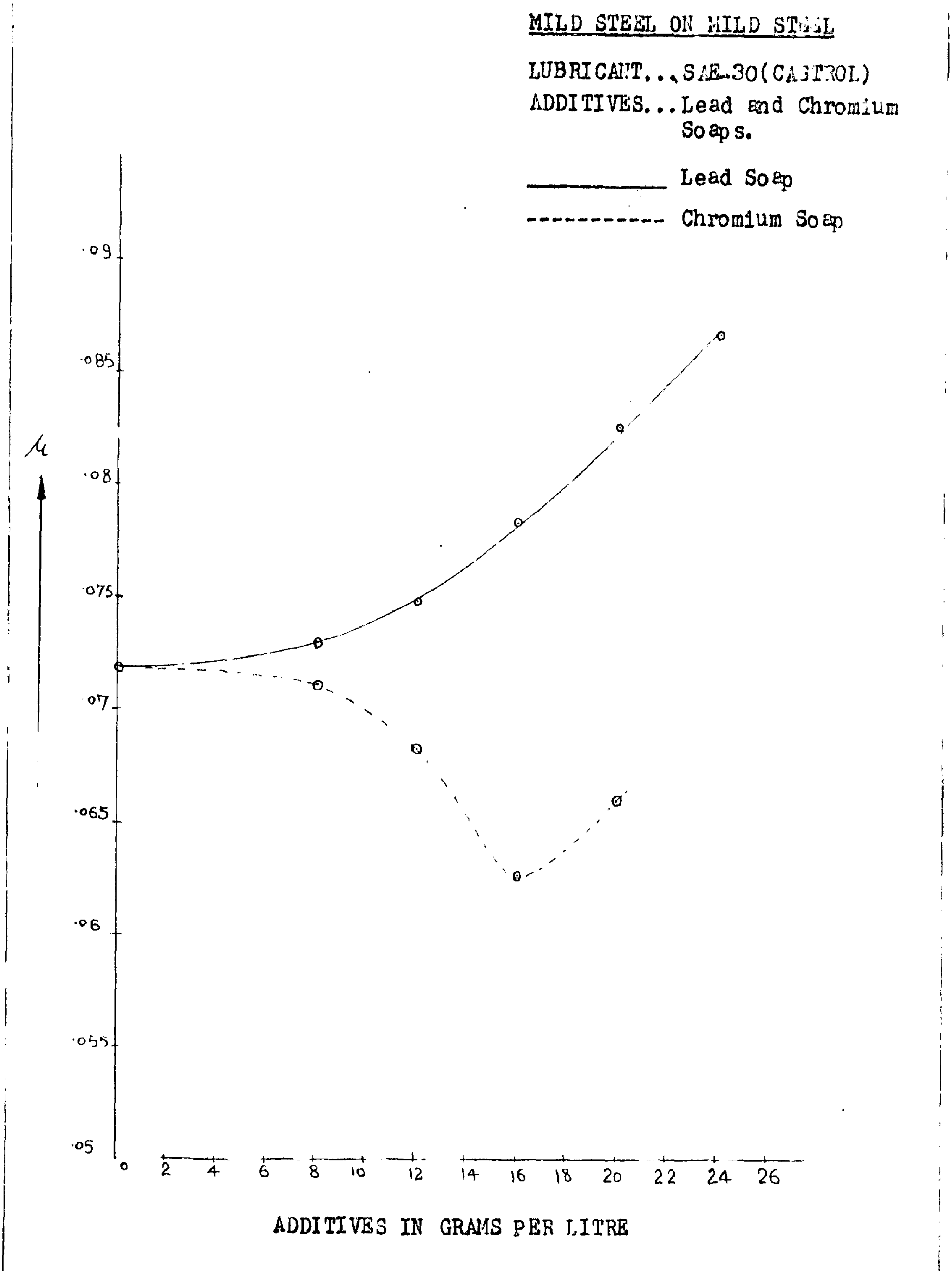

MILD STEEL ON MILD STEEL
LUBRICANT...SAE-30(CASTROL)
ADDITIVES...Lead and Chromium Soaps.
Lead Soap
Chromium Soap
μ
·09
·085
·08
·075
·07
·065
·06
·055
·05
0
2
4
6
8
10
12
14
16
18
20
22
24
26
ADDITIVES IN GRAMS PER LITRE

FIG. 9

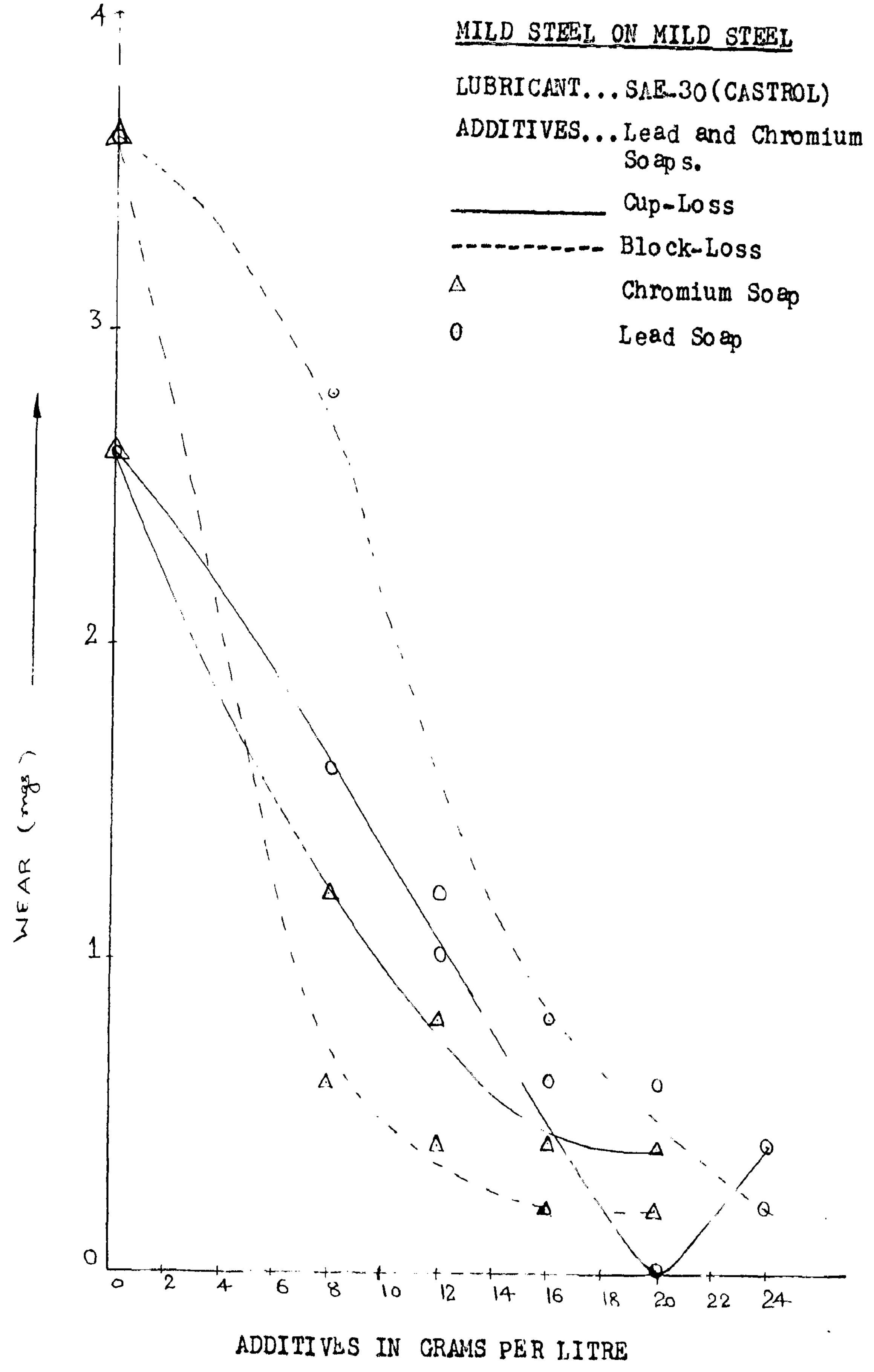

MILD STEEL ON MILD STEEL
LUBRICANT...SAE-30(CASTROL)
ADDITIVES...Lead and Chromium Soaps.
Cup-Loss
Block-Loss
Chromium Soap
Lead Soap
WEAR (mgs)
0
1
2
3
4
0
2
4
6
8
10
12
14
16
18
20
22
24
ADDITIVES IN GRAMS PER LITRE

FIG. 14

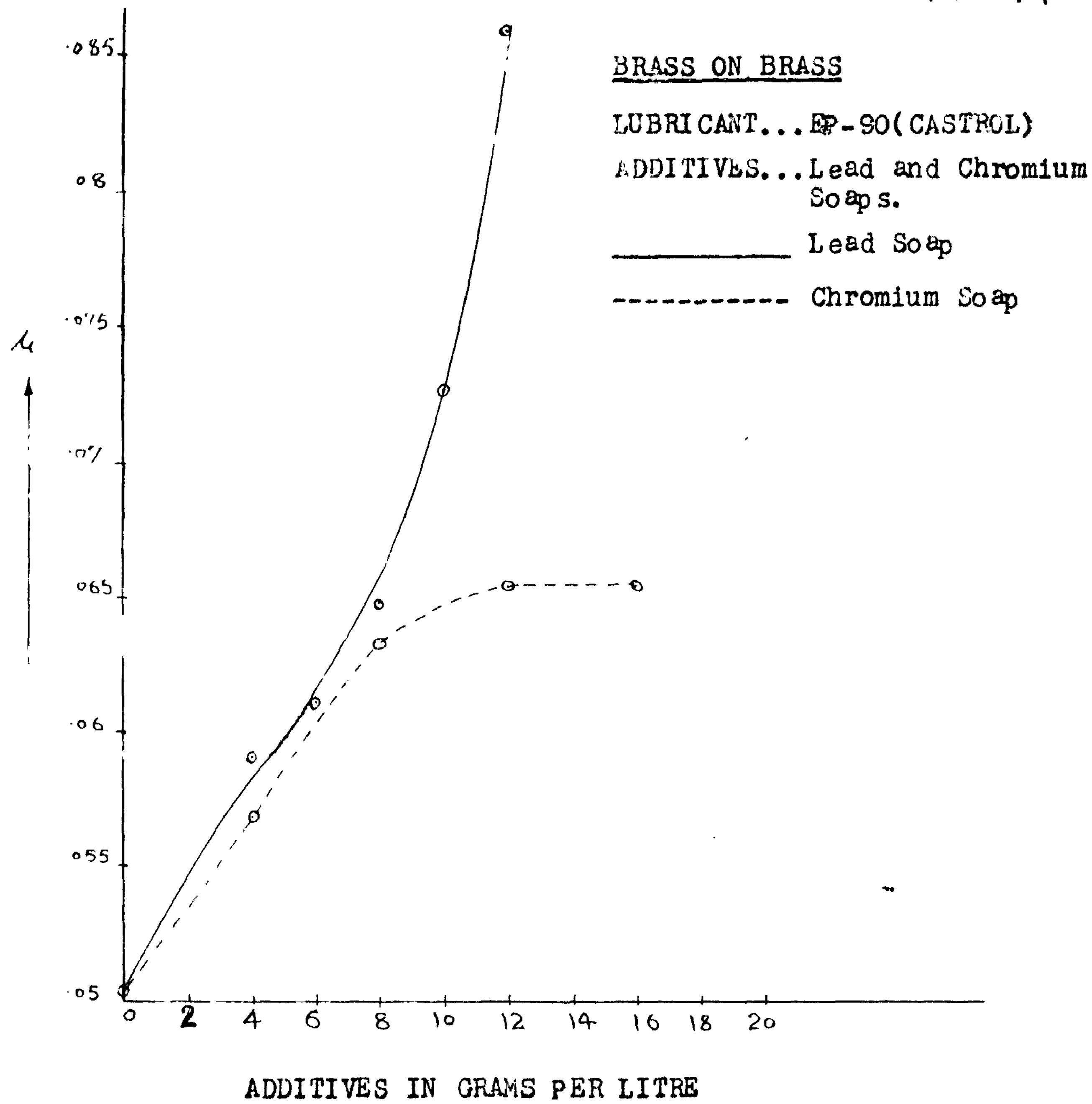

BRASS ON BRASS
LUBRICANT...EP-90(CASTROL)
ADDITIVES...Lead and Chromium Soaps.
Lead Soap
Chromium Soap
μ
·085
·08
·075
·07
·065
·06
·055
·05
0
2
4
6
8
10
12
14
16
18
20
ADDITIVES IN GRAMS PER LITRE

FIG 10

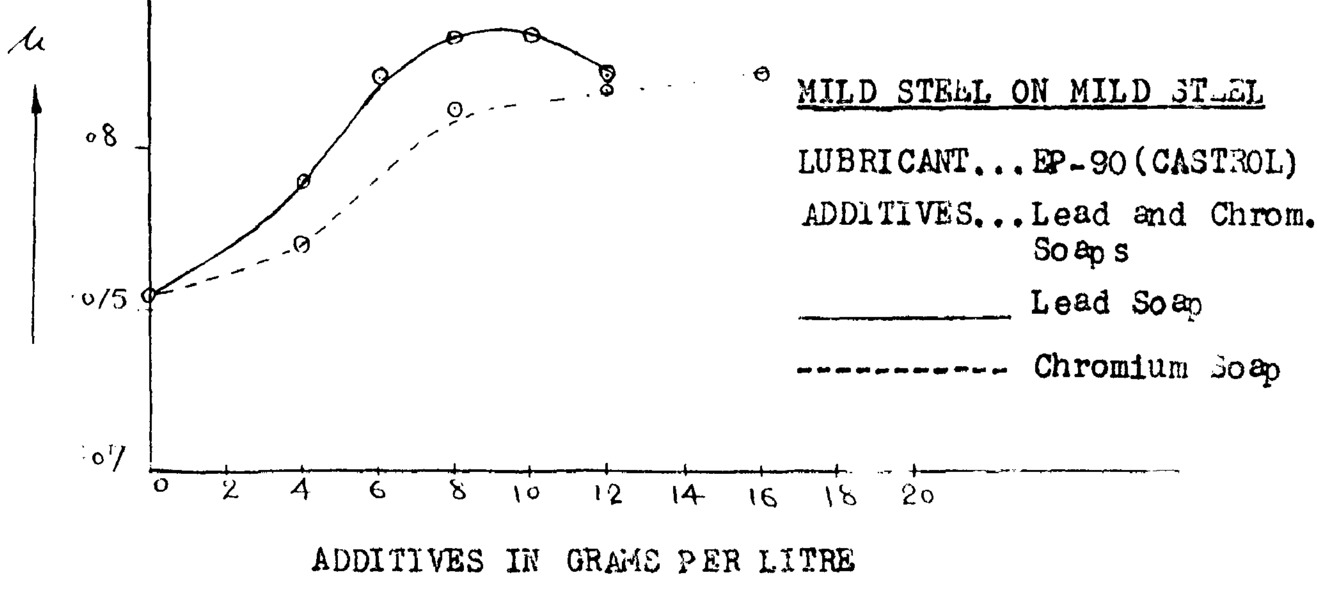

MILD STEEL ON MILD STEEL
LUBRICANT...EP-90(CASTROL)
ADDITIVES...Lead and Chrom. Soaps
Lead Soap
Chromium Soap
μ
·085
·08
·075
·07
0
2
4
6
8
10
12
14
16
18
20
ADDITIVES IN GRAMS PER LITRE

FIG. 11

MILD STEEL ON MILD STEEL

LUBRICANT...EP-90(CASTROL)

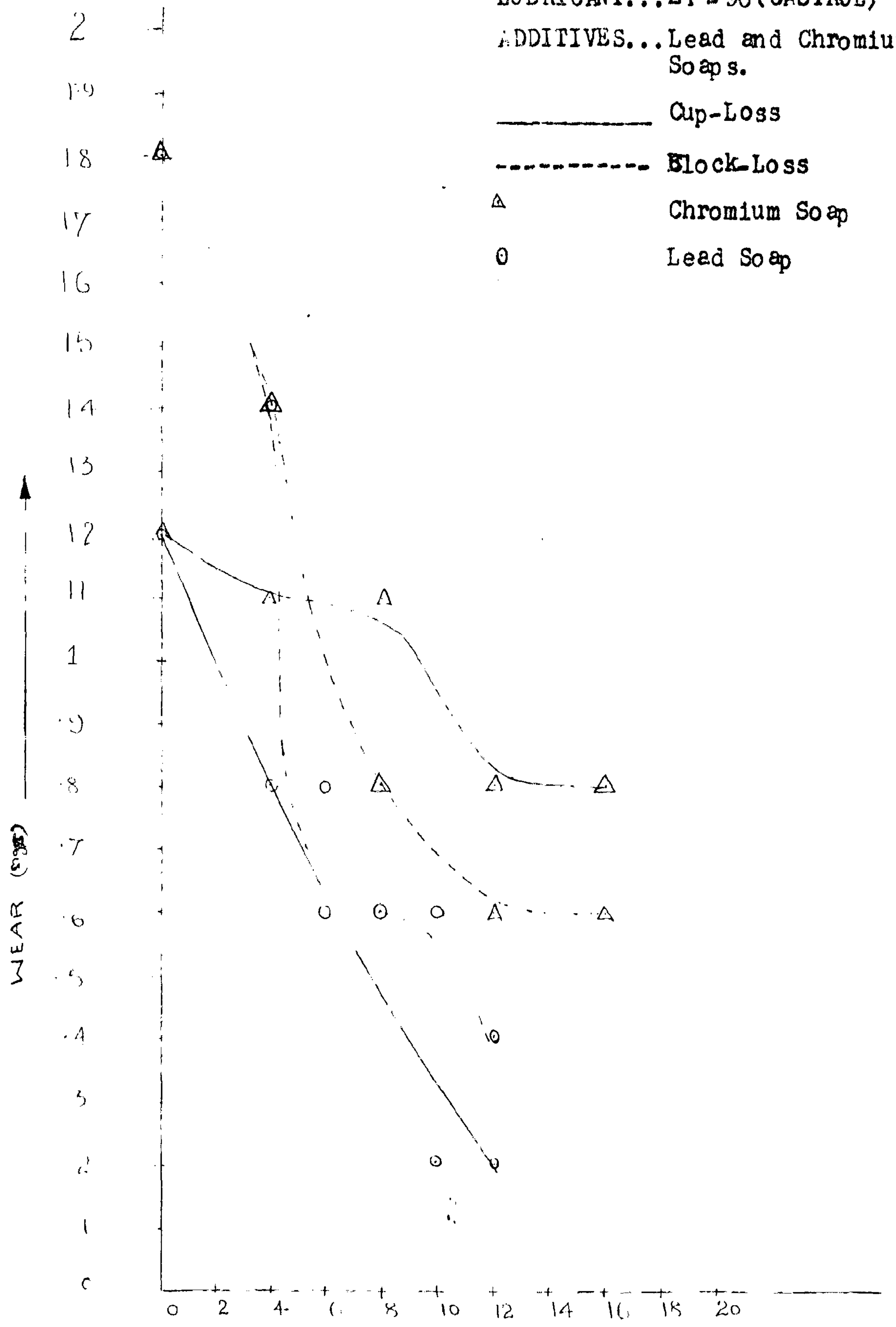
ADDITIVES...Lead and Chromium Soaps.

———— Cup-Loss

- - - - - Block-Loss

Δ Chromium Soap

O Lead Soap



ADDITIVES I RAMS PER LITRE

FIG. 12

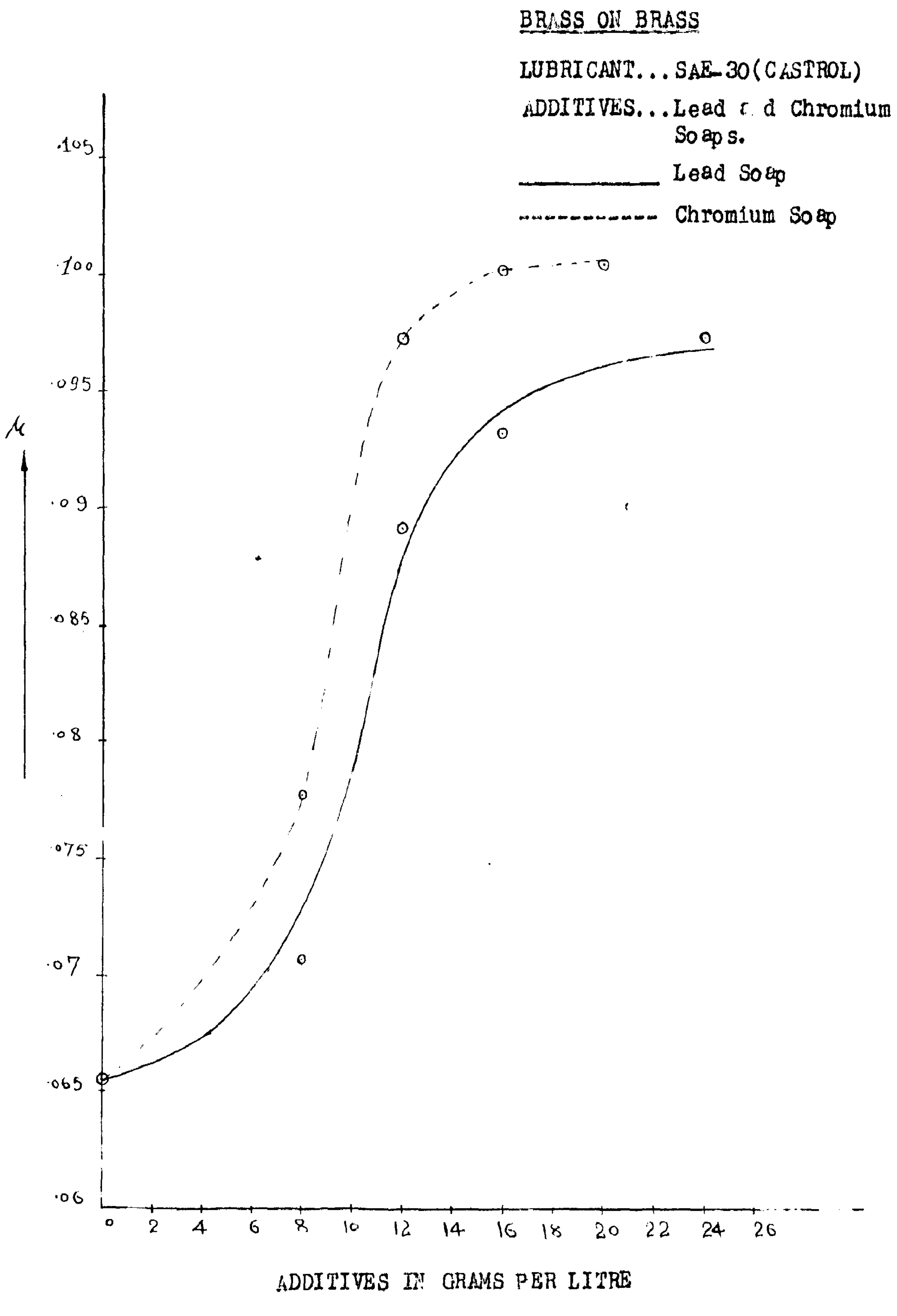
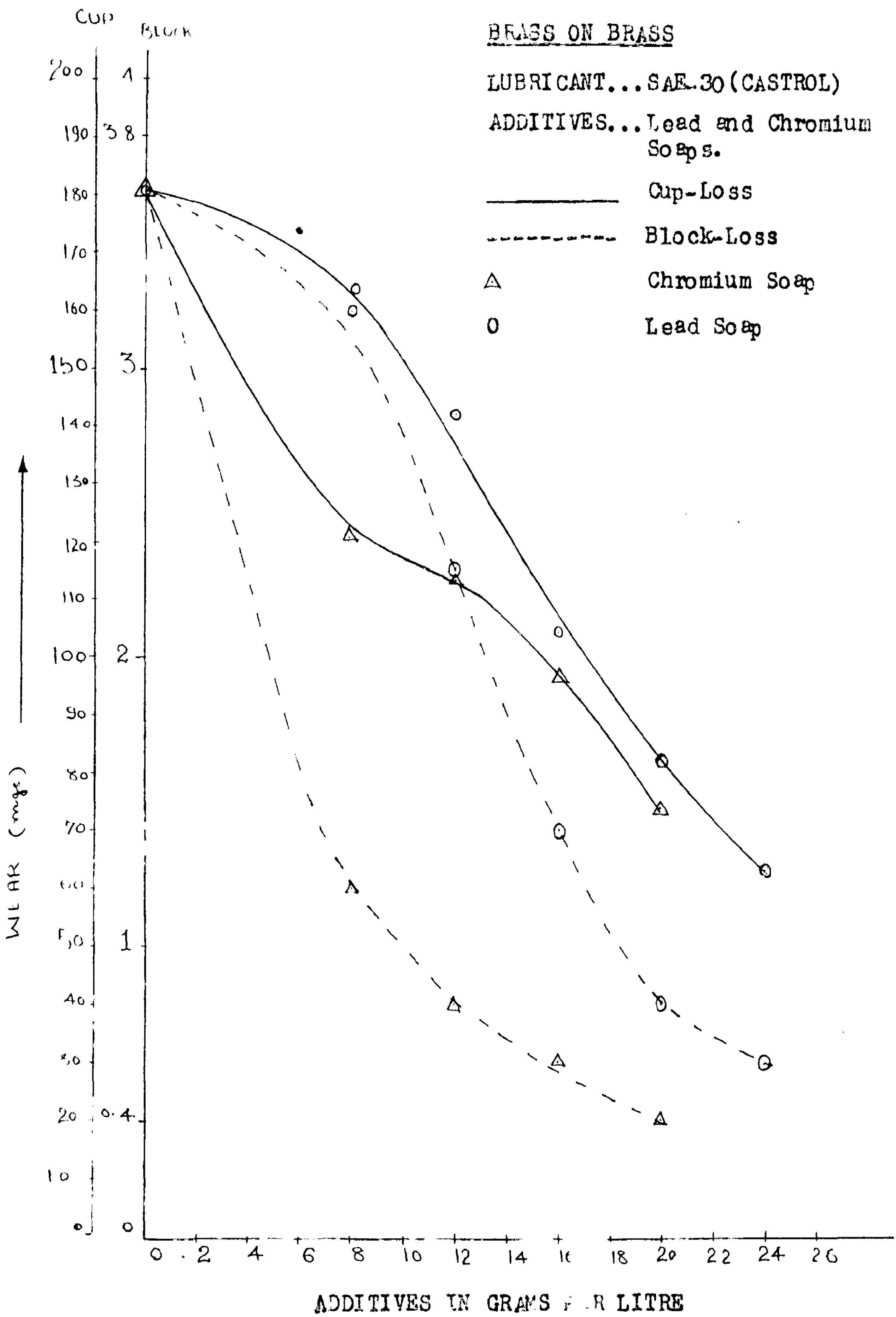

BRASS ON BRASS
LUBRICANT...SAE-30(CASTROL)
ADDITIVES...Lead and Chromium Soaps.
Lead Soap
Chromium Soap
·105
·100
·095
·09
·085
·08
·075
·07
·065
·06
μ
0
2
4
6
8
10
12
14
16
18
20
22
24
26
ADDITIVES IN GRAMS PER LITRE

FIG. 13



BRASS ON BRASS
LUBRICANT...SAE-30 (CASTROL)
ADDITIVES...Lead and Chromium Soaps.
Cup-Loss
Block-Loss
Chromium Soap
Lead Soap
CUP
BLOCK
WEAR (mgs)
ADDITIVES IN GRAMS PER LITRE

FIG. 15

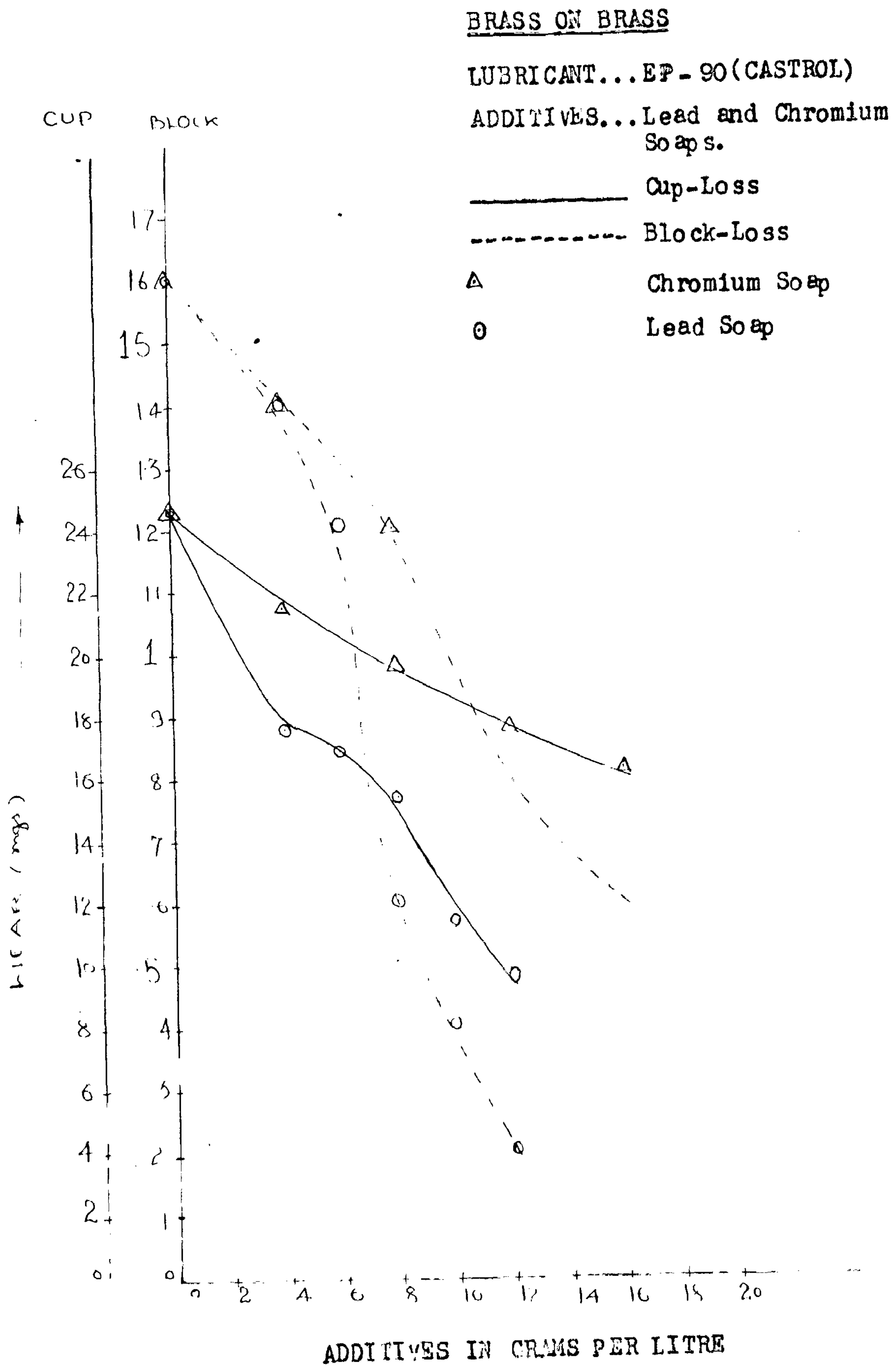

BRASS ON BRASS
LUBRICANT...EP-90(CASTROL)
ADDITIVES...Lead and Chromium Soaps.
Cup-Loss
Block-Loss
Chromium Soap
Lead Soap
CUP
BLOCK
ADDITIVES IN GRAMS PER LITRE

FIG. 16

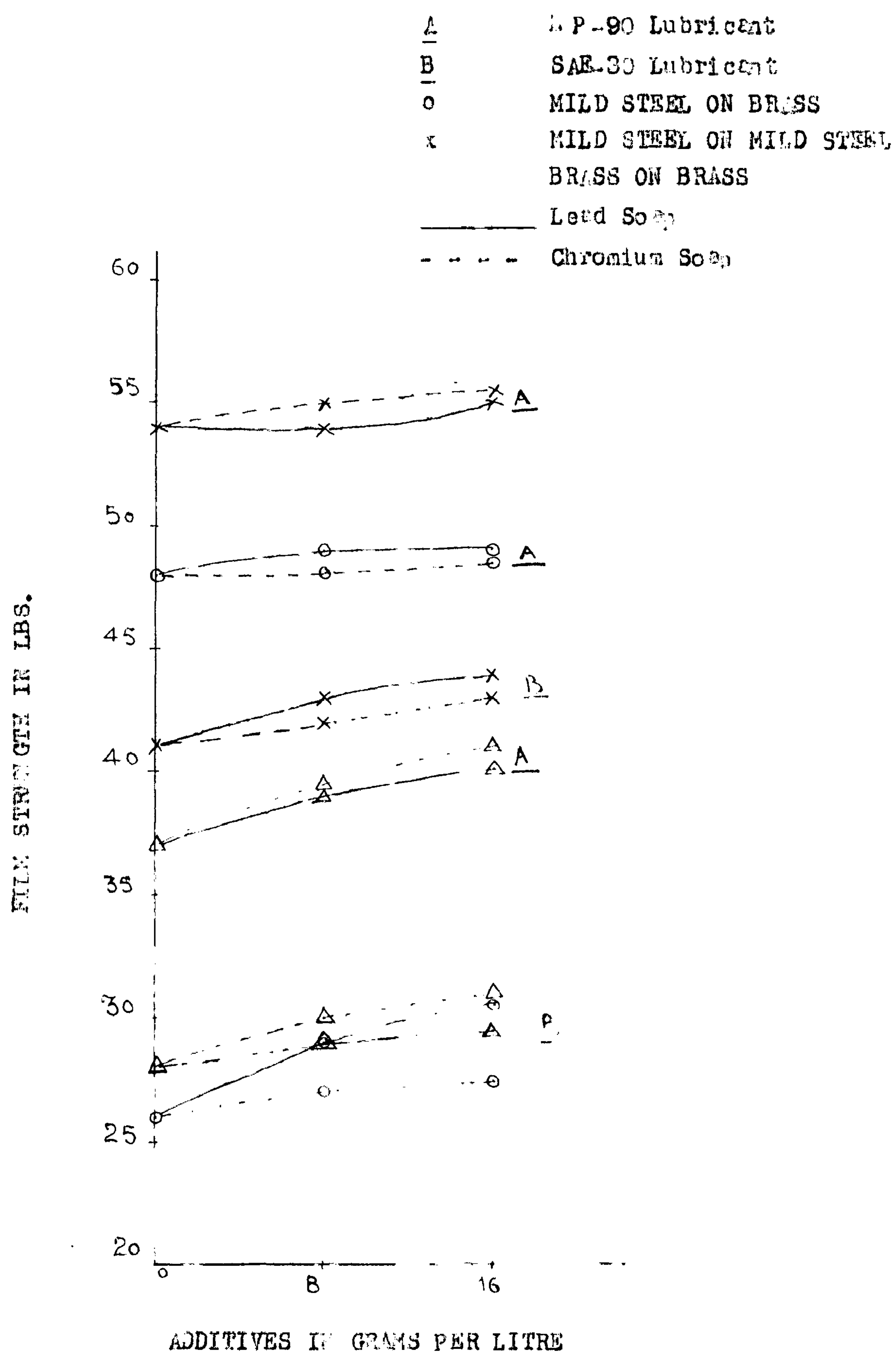

A P-90 Lubricant
B SAE-30 Lubricant
o MILD STEEL ON BRASS
x MILD STEEL ON MILD STEEL
BRASS ON BRASS
Lead Soap
Chromium Soap
FILM STRENGTH IN LBS.
ADDITIVES IN GRAMS PER LITRE
60
55
50
45
40
35
30
25
20
0
8
16
A
A
B
A
B

FIG. 17

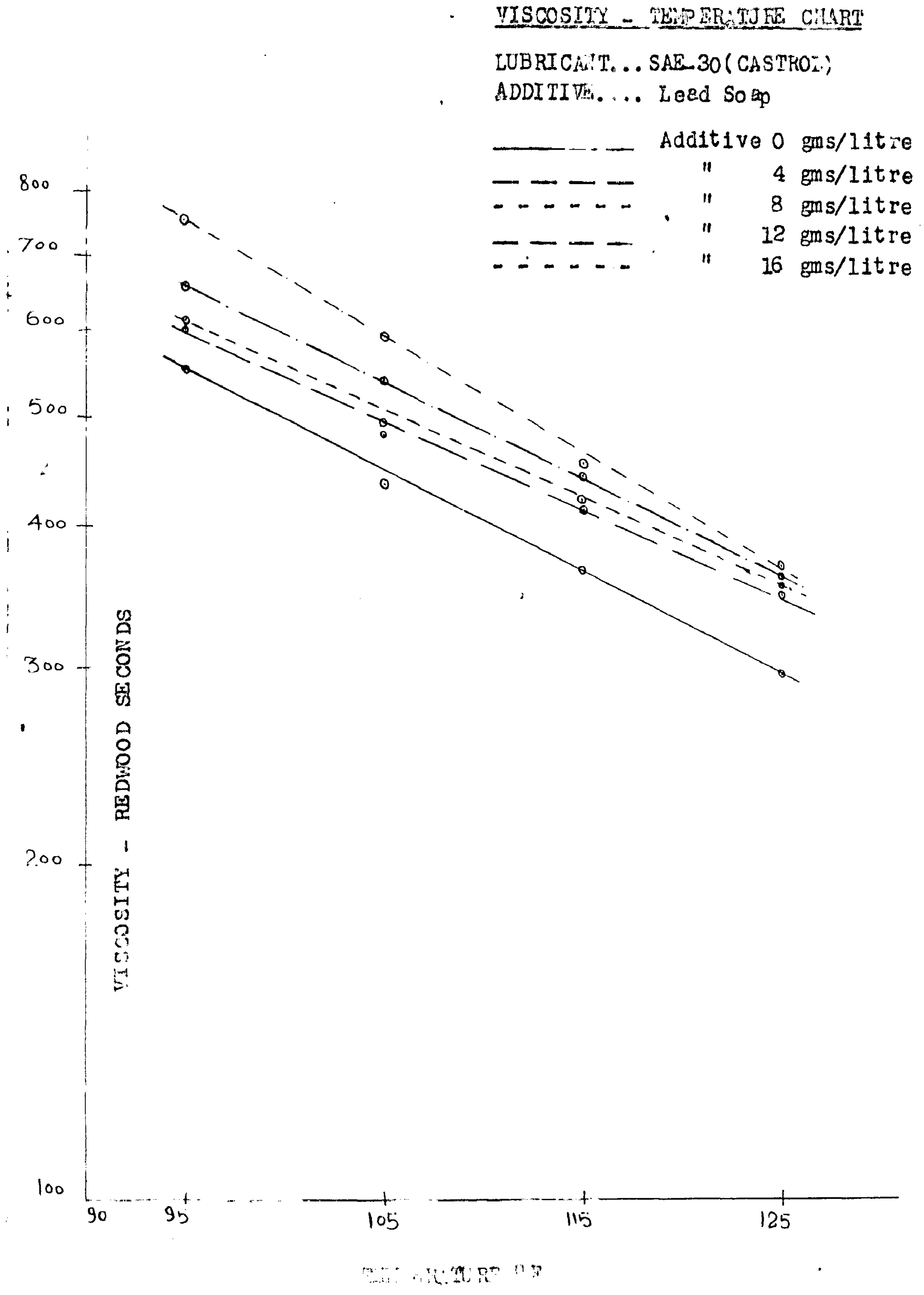

VISCOSITY - TEMPERATURE CHART
LUBRICANT... SAE-30 (CASTROL)
ADDITIVE.... Lead Soap
Additive 0 gms/litre
" 4 gms/litre
" 8 gms/litre
" 12 gms/litre
" 16 gms/litre
800
700
600
500
400
300
200
100
VISCOSITY - REDWOOD SECONDS
90
95
105
115
125

FIG. 18

VISCOSITY .. TEMPERATURE CHART

LUBRICANT.. ..0 (CASTROL)

ADDITIVE ... Chromium Soap

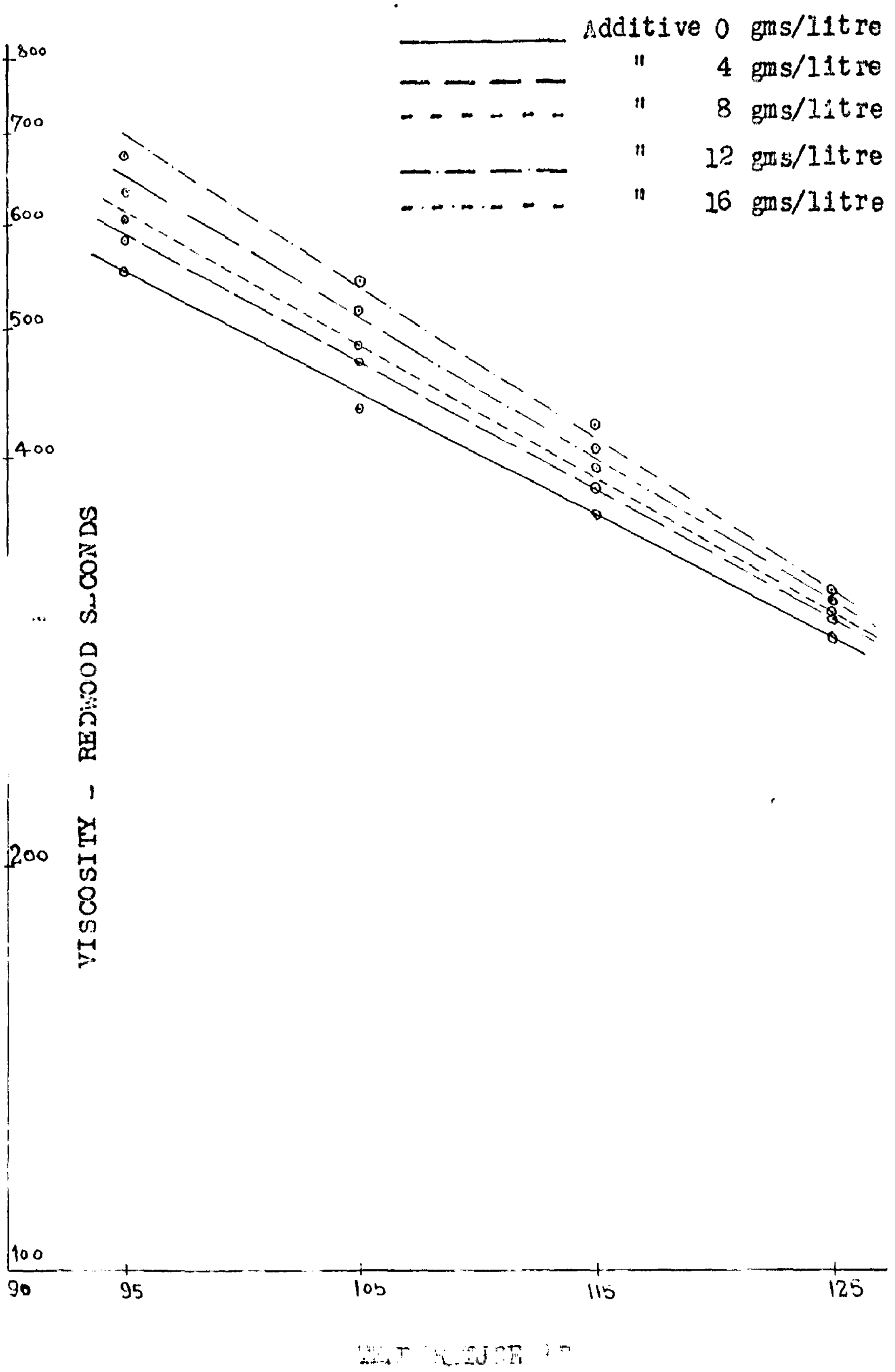
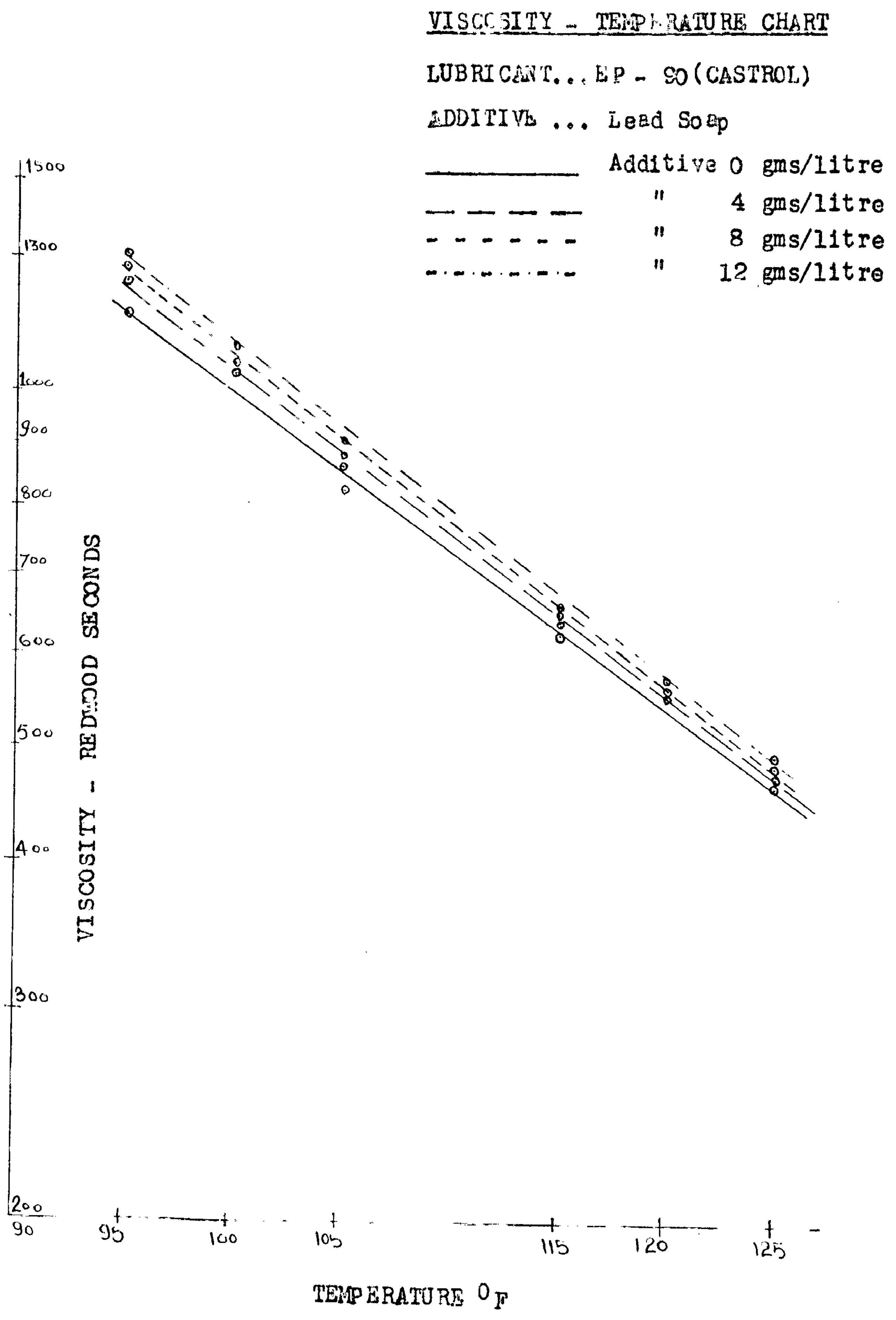


FIG. 19


VISCOSITY - TEMPERATURE CHART
LUBRICANT... EP - 90 (CASTROL)
ADDITIVE ... Lead Soap
Additive 0 gms/litre
" 4 gms/litre
" 8 gms/litre
" 12 gms/litre
1500
1300
1000
900
800
700
600
500
400
300
200
VISCOSITY - REDWOOD SECONDS
90
95
100
105
115
120
125
TEMPERATURE °F

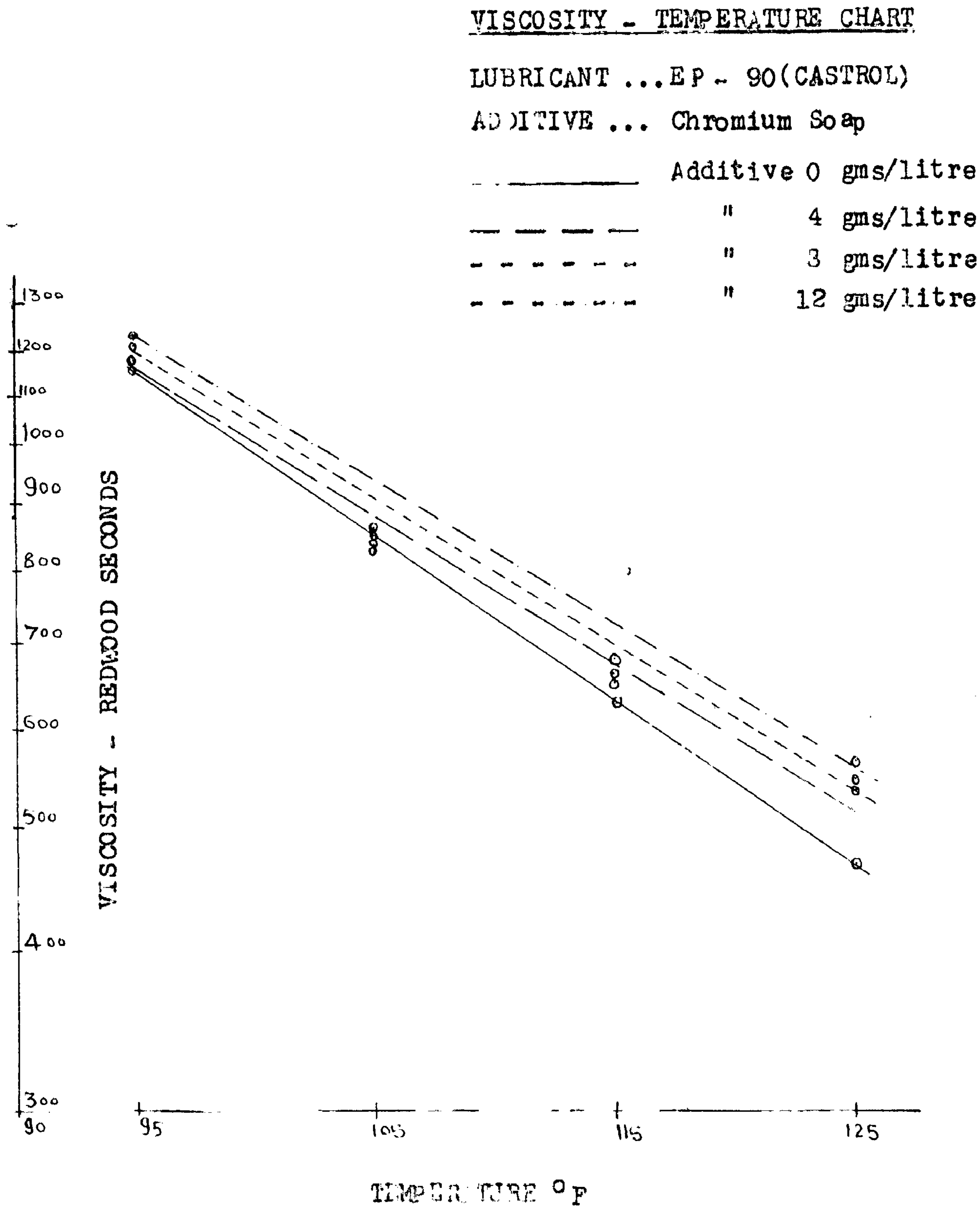
ANALYSIS AND DISCUSSION

Mild Steel on Brass:

The data obtained for "mild steel on brass" are given in tables 1, 2, 7, and 8. Tables 1 and 2 are for SAE-30 oil and their plots are given in Figures 4 and 5. Tables 7 and 8 are for EP-90 oil and their plots are given in Figures 6 and 7.

From Figure 4, it is observed that coefficient of friction μ decreases for both lead and chromium soaps as the quantity of additives is increased. For chromium soap, the decrease in coefficient of friction after 12 grams per liter becomes small. It is also observed that by adding 14 grams per liter of additives, the value of coefficient of friction is same and equal to 0.046. The value of μ decreases from 0.076 to 0.0315 by adding 20 grams per liter of lead soap but in case of chromium soap the value decreases to only 0.045. Beyond μ = 0.046, lead soap causes a rapid decrease in μ but the chromium soap has little effect. Before the intersection point, chromium soap has a better effect.

FIG. 20


VISCOSITY - TEMPERATURE CHART
LUBRICANT ... EP - 90 (CASTROL)
ADDITIVE ... Chromium Soap
Additive 0 gms/litre
" 4 gms/litre
" 3 gms/litre
" 12 gms/litre
VISCOSITY - REDWOOD SECONDS
1300
1200
1100
1000
900
800
700
600
500
400
300
90
95
105
115
125

ANALYSIS AND DISCUSSION

Mild Steel on Brass:

The data obtained for "mild steel on brass" are given in tables 1, 2, 7, and 8. Tables 1 and 2 are for SAE-30 oil and their plots are given in Figures 4 and 5. Tables 7 and 8 are for EP-90 oil and their plots are given in Figures 6 and 7.

From Figure 4, it is observed that coefficient of friction μ decreases for both lead and chromium soaps as the quantity of additives is increased. For chromium soap, the decrease in coefficient of friction after 12 grams per liter becomes small. It is also observed that by adding 14 grams per liter of additives, the value of coefficient of friction is same and equal to 0.046. The value of μ decreases from 0.076 to 0.0315 by adding 20 grams per liter of lead soap but in case of chromium soap the value decreases to only 0.045. Beyond μ = 0.046, lead soap causes a rapid decrease in μ but the chromium soap has little effect. Before the intersection point, chromium soap has a better effect.

In Figure 5, wear in both cup and block can be seen. There is not much difference in wear of block due to presence of additives, but the wear of cup is more when lead soap is used as an additive.

For EP-90 oil (Figure 6), it is observed that coefficient of friction decreases rapidly due to both the additives. However, the decrease in coefficient of friction due to lead soap is more than that due to the chromium soap. By adding 12 grams per liter of additives, coefficient of friction decreases from 0.061 to 0.028 by the use of lead soap and to 0.0365 by chromium soap. Slope of both the curves is nearly same after 4 grams per liter. Comparing this with SAE-30 oil, it is seen that a small percentage of additive to EP-90 oil has a more profound effect in reducing coefficient of friction.

Both the additives to EP-90 oil reduce wear considerably, and there is not much difference upto 10 grams per liter of addition, after which wear with chromium soap decreases (Figure 7).

It is observed that good performance (low wear and reduced friction coefficient values) of metal pair is obtained due to lead and chromium soaps. This is because of the formation of a film of low shear strength by the chemical attack of lead and chromium soap on rubbing surfaces. The film of low shear strength shears easily and prevents metallic contact.

Mild Steel on Mild Steel:

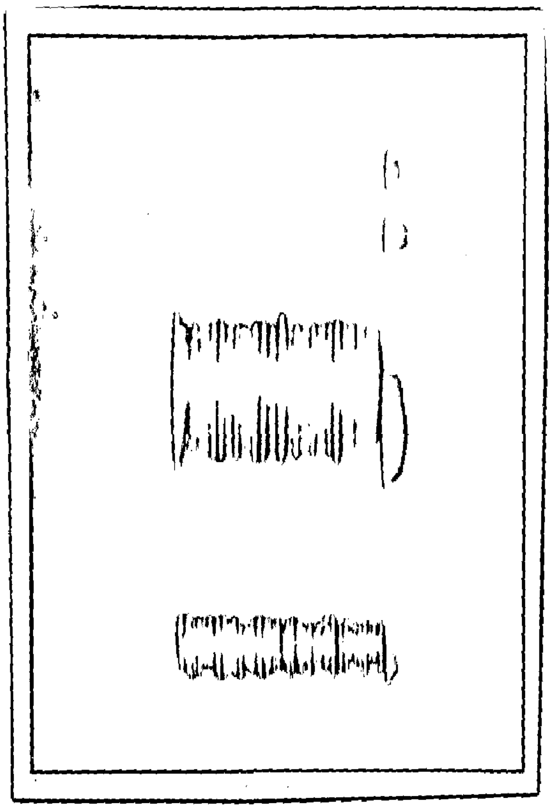
The data for "mild steel on mild steel" are given in tables 3, 4, 9, and 10. Tables 3 and 4 give the data for SAE-30 oil and tables 9 and 10 give the data for EP-90 oil. The plots of tables 3 and 4 are given in Figures 8 and 9 and those of tables 9 and 10 are given in Figures 10 and 11.

From Figure 8, it is observed that coefficient of friction increases slowly from 0.072 to 0.078 when additive content is 16 grams per liter of lead soap, whereas with 16 grams per liter of chromium soap additive, it decreases slowly from 0.072 to 0.0625 and then increases.

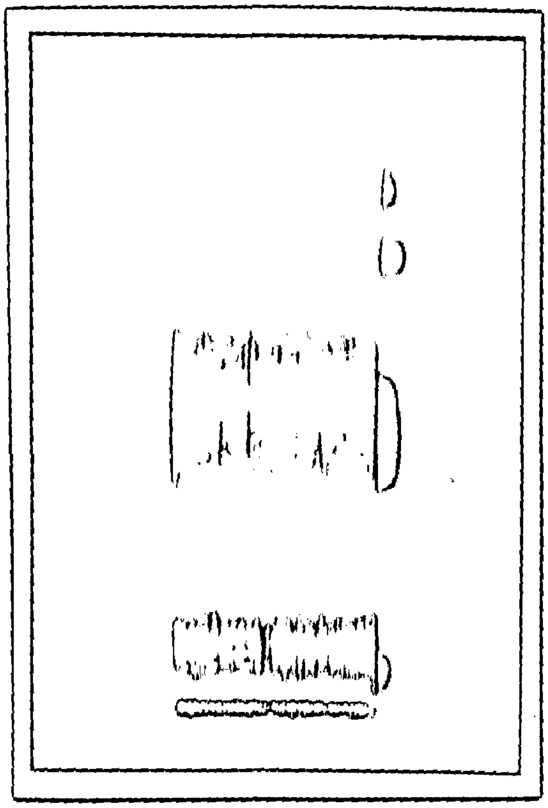
From Figure 9, it is observed that wear is reduced to a large extent by both the additives. The decrease in wear by using chromium soap is more than that for lead soap. The decrease in wear by chromium soap after addition of 16 grams per liter, becomes almost constant, but with lead soap, the wear in cup increases after 20 grams per liter.

It is seen from Figure 10, that for EP-90 oil, coefficient of friction increases by both the additives, but the increase with chromium soap is less than that with lead soap. With lead soap, coefficient of friction increases from 0.076 to 0.083 and then falls. With chromium soap, coefficient of friction increases from0.076 to 0.081 and then increases slightly.

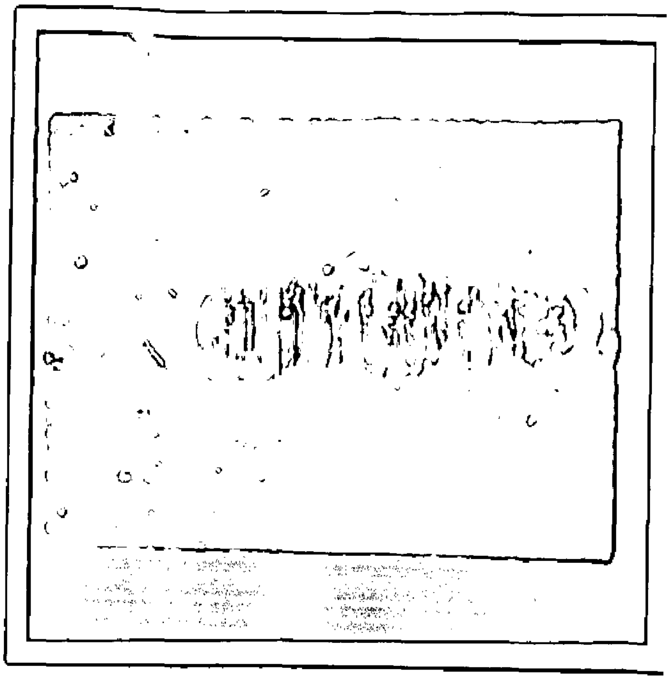
Brass test cup-showing wear



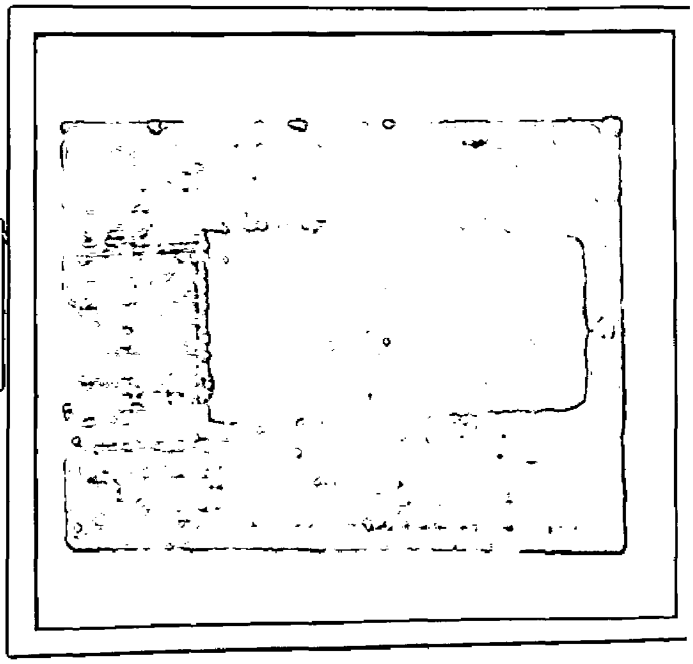
Mild Steel test cup - showing wear.



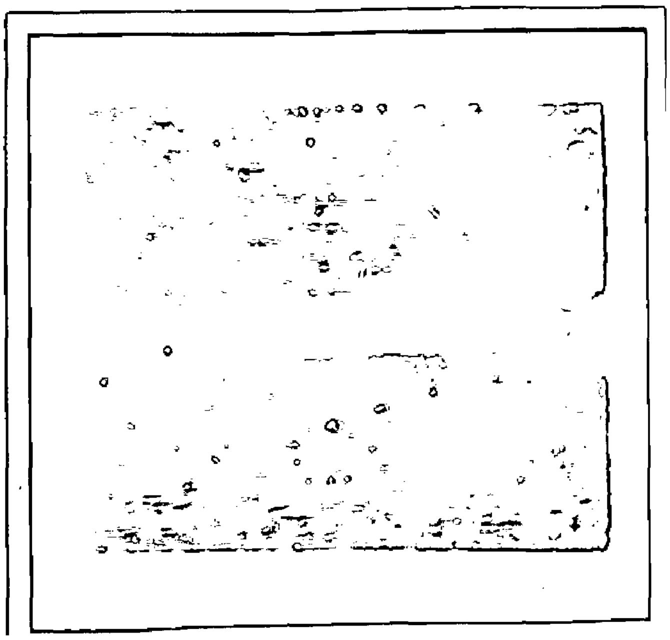
Brass test block-showing wear caused by brass test cup.



Brass test block- showing wear caused by mild steel test cup.



Mild steel test block-showing wear caused by mild steel test cup.



From Figure 11, it is observed that decrease in wear with lead soap is more than chromium soap for both cup and block.

Brass on Brass:

For "brass on brass", the data are given in tables 5, 6, 11, and 12. The plots of tables 5 and 6 for SAE-30 oil are given in Figures 12 and 13. For EP-90 oil, the plots of tables 11 and 12 are given in Figures 14 and 15.

From Figure 12, it is seen that coefficient of friction increases by the use of both the additives. Increase in coefficient of friction with lead soap is less than that with chromium soap. For 20 grams per liter of additives, coefficient of friction increases from 0.0655 to 0.01005 with chromium soap and from 0.0655 to 0.096 with lead soap.

From Figure 13, it is observed that wear decreases rapidly by the presence of both the additives. The decrease in wear due to chromium soap is more than that that due to lead soap.

For EP-90 oil (Figure 14), coefficient of friction increases due to both the additives. The increase in coefficient of friction does not differ much upto 0.063 with 8 grams per liter; after this, lead soap increases the coefficient of friction to 0.086 for 12 grams per liter. For chromium soap, there is no appreciable increase in coefficient of friction by increasing the quantity of additive.

From Figure 15, it is seen that wear decreases due to both the soaps, but the reduction in wear with lead soap is greater.

Film Strength:

The data of film strength are given in table 13 and their plots are given in Figure 16.

From Figure 16, it is observed that for the pair "mild steel on brass", film strength of SAE-30 and EP-90 oils increases due to both the additives. Increase in film strength with lead soap is more than that with chromium soap. Increase in film strength with lead soap is better in SAE-30 oil than that in EP-90 oil. There is not much difference in increase of film strength with chromium soap in both the oils. By adding 16 grams per liter of lead soap to SAE-30 oil, film strength increases from 26 pounds to 30.5 pounds, whereas with chromium soap it increases from 26 pounds to 27.5 pounds only. By adding 16 grams per liter of lead soap to EP-90 oil, film strength increases from 48 lbs. to 49 lbs., whereas with chromium soap it increases to 48.5 lbs. only.

For the pair "brass on brass", it is observed that film strength of both the oils increases due to both the additives (Figure 16). Increase in film strength with chromium soap is more than that with lead soap. By adding 16 grams per liter of lead soap to SAE-30 oil, film strength increases from 28 lbs. to 29.5 lbs., whereas with chromium soap, it increases to 31 lbs. By adding 16 grams per liter of lead soap to EP-90 oil, film strength increases from 37 lbs. to 40 lbs., whereas with chromium soap it increases to 41 lbs.

For the pair "mild steel on mild steel", it is observed that film strength of both the oils increases due to both the additives (Figure 16). Increase in film strength with lead soap is more than that with chromium soap in SAE-30 oil, whereas increase in film strength is more with chromium soap than that with lead soap in EP-90 oil. By adding 16 grams per liter of lead soap to SAE-30 oil, film strength increases from 41 lbs. to 44 lbs., whereas with chromium soap it increases to 43 lbs. By adding 16 grams per liter of lead soap to EP-90 oil, film strength increases from 54 lbs. to 55 lbs., whereas with chromium soap it increases to 55.5 lbs.

<u>Viscosity Results:</u>

a) <u>Lead Soap in SAE-30 Oil:</u>

The data for lead soap in SAE-30 oil are given in table 14 and their plots are given in Figure 17. It is observed that the addition of lead soap increases viscosity. By adding 4 grams lead soap per liter, it is found that there is a rapid increase in viscosity at higher temperatures, as compared to that at lower temperatures. By adding a quantity of soap more than 4 grams per liter, the viscosity increases slowly at higher temperatures but this increase is found to be slightly rapid at lower temperatures. Viscosity increment by the addition of 4 grams per liter of lead soap is from 295 Redweed seconds to 349 Redwood seconds at 125°F, whereas this value changes from 554 to 604 at 95°F. Also, by adding 16 grams per liter of lead soap the value of viscosity increases from 295 Redwood seconds to 367 Redwood seconds at 125°F, whereas this value changes from 554 to 758 at 95°F.

b) Chromium Soap in SAE-30 Oil:

The data for chromium soap in SAE-30 oil are given in table 14 and their plots are given in Figure 18. It is observed that the addition of chromium soap increases viscosity. By adding the chromium soap to SAE-30 oil, it is found that there is a more rapid increase in viscosity at lower temperatures as compared to that at higher temperatures. Viscosity increment by adding 4 grams per liter of chromium soap is from 295 Redwood seconds to 306 Redwood seconds at 125°F, whereas at 95°F it changes from 554 to 587 Redwood seconds. Also, by adding 16 grams per liter, viscosity increases from 295 Redwood seconds to 322 Redwood seconds at 125°F, whereas at 95°F it increases from 554 to 676 Redwood seconds.

c) Lead Soap in EP-90 Oil:

The data for lead soap in EP-90 oil are given in table 14 and their plots are given in Figure 19. It is observed that the addition of lead soap increases viscosity. It is seen that there is an increase in viscosity at lower as well as at higher temperatures, but increase in viscosity at lower temperatures is more than that at higher temperatures. Addition of 4 grams per liter of lead soap increases viscosity from 467 Redwood seconds to 474 Redwood seconds at 125°F, whereas this value increases from 1166 to 1244 at 95°F. Also, by adding 12 grams per liter of lead soap the increment in viscosity is from 467 Redwood seconds to 494 Redwood seconds at 125°F, whereas at 95°F, it increases from 1166 Redwood seconds to 1303 Redwood seconds.

d) Chromium Soap in EP-90 Oil:

The data for chromium soap in EP-90 oil are given in table 14, and their plots are given in Figure 20. It is observed that the addition of chromium soap increases viscosity. It is found that there is a rapid increase in viscosity at higher temperatures, as compared to that at lower temperatures. By adding 4 grams per liter of chromium soap, increment in viscosity is from 467 to 533 Redwood seconds at 125°F, whereas this value increases from 1166 to 1203 at 95°F. Also, by adding 12 grams per liter of chromium soap, the increment in viscosity is from 467 to 564 Redwood seconds at 125°F, where as this value changes from 1166 to 1217 at 95°F.

CONCLUSION

The following conclusion may be written from the analysis and discussion presented in this investigation:

It is concluded that the experimental results for wear of metal pair agree well with the theoritical results. Results of this investigation show that the presence of certain low shear strength solid surface films can markedly reduce friction of dissimilar metal pairs and also reduce wear for any metal pair. These wear studies also show that prevention of wear and maintenance of low wear could be associated with the formation of surface films. In general, lead and chromium soaps used in this study reduce wear considerably.

In fact, the physical and chemical processes involved at the localized region of contact of surfaces rubbing in presence of lead and chromium soaps are likely to be complex. The friction and wear behaviour of a given combination in the metal would depend on many factors. These factors would include the composition of materials, since this determines the resistance of normal surface oxide films and of the material itself, to chemical attack by lead and chromium soaps under the conditions of running. It is also shown[3] that factors like interruptions (cracks, gas cavities etc.) which tend to reduce friction may increase wear and vice-versa.

In general, it is observed that by adding only as little as 12 grams per liter of these additives (chromium and lead soaps) the wear decreases considerably. Addition of greater amounts shows relative smaller effect.

It is seen that with both the additives, the film strength of both the oils has increased for the above metal pairs. However, lead soap is found to be more suitable in SAE-30 oil, whereas chromium soap is found better in EP-90 oil except in the case of mild steel on brass metal pair.

Further, the viscosity of oils also increases with the additives, and it is seen that viscosity increases more with lead soap at lower temperatures. Chromium soap increases viscosity of EP-90 oil at higher temperatures more than that of SAE-30 oil.

Also, as the oiliness is the reciprocal of coefficient of friction, it means that smaller coefficient of friction will give greater oiliness and hence the favourable results with respect to coefficient of friction may be considered as satisfactory results for oiliness too.

SCOPE FOR FURTHER WORK

Further work can be done in this field for other metal pairs such as "aluminium on aluminium", brass on aluminium etc. Also, other additives may be treated for friction and wear characteristics of metal pairs.

Furthermore, oiliness, assumed to be the reciprocal of coefficient of friction, has not been measured separately because of non-availability of oiliness testing machine. It can, however, be determined separately if machine is available, and the above assumption can be varified or the comparison of results can be made.

The machine capacity did not allow to perform tests at higher temperatures and higher speeds which are generally encountered in practice. The investigation at higher temperatures and higher speeds can be made for the same additives and metal pairs if suitable machines are available.

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