ADMIRALTY OIL LABORATORY

THE FIRST TWENTY-ONE YEARS

BY

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The Royal Navy has used oils of various kinds as lubricants ever since machinery which required lubrication came into use. A major change resulting from a committee appointed by Lord Fisher was the introduction of oil fuel in place of coal, first for the *Queen Elizabeth* Class (1912 estimates). In 1914 the Government purchased about a 50 per cent. holding of the shares of the then Anglo-Persian Oil Company, now British Petroleum, and construction of the first R.N. Oil Fuel Depots was put in hand.

Between the wars, fuels and lubricants were among the materials used by the Navy which needed inspection, almost entirely using physical and chemical methods, but little research was employed. In the 1930s some lubricants first came to include additives, notably in the detergent engine oils and the turbine oils. The R.N. first introduced these during the Second World War, mainly in the form of formulations to specifications already used by the American Forces. After the war a specification was developed for a turbine oil containing oxidation and anti-rust inhibitors and research and development was conducted in this and other areas. However, the Navy did not possess any facilities for performance evaluation oil test engines, mechanical rigs, etc.

A formidable group of problems requiring a multi-disciplinary approach was upon us by 1950 and the Admiralty Oil Quality Committee, now the Navy Department Fuel and Lubricants Advisory Committee (NAFLAC), was set up largely at the instigation of Commander Le Bailley, now Vice-Admiral Sir Louis Le Bailley, to investigate how best these could be tackled. The committee which was headed by an independent chairman, the Hon. Ross Geddes, the late Lord Geddes, has always consisted of experts from the oil industry, universities and Navy Department staff.

FIG. 1—ADMIRALTY OIL LABORATORY, COBHAM

It was strongly recommended that a central laboratory be established, fully equipped and staffed to tackle all aspects of research, development, advice, and liaison with the petroleum industry on fuels and lubricants for the Royal Navy. The Admiralty Oil Laboratory came into being in consequence of this recommendation in premises on the Great West Road at Brentford, which could be purchased in 1952 at a time when the housing shortage prevented any attempt to build a new laboratory from scratch. It was fortunate to be able to move later to the present premises which were fitted out as the second A.O.L. in 1968.

The work of the laboratory over the twenty-one years has been diverse. This article describes the main items.

Furnace Fuel Oils

Before the establishment of A.O.L., a means of breaking viscous emulsions of fuel oil and sea-water which could form in ships' tanks had been evolved. This depended on the addition of a well-known synthetic detergent in just sufficient quantity to break the emulsions. The precise dosage used was somewhat critical. Too much of this detergent would promote emulsions of a different type. Improved emulsion breakers with which the dosage was less critical were found in conjunction with the Department of Scientific and Industrial Research Fuel Research Station, and fuel recovery plants were installed in Oil Fuel Depots.

A major problem was presented by furnace fuel oils to Navy specifications; some were pumpable on receipt but, after standing in unheated storage at winter temperatures, became virtually unpumpable. In cold weather some tanks in shore depots developed outer layers of waxy congealed oil which were strong enough to support a brick. A major study of this problem by

FIG. 2—FUEL OIL PUMPING TRIALS AT LYNESS

A.O.L. and NAFLAC included rheological studies in the laboratory, full-scale winter pumping trials in Oil Fuel Depots in the U.K. and in ships in Arctic waters, and pumping trials in a rig designed and built for the purpose.

The significance of laboratory data in relation to fuel pumping was established and a test devised to predict the probable behaviour of fuels after storage. This eliminated unpumpable or near unpumpable fuels from R.N. stock. Moreover, tank heating was installed in most installations to increase maximum pumping rates where necessary.

It is not commercial practice to store fuel for any length of time beyond what is necessary to meet continuity of supply. However, industry members who had been much involved in the NAFLAC work later devised a similar pumpability test for commercial fuels which is now widely used.

Fireside Deposits in Boilers

The boilers installed in R.N. ships up to a few years after the last war were not designed for steam temperatures above 650°F. At these temperatures and below, fireside deposits consisted of some carbon and sodium sulphate and other compounds not too difficult to remove by water washing. Care in fuel handling to minimize sea-water contamination helped to reduce the amount of such deposits.

The post-war decision to improve efficiency by going to substantially higher steam temperatures, starting with the *Blackwood* and *Whitby* Class frigates with steam temperatures of 850°F, changed the situation. A new type of adherent deposit much more difficult to remove was found. The cause was the formation of troublesome vanadium compounds. Vanadium which is a minor constituent of the ash of furnace fuel oils forms a range of oxides and vanadates. Below 650°F these are relatively harmless, at 850°F and above they change character and form these strongly adherent deposits. Some of the new oil-fired electricity-generating stations ran into the same problem but in these the available space for access, etc. is much more than in a very compact naval boiler and this alleviates to some extent the problem of boiler cleaning and tube inspection.

A.O.L. and others tackled this problem and all available information was obtained on industrial and university studies and parallel work being conducted by the U.S.N. and R.C.N. Possibilities included more vigorous cleaning using hydrogen peroxide, the use of fuel additives such as some magnesium compounds to form harmless vanadates, and changes in combustion systems. Removal of the vanadium from the fuel was not feasible since the vanadium in the form of porphyrins is an ingredient of the residues from refinery processes which are thinned down with gas oil to give furnace fuel oils of varying pumpability.

The R.N. solution was to burn a gas oil, i.e. diesel fuel, under boilers. This not only cured the problem but eased the logistics of fuel supply to the many ships using FFO for boilers and diesel fuel for diesel engines.

Diesel Fuels

Diesel fuel as supplied for many years had been 'straight run', that is, it had been produced by taking appropriate fractions from the distillation of crude oil and refining these to the required standards. A major change in refinery practice after the Second World War was the production of increased quantities of such fuel stocks by catalytic cracking operations. These fuels would undoubtedly be offered for R.N. use and it was feared that undue sediment and suspended matter might develop in long term storage. No certain guidance could be obtained from industrial experience as normal commercial stocks are turned over quickly. Once again a co-operative programme involving the study of possible test methods and the behaviour of a variety of fuels in storage was applied to the problem, as a result of which an adequate control test was devised. Moreover, the introduction of hydrofining by which the most unstable bodies in cracked fuel could be eliminated ensured that industry could meet the requirements.

The changeover to increased use of diesel fuel and less furnace fuel oil presented DGST(N) with the problem of changing part of his bulk storage from 'black' to 'white' oil. This is slow and tedious. A.O.L. was able to assist with improved methods. Diesel fuel is currently also used in gas turbines as discussed subsequently.

Diesel Engine Lubricating Oils

The R.N.'s lack of engine test facilities for setting performance standards for the new detergent type engine oils, whether for general use or for advanced engines such as the Deltic, had resulted in considerable quantities of such oils being imported at a time when the country was attempting to conserve dollars. One of the first actions was to install a range of oil evaluation engines at A.O.L. and to start an active programme to establish the performance standard required for naval diesels both in use and on trial at A.E.L. or elsewhere. Successive specifications have been evolved for oils to meet the needs of successive generations of engines.

It was realized at an early stage that a significant difference in fuel quality would be reflected in the quality level which the lubricating oil must meet. One significant factor was the sulphur content of the fuel. U.K. supplies made from Middle East Crude might have sulphur contents up to about 1 per cent. whereas fuels in common use in North America were much more likely to contain less than 0·5 per cent. of sulphur. An early instance occurred when diesel engines in minesweepers suffered from excessive deposits. It was established that fuel of low sulphur content had been used when this oil, supplied from overseas, had been engine tested. Later, oils introduced into service on the basis of engine tests with high sulphur fuel were satisfactory in these minesweepers.

To withstand conditions in high-performance engines running at full power, oils of high resistance to oxidation are required. On the other hand, one must not forget that when engines operate at low speed and low power the conditions are more conducive to sludge formation. A problem peculiar to two-stroke engines, such as the Deltic, is port blocking by accumulated carbon. Using a standard Rootes engine, A.O.L. developed a special procedure to select oils which can cope with conditions conducive to port blocking. More recently, A.O.L. has taken a leading part in developing into a European standard an oil evaluation procedure in a small Petter engine which may replace a test procedure using a large single-cylinder engine of U.S. origin, with a saving in time and money.

An oil test kit has been developed for on-the-spot monitoring of oil condition to give guidance whether it is time to change the oil. Studies of oil life have included extended running in service engines at A.O.L. and elsewhere. Oil film thickness in the ring zone of diesel engines can be measured by equipment devised by Reading University research staff. A.O.L. has collaborated in this to the mutual benefit of both by supplying the engine facilities on which the technique was tried out.

The whole complex field of evaluation procedures for internal combustion engine oils is the subject of much co-operation at the Institute of Petroleum and elsewhere. A.O.L. staff are regularly invited to take part as user representatives in U.K. delegations to European meetings on this subject.

Turbine Oils

The first of the *Blackwood* and *Whitby* Class anti-submarine frigates was being laid down in 1952-3. As well as new design boilers, these employed steam turbine main machinery with gearing carrying much heavier loads than had ever been attempted previously by the R.N. or Merchant Navy. It was not thought likely that these could be lubricated by mineral lubricating oils without the addition of special load carrying additives. It was also known that such additives might have deleterious effects such as promoting corrosion in the steam-turbine bearings. Much discussion had taken place as to whether the oil for the gearing should in fact be separate from that used for the turbine bearings. Due to the consequent penalties of separate tanks, separate coolers, separate pumps, etc. this had been ruled out. One of A.O.L.'s first tasks was to select and develop means for assessing the load carrying properties of oils for this highly rated gearing and to continue work already started towards studying the general properties of these oils.

This resulted in the introduction of an oil with enhanced load-carrying capacity which has given good service, and also increased our knowledge of the inter-action between lubricating oils and the types of steel which may be used in the construction of highly loaded gears. More recently, work has aimed at conditions that may occur in even more highly loaded systems, should they be required. The A.O.L. Disc Machine, developed as a research tool for such studies, has been of great value.

Extensive sea trials both with the older oils and the new oils containing load-carrying additives showed that the fairly high oil make-up needed to replace miscellaneous losses from the system was normally adequate to counteract deterioration from oil oxidation and additive depletion. More recently calculations have been attempted to establish what will happen if these miscellaneous losses are heavily reduced in future designs.

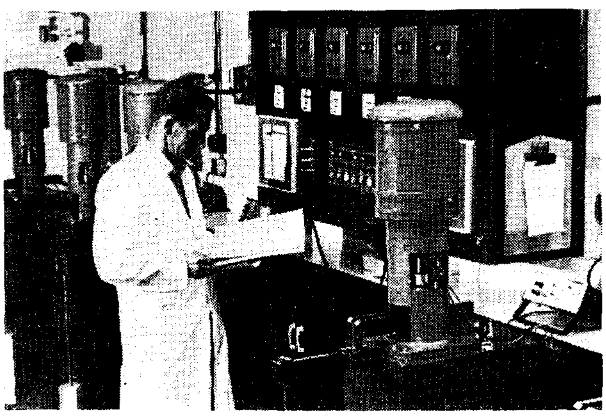

FIG. 3—VERTICAL FATIGUE RIGS

Grease and Rolling Bearings

The manufacture of grease had for long been more an art than a science but, as in other areas of petroleum technology, radical changes were taking place during and after the last war. When A.O.L. was set up, the R.N. still used an old and now obsolete conventional grease in electrical machinery. There was an urgent need firstly to raise the standard and secondly to evolve reliable methods of evaluating performance. This was tackled and in conjunction with a very active NAFLAC panel, achieved the introduction of a new multi-purpose grease which is still in use.

It was then found that there was little reliable information on either the causes of failure or the real failure rate of rolling bearings in service. After a preliminary trial in two frigates, a full-scale trial was put in hand in which all surface ships in service were required to report failures of grease-lubricated bearings in electrical machinery to A.O.L. and the Ship Maintenance Authority and forward the failed bearings to A.O.L. for examination. Over 600 were received in the twelve months of the trial. It was established that the overall failure rate was low, but that corrosion and various mechanical and fitting defects accounted for a substantial proportion of these failures.

Other items undertaken have included the study of grease rheology to meet dispensing problems with grease on board ship and improvement of grease for water washed situations.

Hydraulic Fluids

The first major problem on hydraulics put to A.O.L. concerned the aqueous fluid employed in arrester gear in aircraft carriers where excessive corrosion was being experienced. This corrosion was stopped by the incorporation of rust inhibitors to a formulation based on previous work by staff now at A.O.L. and as a further step fungicides were added to take care of microbiological growth.

It appeared that a reduction in the number of hydraulic fluids might be achieved if viscosity temperature properties were improved by the incorporation of polymeric additives. A fluid of this type was devised and trials conducted but advantages gained were not sufficient to enable it to replace more than one of the existing fluids and this project was not taken further.

Submarine hydraulic systems may suffer accidental contamination by sea-water. This can cause pump failure and other troubles. An emulsifying fluid similar to an experimental product used by the U.S.N. had been tried for flushing systems. This fluid could take up water as an emulsion thus preventing slugs of water reaching the pumps. An extensive laboratory programme to study corrosion resistance, emulsion stability, and the effects of water on the fatigue properties of rolling bearings was undertaken by A.O.L. Emulsifying fluid has been introduced as the actual hydraulic fluid for these systems. Work on fatigue lubrication, and wear, etc. continues and possible types of fire-resistant fluids are under study.

Gas Turbines

The first gas turbines used in the Fleet were industrial gas turbines. The new generation of ships are powered entirely by gas turbines originally developed for and used in aircraft. These gas turbines use the lubricants on which they were first developed but, for logistic reasons, burn diesel fuel. Small amounts of sea-water if present in the fuel can attack the turbine blades in conjunction with the sulphur in the fuel.

Coalescer filters are used to separate by coalescence the water present in fuels for aircraft. They are also fitted in the ships with gas turbines. Since diesel fuel has a higher viscosity and density than aviation fuels, may contain more dirt and surface active materials, and may be stored in tanks with sea-water ballasting systems, the coalescer may not cope with some conditions. Extensive coalescer trials monitored by A.O.L. at an Oil Fuel Depot have been followed by laboratory studies of the fuel factors involved. Another trial was devoted to assessing the dirt content of fuels as supplied from R.F.A.s.

A research contract has been placed at the University of Manchester Institute of Science and Technology, and trials in large coalescers are being organized by A.M.E.E.

Fire and Explosion Hazards

For many years the fire hazard has been arbitrarily linked with the flashpoint of the fuel. A meaningful assessment of the significance of flashpoint was required, since an unnecessarily high figure would restrict supply and the appropriate level of flashpoint for fuels for marine use was in question. A.O.L. has devoted attention to this problem, especially to the amount of explosive vapour likely to be found in ships' tanks filled to various levels. In the light of these investigations the recent acceptance by Lloyds Register of Shipping of 140°F as the minimum flashpoint for marine fuels in place of the long established 150°F was regarded as acceptable to the R.N. also, subject to certain precautions being taken.

Occasionally catastrophic explosions have occurred in crankcases of large slow moving engines as fitted to merchant ships. The causes and prevention of these have been comprehensively studied elsewhere. More recently it has been considered possible that under extreme conditions dense inflammable oil mists might form in gear boxes and be ignited. This has been tackled in two ways. A.O.L. is studying mists produced in laboratory apparatus and has found that these mists have to be extremely dense before ignition can occur. The parameters governing their ignition and resultant flame speeds are being explored. At the same time surveys of the amount of mist, if any, occurring in actual machinery are in hand. Research contracts at City University are giving additional support in these studies.

Destructive explosions in 'empty' tanks of giant supertankers may have been caused by electrostatic charges, but no one knows for certain. A.O.L. took a close interest in the Public Enquiry into the explosion in the S.S. *Mactra.* It is known that electrostatic charges can be developed when pumping fuels at high speeds and precautions and safety codes are laid down for the refuelling of aircraft. H.M.S. *Wilton,* the first minesweeper to be constructed entirely of glass reinforced plastic, presented a novel problem. Could electrostatic charges develop to a dangerous extent in her fuel system? A.O.L. has devoted some time to this matter and both laboratory experiments and ship trials have been conducted. First results have been encouraging and further work including a research contract at Southampton University is in hand.

Pollution

From time to time A.O.L. has advised on cleaning up of minor spillages of oil fuels in naval dockyards and has conducted bilge cleaning trials. The normal method was the use of detergents. When the *Torrey Canyon* ran aground, A.O.L. became the centre for the evaluation of the various detergent materials proposed for use on sea and beaches and a senior member of the staff spent several weeks acting as an adviser in Cornwall. Afterwards a Navy Department Working Party was set up to review the efficiency and the after-effects of the measures taken. A.O.L. staff served on this committee, contributed reports on what had been achieved in Cornwall, and also visited Brittany for consultation with the French authorities. The research programme which ensued included a Navy Department Working Committee on the Fate of Oil at Sea. A.O.L.'s contribution made use of our expertise in the field of emulsification and included monitoring of University Research Contracts.

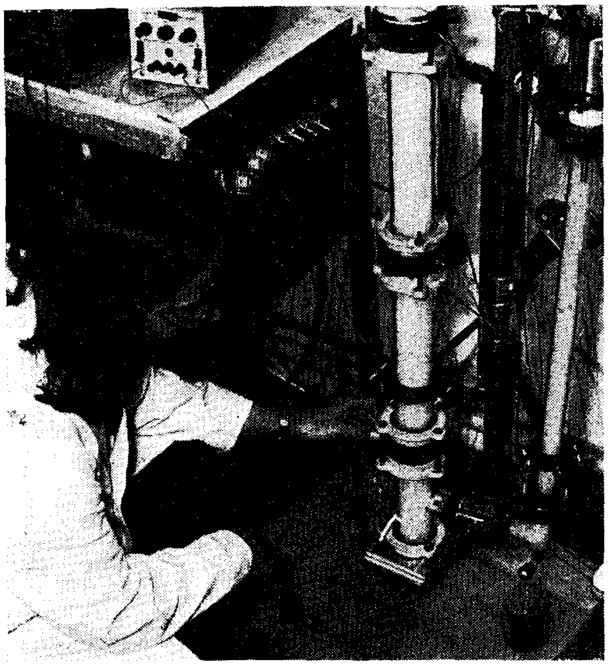

FIG. 4—SANDWICH STUDENT STUDYING THE FLAMMABILITY OF LUBRICATING OIL MISTS

Recently a NAFLAC Pollution Working Group has been set up to consider the consequences of recent changes in international legislation on oil discharges at sea in so far as they could affect H.M. ships and R.F.A.s. These involve the reduction of the amount of oil in water discharged to levels at which they can scarcely be measured.

Air pollution standards for engine exhausts in the U.S. also apply to ships in harbour. Gas turbine ships use diesel engines to provide electricity in harbour and it is prudent to take steps to monitor engine exhausts if need be. A.O.L. has installed a special trolley equipped with such measuring devices. It may be used as an additional check in performance of service engines used in lubrication studies.

Tribology

A frequent question is 'Does A.O.L. do any tribology?' So far this article has been arranged in relation to materials and equipment. It could have been treated in relation to scientific disciplines, i.e. engineering, chemistry, etc., or in relation to lubrication, corrosion, rheology, etc.

Whatever it is called, interest in fuel and lubricant matters grew steadily in the last 25 years. In the early 1960s there was an increasing national awareness of failures in plant and machinery due to wear and associated causes. This field, often loosely described as lubrication, friction and wear, was the subject of an enquiry set up by the then Minister of State for Education and Science. The inter-disciplinary nature of the subject was stressed and the Committee estimated that potential savings of £515 million per annum might be achieved for U.K. industry by better application of tribology.

Tribology is a new term introduced to describe and highlight the subject and is defined as:

> The science and technology of interacting surfaces in relative motion and of related subjects and practice.

Practically all of A.O.L. work on lubricants and hydraulic fluids and also some of the fuel problems could therefore be listed under tribology. A.O.L. thus has no tribology section set apart as such; tribological thinking pervades the whole of the establishment.

The Laboratory at Cobham

The aerial view shows the house, known on the ordnance survey map as Fairmile Cottage, with behind it a range of single storey buildings. The house is now the Administrative Block and the laboratories, canteen, stores and other facilities are well housed in the single storey buildings. It has been possible to provide adequate height in the engineering block in which to build in soundproof cells for oil evaluation engines and the noisier of the mechanical rigs and allow easy movement of equipment, while the lower

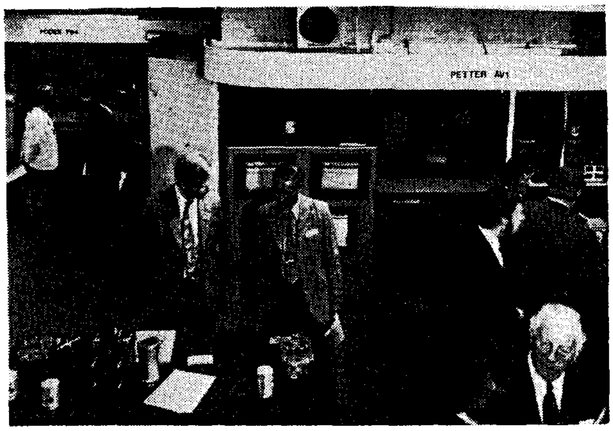

FIG. 5—A.O.L. OPEN DAYS: READING UNIVERSITY EXHIBIT IN THE ENGINE SHOP

ceilings in the chemistry buildings are ideal for maintaining the necessary high standards of cleanliness in these areas. The buildings are situated in pleasant grounds, the total area of the site being about six acres. The amenities are enhanced by the fact that the Old Surbitonians' sports field is next door and the whole is set in a highly sought after residential area.

A brief article on the recent Open Days held to celebrate the laboratory's coming of age has already appeared in the *J.R.N.S.S.* This notes some of the items which were on view. Experience has shown that the diverse equipment and expertise required are best grouped in three sections; an Engineering Section dealing with the mechanical evaluation of lubricants but also including the machine shop, and miscellaneous support facilities, and two sections mainly containing chemical and physical facilities. One, known as the Fleet Support Section, houses the Advisory Service, the standard physical and chemical tests for petroleum and its products, and up-to-date instrumental chemical analysis equipment. The Applied Physical Chemistry Section is aimed at research and development in specific areas, currently on fire and explosivity hazards with fuels, lubricating oils, mists, etc., on hydraulic fluids and fuels for gas turbines. It also houses the scanning electron microscope which is mainly used in support of lubrication and wear studies.

A.O.L's. Varian 620L-105 mini computer is a very useful facility not specifically tied to any one section. The computer manager is a member of the Fleet Support Section. Many of the tasks falling to A.O.L. are such that a multi-disciplinary approach is required. For this reason all work in specific areas such as on fuels or on hydraulic fluids is co-ordinated by individual members of the staff.

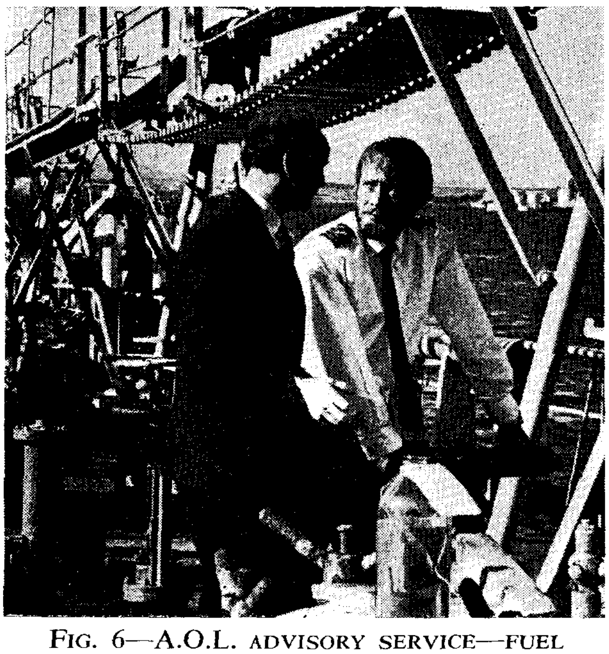

FIG. 6—A.O.L. ADVISORY SERVICE—FUEL PROBLEMS ON A R.F.A. AT GIBRALTAR

Contacts with industry are maintained through individual contacts or through NAFLAC. Standardization of test methods is discussed at the Institute of Petroleum, B.S.I., and increasingly at the Co-ordinating European Council and European Standardization Committee Working Groups. The interchangeability of products is discussed at NATO Fuel and Lubricant Working Parties; information on all aspects of fuels and lubricants is discussed at biennial Quadripartite Meetings between the navies of the United Kingdom, United States, Canada, and Australia, at which oil industry advisers take part. Links

FIG. 7—CHARGE CONFIRMATION COURSE FROM H.M.S. 'SULTAN' AT A.O.L.

with relevant parts of the MOD and other government departments are maintained both formally and informally. Over the years research contracts have been placed with a number of universities and a close eye is kept on new advances.

An important feature is contact with training establishments such as the Royal Naval Engineering College and H.M.S. *Sultan*. The latter regularly sends Charge Confirmation Courses for a day at A.O.L.

The Future

There will continue to be a need for research, development and advice on fuels and lubricants and related materials. The problems under study will change with changes in machinery and equipment and developments in the oil industry. Although oil appears prominently in A.O.L's. title, it has always been taken to include synthetic lubricants and fluids used to do the jobs traditionally done by oil. This includes both highly specialized synthetic materials developed to meet extreme conditions and the various types of fire-resistant fluids.

The energy crisis and sharp changes in the price and supply pattern have led to shortages and difficulties for oil companies and their additive suppliers from which the Navy cannot expect to be insulated. A.O.L. must be continually aware of the nature of such problems and endeavour to meet them to the best advantage. Forty years ago the synthetic chemical industry was largely based on coal products. The rise of the petrochemical industry completely changed the situation. Many synthetic lubricants are based on the petrochemical industry. A changing world energy pattern in future years must also lead to changes in the synthetic chemical industry. A.O.L. will endeavour to keep abreast of whatever changes impinge on the Royal Navy's needs.