

TABLE LXXIII
PROPERTIES OF SOME SYNTHETIC LUBRICATING OIL ESTERS

Acid	Adipic	Beta methyl adipic	Sebacic	Mixed C ₇ monocarboxylic acids
Alcohol	Iso and normal octyl*	Normal octyl	Iso-octyl	Tri-methylol ethane
Sp. gr 20°C	0.922	0.920	0.912	0.958
Viscosity at 38°C cs	7.4	0.9	11.8	16.0
" " " 100°C cs	5.9	6.7	8.5	10.8
VI	191	228	189	157
Pour point °C	-24	-36	Below -70	-70
Flash point °C	207	227	235	241

* Half ester of each alcohol.

together with greater lubricating ability or "oiliness" than hydrocarbon oils.

As an outcome of this research, it was found that of the materials available for full-scale production, adipic or methyl adipic acids were the most suitable. Various cuts of the higher alcohols from the isobutyl alcohol synthesis were used to esterify the acid.

Esterification

The actual production method, given below, does not require unusual purities of raw materials.

The required quantities of the alcohol and the acid are charged to a stainless steel reaction vessel fitted with agitators and about 1% of benzene or naphthalene sulphonic acid added as the catalyst. The mixture is heated to 150 to 180°C and the water of reaction distilled off as it is formed. The product is washed with water and soda which removes the catalyst, unreacted acid and half esters. It is next distilled to remove alcohol and low boiling secondary products. The ester oil is then contacted with 0.5% wt bleaching earth at 70 to 80°C and filtered. The product thereafter is handled as a normal refined oil. No stabilisers are added and no special handling precautions are necessary.

While the preferred catalyst for the above reaction was a sulphonic acid, for more difficult esterification such as with tri-methylol ethane, when a temperature of above 200°C is used, the best catalyst is zinc dust.

Products.—Details of the range of esters produced are as follows:—

Number	Constitution
E455	Mixed adipic esters of the 140-180°C cuts from the higher, branched-chain alcohols from the isobutyl synthesis.
E504	Mixed adipic esters of the 160-200°C cut of above
E515	" " " " 180-250°C " "
E1321	" " " " iso C ₇ alcohols. " "
E1473	Adipic ester of the product obtained by condensing one molecule of ethylene oxide with i-nonyl alcohol.

Number

E3022 Ester of cyclohexanol and 2-methyl adipic acid.
E3025 Adipic ester of p-methylcyclohexanol.

Constitution

The properties of some of these esters are given in Table LXXIII.

ii. OTHER SYNTHETIC LUBRICANTS

Several other types of compounds were developed for special lubrication purposes, among which may be mentioned:—

- The IG Ludwigshafen product LK2260 made by the addition of about 20 molecules of ethylene oxide to one molecule of tri-methylol propane. These compounds are very viscous with a very good VI. They are soluble in water in all proportions but insoluble in hydrocarbons unless the terminal hydroxy group is esterified.
- Similar products had been made at Leverkusen by reacting tetra-hydrofurane, or mixtures with ethylene oxide, etc., with anhydrous metal chlorides, e.g. FeCl₃ when polymerisation took place.

Although work on these and related products was actively proceeding, they had been produced in small quantities only and had not reached a stage of useful application.

Bibliography

The most important CIOS reports which supplement the information given in this section are:—

XXIV-9	"Synthetic Lubricating Oil Plant—Rheinpreussen, Homburg."
XXVII-69	"The Fischer-Tropsch Plant of Ruhrchemie, Sterkrade-Holten."
XXXII-68	"The Manufacture and Application of Lubricants in Germany."
XXXII-94	"The German Petroleum Industry—Hamburg District."
XXXII-96	"Rubrchemie, Sterkrade-Holten."
XXXII-107	"IG Farbenindustrie, Leuna."

H—Testing and Evaluation of Products

1. INTRODUCTION

The appraisal of the work done in the development of new fuels and lubricants was made the subject of a separate study, but since a valid appraisal is impossible until all the available documents have been examined, this report must be confined to a record of the major problems studied by the Germans which have so far come to light, without passing judgment on the work done.

2. FUELS

i. AVIATION PETROL

The German supply of aviation fuels was based on the hydrogenation of coal, and this fact caused them to follow a different path from that of the Allies to high engine performance. At the start of the war they had standardised on an 87ON grade (known as B4) of leaded hydro-petrol from brown coal, and which contained 5-15% of aromatics. In 1940 an improved fuel (C2) of

95ON (CFR-Motor Method) was introduced having a higher aromatic content of 35-38%, and giving a performance equivalent to the Allied 100 ON grade of that time. At the end of 1942 a different kind of C3 began to come into service with a still higher performance, and was equivalent to the Allied 150 grade. This fuel contained some 5% more iso-octane than the previous version, but the aromatic content was maintained at the previous level by dehydrogenation of the higher boiling naphthenes in the fuel. The policy background to these changes in fuel type is not yet fully known, but the new fuel was an outstanding development and was a result of the introduction of the DHD process which is dealt with under hydrogenation.

No conclusive evidence was obtained to show that piston-ring sticking was increased as a result of the use of these aromatic fuels.

The standard test for knock-rating of aviation fuels was the BMW132 supercharged method, in which a full mixture-response curve of the test fuel was compared with the appropriate reference curve, the test curve being required to be above the reference curve over the significant mixture range. This requirement was slightly relaxed at the end of the war owing to supply difficulties. Extensive correlation test programmes were undertaken between the various test stations. Several small-scale test units were also developed, as exemplified by the supercharged IG engine, the IG "K" unit and the supercharged NSU (motor cycle) engine, these being devised with the object of reproducing the BMW 132 ratings and achieving adequate correlation for the purpose of investigating new fuel components. The CFR and its counterpart, the IG Prüfmotor, using both the Motor and Research Methods, were also used for control purposes.

No improved fuel was actually in sight at the end of the war, and although the permissible TEL concentration was raised from 0.12% to 0.18%, this was to assist in the maintenance of supplies; the extent to which advantage was taken of this relaxation is not yet known.

The use of 2% aniline was also proposed as a blending agent and a C3 type fuel was produced from B4 (the 87ON aviation fuel) by blending with aviation benzole and aniline, and adding TEL to 0.16%.

The use of GM-1 (nitrous oxide) for emergency power boosting at altitude was developed for operational use in 1943. Approximately 3hp per gm/sec GM-1 was obtained, irrespective of altitude, and rates of flow up to 120gm/sec were employed. The material was carried in Dewar type containers at -80°C and was metered into the engine before the blowers. Difficulties were experienced with explosions occurring in the induction system, and engine temperatures were generally higher when using GM-1.

Little information has yet been discovered on the use of internal coolants but reference is made to the use of methanol for this purpose, in conjunction with GM-1 operation. Pre-ignition was experienced in this connection, although normally it was not a Service problem, probably on account of the use of direct fuel injection. The tendency of methanol to pre-ignite was the subject of a good deal of research and various additives were tried experimentally to reduce pre-ignition in this fuel, but no success was achieved.

Large numbers of pure aromatics and other components were tested for anti-knock quality. Of a wide range of alkyl benzenes, di-ethyl benzene was particularly satisfactory and was used extensively as a blending component under the name of Kybol. Pinacoline—tertiary butyl methyl ketone—was found to be exceptionally good experimentally, being about equal to triptane,

illustrating the use of the tertiary carbon atom structure to obtain high anti-knock effects; it was not, however, put into operational use, although production could apparently have been arranged.

A good deal of fundamental research on combustion problems was in progress. This included laboratory tests concerned with flame propagation in relation to detonation and also in connection with gas turbine development. Detonation was also studied from the points of view of adiabatic self-ignition, and slow oxidation of hydrocarbons. Engine work in the same sphere involved the use of ionised gap and photo-cell methods for studying combustion.

The effects of engine design, operating temperature and chemical composition on the knock-rating of a fuel were studied extensively in an attempt to formulate a theory of knock mechanism. The effect of large valve overlap in fuel injection engines, which results in the highest knock-free BMEP point with paraffinic fuels occurring at weak mixtures, and which was observed on trials of captured German engines in this country some time ago, was one of the principal starting points for the experimental investigation, and considerable progress had been made.

Both Daimler Benz and BMW were developing engines with variable valve timing for automatic reduction of valve overlap with increase in altitude. This development work was abruptly stopped when the German Air Ministry ruled that everything else must be dropped in favour of jet turbines.

The problem of lead attack had been largely solved by stellite and chromium plating exhaust valves and, in addition, an unleaded running-out fuel was introduced on which the engine was shut down, to avoid cold corrosion. To what extent this fuel was used in service is not yet known.

The only inhibitor found in service was known as ZV1 and consisted of 0.01% mixed cresols. Cadmium-plate filters had to be adopted to avoid plugging which arose from a reaction between the ethylene bromide in the TEL and the zinc in the galvanised filter that was previously in use.

The Deutsche Versuchsanstalt für Luftfahrt (DVL) carried out some studies on lead deposition in storage which became serious with the introduction of high-performance fuels of relatively high aromatic content and, as a result, an autocatalytic mechanism has been suggested as the explanation. According to this theory, initial oxidation of the hydrocarbons causes the decomposition of the TEL, and the decomposition products then accelerate the further oxidation of the hydrocarbons, resulting in the deposition of lead sludge. By the use of substances which make innocuous the primary decomposition products of TEL (fuel soluble tri-, and di-ethyl lead compounds with one or two free valencies have been identified), or which suitably combine with the primary products of hydrocarbon oxidation, the stability of the leaded aromatic fuels could be appreciably increased. In practice, the use of small quantities (about 0.01%) of a phenolic extract from the product of bituminous coal hydrogenation was specified.

In connection with this work, a method was devised for estimating the bromine from the ethylene dibromide in the fuel.

Several test methods were developed for the determination of TEL in petrols, including one which is reported to employ X-rays, but, in general, the methods at present known do not seem to be of general application.

and are suitable only when the source and composition of the aviation petrol are known.

Operations on the Eastern Front led to cold starting difficulties, but as far as can be seen these were less severe with aircraft than with vehicles. For aero-engines induction priming with a light petrol of 30–100°C boiling range, containing 4% lubricating oil, was satisfactory down to –30°C, below which acetylene was used on certain engine types. Various ethers and pure hydrocarbons were investigated with a view to developing a liquid fuel suitable for –60°C, and the behaviour of current aviation fuels with respect to viscosity and water separation was studied down to –70°C, in view of possible fuel distribution difficulties in low temperatures.

On account of the shortage of aviation fuel components, the A3 grade used for training aircraft was later blended with 30% ethanol and troubles were consequently experienced with separation, corrosion, etc., as well as with cold starting.

Work was begun some years before the war on the development of a true safety fuel, which had not only a higher flash point than conventional fuel, but which, unlike the usual safety fuels, also had a low velocity of flame spreading over the liquid surface. An isobutylene polymer of approximately 3,000 molecular weight was applied for this purpose in engines operated by the "Ring process," which employed a system of compression ignition. This involved the separate injection of the di-ethyl-ether of di-ethylene-glycol (listed as R-300) into the fuel charge towards the end of the compression stroke. This ignition fuel could be used with diesel fuel. Flight testing was carried out, but the system had not been fully proved and difficulties were expected at high altitudes with low temperatures. The system was claimed to give lower cruising consumptions.

ii. AVIATION DIESEL FUEL

Only a very small amount of work on aviation diesel fuels has so far come to light, but this is in accordance with the limited use of diesel powered aircraft in the German Air Force. The Junkers engine was the only aero engine in service, and for it a minimum cetane number of 50 was specified, and a pour point of –45°C. The fuel contained no ignition accelerator additive, but a special starting fuel was supplied containing 25% ether.

Electrostatic charging with these engines caused trouble which was overcome experimentally by adding halogen or sulphur compounds to the fuel.

iii. GAS TURBINE FUEL

No fundamental work on the constituents of gas turbine fuels has been discovered, although studies were made of the effect of different burners on the flames obtained with different fuels. It is reported that the initial specification requirements were quite strict owing to early difficulties with corrosion, coking of burner jets, and the effect of phenols and aromatics on packing materials and liners, but the latest gas turbine fuel specification provided for a maximum of 1½% sulphur, 1% phenols and 1½% Conradson carbon, which may be considered quite lenient.

The standard fuel for jet engines was J2, a carefully refined distillate fuel, of which important properties were a setting point below –25°C, and adequate filterability at the same temperature. A running-in fuel, J2-einlauf, for which satisfactory low temperature behaviour only at 0°C was specified, was also supplied, presumably as a fuel economy measure.

Towards the end of the war, an unrefined distillate

of higher boiling range was used in jet planes, the oil being heated before filling the tanks. No trouble was experienced as a result of this expedient, beyond the sooting up of ignition plugs.

As special fuels for restarting at altitude following flame extinction, the nitro-alkyls were found to be satisfactory and a starting device with a glow plug was developed for starting these fuels.

iv. MOTOR PETROLS

The documents so far seen are remarkable for the small content of information about either research or technical service studies of motor petrols. It is known from captured samples that reasonable consistency in quality was maintained until nearly the end of the war, although the variety of blends employed was quite large. TEL concentrations were relatively low and there appears to have been no trouble with lead attack or lead deposition. At the present stage of the investigations cold starting stands out as the most serious problem followed by vapour lock troubles and, towards the end of the war, barrel corrosion, consequent upon the necessity of using unlined barrels when the zinc shortage became critical.

It would seem that Army transport was catastrophically affected by the Russian winter in the first year of the campaign in the East. In the second winter a conventional starting fuel of high volatility was introduced, as in the case of aircraft, but it was found that this alone was inadequate for the worst conditions and by the third winter vehicles were almost universally equipped with mixture heaters, air intake heaters, or coolant heaters for warming the whole engine to the point where a starting fuel was generally unnecessary. The corresponding work on lubricating oils under conditions of extreme cold is discussed below.

Vapour lock difficulties appear to have persisted throughout the war and various research contracts were placed because of Army dissatisfaction with the Reid vapour pressure test as a criterion of vapour locking tendency. Two rival pieces of apparatus were developed, a static method at T-H Dresden, and a dynamic test by Ruhrchemie. Controversy over their respective merits was still not resolved at the end of the war.

The problem of corrosion in unlined barrels was tackled by seeking an additive which would form an impervious phosphate layer on the inner surface. A new product of IG Hoechst to replace Hoechst additive 136 is reported as promising but was not fully proven when the war ended. Hoechst 136 was tried in service but was found to cause engine troubles.

Difficulties in the fuel supply situation were responsible for the undertaking of several research projects dealing with engine performance and operational procedure for the use of alternative fuels, e.g. propane, butane, methanol. The last fuel was blended in fuels for civilian use and home front Army vehicles.

v. AUTOMOTIVE DIESEL FUEL

Before the war the Germans established diesel fuel standards appreciably lower than those of the Allies, and here, too, relatively little development work has come to light. The introduction of the SDK fuel containing a petrol fraction as a consequence of the supply difficulties caused some vapour lock troubles. At the end of the war, plans were being laid for further fundamental work on the combustion mechanism in diesel engines.

A cetane number of about 40 was specified for motor fuels, cetane number being measured on CFR or IG

diesel engines by the constant ignition delay method, or on the HWA Humboldt-Deutz unit using the throttling method. Correlation between the various test engines was entirely satisfactory.

Methods of improving the ignition quality were studied extensively. As ignition accelerators the alkyl nitrates and butanone peroxide were successful. Treatment of the fuel with NO_2 also produced a considerable increase in cetane number. Increase above 60 cetane number was found to be undesirable, however, since it led to slow, incomplete combustion and soot formation.

A satisfactory petrol substitute for diesel fuel was developed, and consisted of a petrol containing 4% lubricating oil and 1% dibutin. The latter additive was particularly suitable, being stable, non-corrosive and of high bp (180°C). Dibutin was also used in blends with cetane to give reference fuels of high cetane number, e.g. 18% dibutin in cetane gave a cetane number of 200.

Road vehicle engines were operated experimentally on spindle oils and also on the poly-isobutylene safety fuels, the latter necessitating preheating of the fuel.

Considerable attention was given to the problem of cold starting. The relation between cetane number and starting performance was examined, and it was established that a combination of high cetane number and high vapour pressure (low bp) was desirable for starting purposes. Various ethers were tested as starting aids, ethyl isopropyl ether being the best. Starting fuel for Army vehicles contained about 30% ether.

Paraflow and PVO (polyvinyl oleyl ether) were used as pour point depressants, and to improve low-temperature pumpability. Fuel specifications included a low-temperature filterability test, the Hammerich method, in which the rate of flow through a filter under specified conditions was determined.

3. LUBRICANTS

Because of the limited supply of natural petroleum resources, the need to make up the deficiency by synthesis, and the necessary economies which have had to be made to make an inadequate supply go a long way, the picture which is being built up differs considerably from, and is not strictly comparable to, that existing in this country. For the reasons given above, the supplies available had been segregated so that they were used to the best advantage: the highest priority user—the Luftwaffe—getting most of the high-quality products, and the civilians—the lowest priority users—having to make do with what was left after other demands had been satisfied.

In general, developments in Germany have gone parallel with those of the Allies, the former being more advanced in some fields and the latter in others.

i. SYNTHETIC PRODUCTS

a. Hydrocarbon Oils

The programme which was instituted in 1936 resulted in two major sources of synthetic oils being developed, viz. the IG ethylene (or substitutes) polymerisation process and the cracked wax olefin polymerisation method. Both of these achieved considerable success and the total production will be seen from the tables to be about 60,000–70,000te/yr.

Attempts by Ruhrchemie to carry out similar polymerisation processes based on Fischer-Tropsch olefins met with only limited success although the work was started at about the same time. Fair quantities of the product were produced, but, because of the poor quality, it was relegated to the lower priority users, and it was

not until the end of the war that a satisfactory aviation oil component was to have been produced on any scale. A smaller quantity of synthetic hydrocarbon oil was made by Rheinpreussen by polymerisation-alkylation of naphthalene.

b. Synthetic Esters

These were based mainly on adipic acid although methyl adipic acid was used in some cases for esterifying a variety of branched-chain alcohols containing 6 to 12 carbon atoms, the particular cut used determining the characteristics of the product; in some instances methyl cyclohexanol was used as the alcohol.

c. Glycol Ethers

These products, which were water soluble, did not find much use although they had appreciable viscosities.

d. Tetrahydrofurane Polymers

Attempts were made to produce a synthetic oil by the polymerisation of tetrahydrofurane and ethylene oxide. The very viscous products which resulted had been used experimentally, but did not find wide application.

ii. PETROLEUM LUBRICATING OILS

These were produced from the various crudes available, both conventional and solvent methods of refining, using furfural, phenol and SO_2 being employed. Total production from this source was about 600,000te/yr.

iii. AVIATION LUBRICANTS

a. Engine Oils

Although some straight mineral oils were used, the majority of the S3—the standard aviation lubricant—was made from 50% synthetic bright stock made by either the cracked wax or the ethylene process and 50% thin mineral oil. This procedure has resulted in some variation in quality of the finished products, viscosity indices varying over quite a wide range. In the early days of the war, and for the Junkers diesel engines, a certain amount of V2—a voltol blended oil similar to German Aero Shell Medium—was used, but the amount was not large.

In spite of the fact that it was known that the synthetic oils were much better in regard to ring sticking than the natural products, the Germans persisted in the use of the 50/50 blend. Whether this was due to supply considerations is not clear, but a possible reason given was that the synthetics tended to thicken rapidly in use, and the natural oils were added to retard this.

In fact, the use of the synthetic-natural blend was not found to be entirely satisfactory in the engines in which it was used, difficulties having been experienced with ring-sticking and bearing failures, the latter in the Daimler Benz engine. (In this connection it is worth noting that it was appreciated that V2 was a better lubricant than S3, but it was much more prone to stick the rings.)

Although with S3 an elaborate testing procedure in single-cylinder engines had been worked out and the oils were required to pass such a test, ring sticking appeared to be ever in mind. The use of additives to decrease this tendency was apparently well known, but the particular one which was adopted (the IG additive R, also known as ZS1) appeared to be effective, or ineffective, according to the laboratory carrying out the tests. The bearing failure trouble with lead-bronze bearings was overcome to some extent by an additive made by the IG known variously as IG 891, IG 1586 or IG 1586/BS. This consisted of a mixture of the stearylamine of dichlorodiphenyl phosphorous

acid with the free acid; owing to its insolubility various methods were tried to disperse it in oil, the most successful being the use of a solution aid consisting of a mixture of benzene and alcohol.

For cold starting, dilution of the crank-case oil with the engine fuel, usually petrol, was widely practised. No undue wear was experienced with this method, neither were crank-case explosions found to occur.

b. Engine Corrosion Preventive Oil (Nachlaufschmierstoff)

The procedure followed by the Germans to stop corrosion in engines being put into storage after use with fuels containing TEL was somewhat different from that employed by the Allies, in that they ran out the engines on a clear fuel, possibly containing a neutralising, anti-corrosive material, and then lubricated the engine with a mixture of a spindle oil and a fatty oil. This same oil may have been used for cold starting purposes on the Russian front.

c. Hydraulic Oils

Little is known, as yet, of the exact uses to which the various products discovered were put, but it is known that both HVI mineral oils and blends of synthetic oils with synthetic esters and other additives were made for this purpose.

d. Greases

Parallel to the development by the Allies, the Germans have also gone over to the use of lithium base greases for aircraft lubrication. However, it is suspected that their use was not so widespread and was limited to the lubrication of fine mechanisms (instruments) only.

iv. AUTOMOTIVE (ARMY)

a. Engine Oil

Although the majority of the oil used for this purpose was of mineral origin, a certain amount of synthetic and substitute materials has been used. For example, slops from the blends of aviation oils were passed on to help improve the quality of the Army grades; also certain synthetic oils, made by Ruhrchemie (and others), which were not up to aviation specification requirements, were used entirely for automotive purposes. Exigencies also apparently caused certain refined brown coal tar fractions to be used for this purpose. The use of Oppanol, an isobutylene polymer, for improving the VI of these lubricating oils was quite common.

In the early part of the war the Germans tried to operate with "all-the-year-round" oil. Experience on the Russian Front, particularly, showed that this was impracticable and, in consequence, they changed to summer and winter grades, with a tropical grade for use in the African theatre. Even with the winter grade, starting difficulties were experienced in the Russian winter and the adoption of fuel dilution even in ground equipment was necessary. It would appear that the same oils were used for both petrol and diesel engines.

b. Gear and Transmission Oils

At various times during the war an all-the-year-round oil and separate winter and summer grades have been used in gears.

Initially they were blended with a small addition of fatty oil, but this was later changed to an EP additive; it would appear that either Etrol (Deutsche Vacuum) or Mesulfol (IG) was used for this purpose. Both of these are sulphur-containing additives.

c. Greases

The general purpose grease used by the Army was a soda-base grease made with montan wax. This was

claimed to have a fair measure of water resistance and to be very stable.

v. NAVAL

An outstanding subject of interest, not only to the Navy but also to the Luftwaffe, was the development of suitable torpedo oils. Two principles appear to have been involved: firstly, to obtain a satisfactory lubricant to replace materials in short supply, secondly, to develop a trackless oil either by making the oil heavier than water or by using a water-soluble product.

The first point involved finding a replacement for neatsfoot oil, which was achieved by utilising the synthetic esters of adipic acid with C₉-C₁₀ branched-chain alcohols. For making an oil leaving no oily trace on the water, attempts were made to increase the specific gravity by addition of chloro compounds, the alternative being by utilising the polyglycol ethers. It is not known how successful these methods may have been.

vi. CIVILIAN AND INDUSTRIAL

a. IC Engine Oils

Some evidence has been found of the use of black oils thinned down with spindle oil for this purpose. In general, it is probable that the lowest VI products were released for this usage.

b. Steam Engine Oils

Considerable success seems to have been achieved in the use of emulsion lubricants for this and other applications.

The tetrahydrofurane-ethylene oxide polymers were tried for this purpose, but were not satisfactory.

c. Railway Axle Oil

A mixture of a synthetic hydrocarbon oil, made by decomposing the sludge from the ethylene synthesis process and mixing the product with one of the synthetic adipic acid esters, provided a low pour lubricant of high load-carrying capacity, which enabled railway wagons to operate normally in the Russian winter and to be overloaded by 100%.

d. Cutting Oils and Drawing Oils

The IG Hoechst produced a synthetic material known as Bohrmittel Hö which had considerable application for soluble oil manufacture, apparently having unique properties; variations of this were successful, not only for the foregoing application, but also as anti-corrosives. Another version for heavy cutting operations, known as Schniedmittel Hö, was also prepared.

The neat Bohrmittel Hö was used with considerable success for the drawing of metals.

vii. RESEARCH AND DEVELOPMENTS—TEST METHODS, ETC.

a. Lubrication

A considerable amount of work was carried out at various research institutions, each of which seemed to develop its individual and original design of testing machine or research equipment. The best and most original work appears to be that carried out by the Physikalisch-Technische Reichanstalt although the further development of the four-ball machine by the DVL should not be overlooked. In general, it can be said that the influence of metals on lubrication was appreciated without any explanation of this having been discovered.

In trying to find a reason for the apparent deterioration in lubricating ability of supplies of aero-engine oils during

the war, some work has been carried out which tended to show that a relation existed between sulphur content and behaviour in an engine. To try to elucidate this further, the activity of the sulphur compounds was measured by passing hydrogen through the oil at different temperatures and measuring the amount of sulphur removed.

Investigation of the EP lubrication of gears had tended to show that with phosphatised or bonderised gears, EP lubricants were unnecessary, but it is not clear if this applied to hypoid axles.

b. Cold Starting

The experience on the Russian front resulted in a considerable amount of work being carried out on this subject and some quite ingenious test techniques were evolved. Great stress appears to have been put on the question of pumpability of the oils when cold and its effect on the starving of the bearings. Some of the test methods might prove, on further investigation, to be worth a trial in this country.

c. Ring Sticking

The engine test for this—in the BMW 132N single-cylinder unit—in which both blow-by and power drop were measured to indicate ring sticking, was well developed and had widespread use. The possible effect of fuel on this property seems to have been well appreciated. To save time and expense other smaller engine tests were under development, such as the DKW two-stroke engine and another method in which the top ring groove was drilled and the time to gain full power output due to closing the holes by deposit build-up was measured.

Very little work appears to have been done in regard to laboratory test techniques for assessing ring sticking and those tests which have been uncovered do not appear very promising.

d. Foaming

Although a fair amount of work appears to have been done on this subject in relation to both aero-engines and gear oils, no reference has yet been discovered to any anti-foaming additive.

e. Oxidation

Some work has been done on the fundamental study of the mechanism of oxidation of oils by the use of pure hydrocarbons and by attempts to utilise adsorption analysis (chromatography) for the separation of the oxidation products.

f. Greases

Besides the lithium grease mentioned earlier, three other novel developments in grease manufacture have been found. The first, a non-soap grease made by oxidising spindle oil, appears to have interesting properties; the consistency was varied by the extent of the oxidation. The second development was also for a non-soap grease, but in this case an air-floated silica gel was used as the

base; the resulting product was claimed to have no melting point. A third development, of which little is known at present, concerned the use of calcium or sodium benzoate in soda base greases to improve their water resistance.

Two novel test methods, which were standard tests for the Army general purpose grease, are worth noting; the first a pressure viscometer type of consistometer and the second a water-resistance test.

g. Analytical Methods Applicable to Used Oils and Deposits

Indications have been obtained that, at least with certain personnel, the Germans were in advance of thought in this country and the US on this subject. The analytical methods suggested would appear to be well worth a trial by workers in this field in this country.

h. Industrial Processes

In connection with improvements in methods of deep drawing, a fair amount of work appears to have been done on the more fundamental aspects of this subject and the application of lubricants of different types.

i. Other Products

Information on fields other than aviation and automotive fuels and lubricants is still very scanty, but this does apparently reflect, at least in part, the relatively small effort expended in these fields.

The majority of the developments that have come to light were initiated by war-time shortages and it is not yet possible to say how far these represent a real advance over the conventional products they replaced.

The following work, based on the utilisation of refinery by-products, is considered worth noting. There was produced from sulphuric acid tars, a fuel that can be burnt under boilers without trouble, a linseed oil substitute for mastic binders, a paraffin wax mineral oil resin compound for floor wax, and resins for compounding with rubber; from SO_2 solvent extract, a fire-preventing cutting oil for use especially when machining magnesium, a softener for synthetic rubber (for which high claims are made) and a preparation for use in coloured varnishes.

There is a reference to naphthalene-butyl rubbers and naphthalene-wax olefin rubbers, but no details of these products are yet available.

Sodium sulphonate soaps of paraffins from Fischer-Tropsch product (Mersols) were claimed to have a future for wool scouring, having the advantage of being non-alkaline and capable of use at low temperature.

A purely war-time requirement for flame-thrower fuels was met by the use of a petrol/tar-oil blend thickened with a synthetic resin, and the use of aluminium powder in flame-thrower fuels to give an exceptionally hot flame was nearing operational applicability at the end of the war.