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The Lubrication of Steam Turbines.

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Chairman: Mr. J. A. Rhynas (Chairman of Council).

Synopsis.

The paper deals primarily with the basic requirements of marine steam turbine lubricating oil as indicated by its purposes as a coolant and as a lubricant for bearings and gears. Oils of greatly improved resistance to heat and oxidation have been developed and put into use and these properties have also been combined with effective rust prevention and resistance to foaming. The methods whereby this has been achieved are described, and lines are indicated whereon specifications for modern turbine oils can be laid down.

The trends in turbine design are towards higher temperatures, higher speeds and forced lubrication involving smaller quantities of oil in circulation. The new types of oil are capable of accommodating these progressively severe conditions of operation, but a plea is entered for the designer to ameliorate the working conditions of the oil so that the length of oil life now achieved can be maintained.

In the course of the paper practical consideration is given, amongst other things, to ventilation, temperature control, centrifuging, cleaning of turbine systems and handling and storage. A section is devoted to the cause of lubricating oil fires.

I. PRELIMINARY.

Marine turbine lubrication is effected either by gravity head or pump circulation in systems common to turbine bearings and reduction gears. The quantity of oil in circulation may differ considerably in the two methods. This is demonstrated by the following typical cases:

TABLE I.

Installation.	*System*	*Amount of Oil.*
(A) 7,000 h.p.	Gravity	3,000 gallons
(B) 9,200 ,,	Forced	800 ,,

The cycle of lubrication also varies appreciably, but in all cases the lubricating oil is circulated rapidly, such conditions being necessary for the removal of frictional and conducted heat. Actual temperature control is effected by suitable heat exchange equipment. As a result sump tank temperatures are seldom higher than 110°F., while bearing return temperatures do not in general practice exceed 150°F. In recent installations, however, bearing return temperatures have been as high as 175°F.

During circulation much air is entrained in the oil. This results chiefly from oil ejection from the bearings, in which the shaft may be revolving at 2,000-3,000 r.p.m., and from particulation of the spray directed to gear wheels and pinions. In addition there may be continued turbulence in the pipe system and splashing on return to the main tank.

Continued exposure of the oil to air in this way results in its deterioration by oxidation. The rapidity of this deterioration depends upon the running conditions and the nature of the oil.

Turbine oil is also likely to become contaminated with water. Such intrusion may cause the oil to emulsify. But whether a true emulsion is formed or whether the water is merely churned round with the oil, the extent of oil-surface thereby exposed to the air is greatly increased. Under these conditions, too, especially with unsuitable oil, foam may be formed which is only resolved with difficulty. Foam and emulsion are ideal conditions for low temperature oxidation.

When water is present, the air within housings, pipes and tanks becomes charged with moisture, which may condense on the cooler parts of the circulation system and drop back into the oil. Such continuous exposure of iron or steel surfaces to water results in rusting. This rust encourages emulsification by its adsorption at the oil-water interface. Moreover, iron oxide is itself an active catalyst which increases the rate of oxidation of the oil and shortens its useful life. Aeration, intrusion of water and heat are therefore liable to involve the oil in a vicious circle of deterioration.

From these preliminaries it is possible to consider the purposes and requirements of turbine lubricating oil and the conditions best suited to its use.

II. REQUIREMENTS OF A TURBINE OIL.

Lubricating Value.

In a marine turbine the three chief functions of the oil are (a) to remove heat; (b) to lubricate the bearings; (c) to lubricate the reduction gears.

As a coolant, the lower the viscosity of the oil the better. This is because heat transmission from a fluid is in direct proportion to the rate of movement, and the latter, in practice, to the ease of pumping. In direct-coupled land installations, even of the largest size, light oils of only 60/75 seconds Redwood viscosity at 140°F. are generally used. For geared turbines as in marine work, oils of higher viscosity are needed for lubrication of the reduction gears, and it is then usual to employ an oil of approximately 120 seconds Redwood viscosity at 140°F. It may be questioned whether this is an ideal figure for gear lubrication and it is, in fact, doubtful whether much advantage is to be gained from the limited increase in viscosity thereby made practically possible. Greater film strength would be an advantage. Indeed, unless it be possible to produce oils of higher lubricating or load-carrying capacity which can be introduced into the circulation system without disadvantages as regards chemical stability or demulsibility, it would seem that bearings and gears should be lubricated separately.

Oxidation Stability.

The continuous oxidation of turbine oils at what are relatively low temperatures produces chemical effects of two kinds—promotion of higher molecular weight condensation products and rise in "neutralization value". The condensation products when first formed are generally soluble in the oil and tend, therefore, to raise its viscosity. As they increase in molecular complexity they become insoluble and lead to the formation of semi-solid deposits which may take the form of varnish-like films on and adjacent to bearings, valve gear, etc. Eventually precipitates and encrustations may be formed. These deposits and sludges contain oxygen and are soluble in alkali. By reason of this capacity for reacting with caustic soda or potash they are classed as "acids". This also applies to the oil-soluble oxidation products wherefrom they are derived. Such materials should be differentiated from true acids, however, as they have little or no solubility in water, and no corrosive action on metals, and thus their inclusion in the "neutralization value" or "acidity" of the oil may be misleading.

At the same time there can be formed substantial quantities of water-soluble low-molecular weight true acids like formic, acetic and caproic acids, which are even more objectionable than the condensation product deposits. These acids in certain circumstances may cause appreciable corrosion of working parts, and in any case they induce rusting and the formation of iron salts and iron hydroxide, the presence of which brings about the most appropriate conditions for the formation of difficult emulsions with which even the centrifuge cannot deal and which may interfere seriously with both heat transference and lubrication.

These extremes in oxidation behaviour can be correlated with corresponding differences in the nature of the oils used. Insufficiently refined oils, especially those derived from crude oils of asphaltic and naphthenic nature, are particularly prone to viscosity increase and the formation of deposits and sludges. Highly-refined paraffinic oils, on the other hand, though non-sludging in character are most liable to develop corrosive acidity on oxidation.

It is a natural deduction from such behaviour that mineral oils "for use in circulatory systems can be *too* paraffinic in nature and that refining processes, which by profound treatment with acid or solvent emphasize such character, may produce oils unduly susceptible to acidic oxidation[1] ".

Measurement of Oil Deterioration.

The deterioration of a turbine oil in use is generally followed by observing its increase of viscosity and by determination of its acidity or neutralization value[2]. The latter is returned in terms of the number of mg. of potassium hydroxide required to neutralize the acidity of one g. of oil. Many other tests have also been considered for the purpose, including the saponification value, the sludging value as carried out for insulating oils, the peroxide number[3] and the alteration of interfacial tension; but most of these follow closely the same lines as the neutralization value and represent the same type of oxidation deterioration. The peroxide test has some interest because the low-temperature oxidation of mineral oil hydrocarbons appears to be a chain reaction in which peroxides act as the chain-initiator[4].

Of recent years a good deal of attention has been paid to measurement of the reduction of surface and interfacial tension resulting from turbine oil oxidation[5]. For a number of reasons this change might be expected to correlate with the behaviour of the oil in practice and it has, in fact, been included in the French naval turbine oil specification[6]. Unfortunately, the interfacial tension measurement is somewhat readily affected by extraneous factors, so that the effect itself is apt to be masked.

Oxidation Tests.

For the purpose of simulating in laboratory measurements the practical effects of oxygen upon mineral oils, a wide variety of oxidation tests have been proposed and a number have been adopted for specification purposes. Two of the best known are of British origin, *viz.*, the Air Ministry test, formerly used for aircraft oils, and the Michie test for transformer oils.

Of recent years much work has been done and is still actively proceeding, both in the U.S.A. and here, for the purpose of developing a standard procedure of determining the oxidation behaviour of turbine oils. It seems to be accepted fairly generally that it is immaterial whether the oxidation effect is produced in the laboratory by means of air or by oxygen, but that it is desirable to have water present; that metallic catalysts such as iron and copper should be included; and that to some extent, at any rate, the volatile products of reaction should be condensed and returned by reflux to the reaction vessel. It is true that the latter feature is not simulative of good turbine practice, in which venting should be carried out as efficiently as possible, but for test purposes it is obviously desirable to make simulative conditions as onerous as might occur. Moreover, refluxing the volatile oxidation products ensures the maximum rate of deterioration of the oil being taken into account, and also that any augmented catalytic effect due to the action of volatile corrosive acids on the metal takes place.

Consideration is at present being given by the Institute of Petroleum to the standardization of an oxidation test involving the use of air. The American Society for Testing Materials on the other hand, for the last two or three years, have had under review a procedure using oxygen. This proposed A.S.T.M. method of test for "Oxidation characteristics of steam-turbine oils"[7] is not yet adopted, but special reference is made to it here because it has been used for a number of the experiments to be described later.

The oil sample is subjected under standardized conditions to a temperature of 95°C. in the presence of water, oxygen and an iron-copper catalyst; and the time required to build up a neutralization value of 2 in the sample is determined. The proposed oxidation cell employed in the test is shown in Fig. 1 and the general set up of numbers of the complete apparatus in Fig. 2.

Resistance to Emulsification.

Emulsions of oil and water are of two main kinds, according as the oil or water forms the external or continuous phase. Gradual introduction of small quantities of water into oil will tend to form water-in-oil emulsions, whereas the introduction of larger amounts is

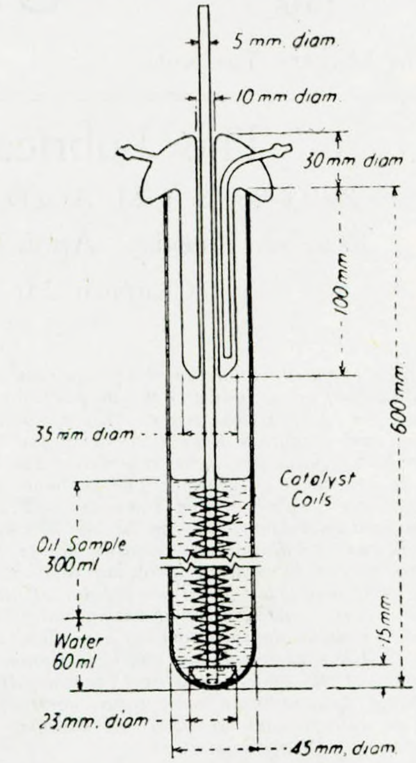

FIG. 1.—*Proposed A.S.T.M. turbine oil oxidation test—oxidation cell.*

more likely to form oil-in-water emulsions. The latter are the more common in practice, and the lacy emulsions which settle out more or less quickly are usually of this kind. The water-in-oil type is often formed under suitable conditions from gradual intrusion of finely-dispersed water in the form of steam as, for example, from a leaky gland. Such emulsions may vary from turbine oils which are merely permanently "damp" oils up to thick emulsions of appreciably higher viscosity than the original oil. Emulsions can "invert" from one type to the other. When large quantities of steam are blown into an oil the initial emulsion is almost certainly water-in-oil, whereas that eventually formed is generally oil-in-water or a complex mixture of both kinds.

Both types of emulsions become stabilized by the presence of a third substance which acts as an emulsifier. Such materials are colloidal in nature and are adsorbed and concentrate as a "cream" at the oil-water interface. Water-soluble colloids promote emulsions of the oil-in-water type, whilst oil-soluble colloids tend to form the reverse type. It is to be noted, therefore, that the two kinds of oil oxidation products previously mentioned will work in different ways. The oil-soluble condensation products and their dispersed precipitates will help to form water-in-oil emulsions, whereas the water-soluble corrosive acids and the gelled metallic hydroxides and soaps, which they are instrumental in producing, tend to develop oil-in-water emulsions.

The viscosity of emulsions increases with increase in volume of the internal or dispersed phase. In a turbine system the worst effects of this kind are therefore likely to be from oil-in-water emulsions owing to the much larger quantity of oil present.

In extreme cases, however, either type of emulsion may become so thick as to interfere with the proper flow of the oil, and hence with both lubrication and cooling. This can be appreciated from a formula[8] which relates η = the Coefficient of Viscosity of the

1. Auld and Lawrie, *Trans. N.E.C. Inst. Eng. & Shipbuilders*, 1942, LVIII.
2. I.P. Standard Method—1/44.
3. Williams, *Analyst*, 70, 409, 1945.
4. Cf. Denison, *Ind. Eng. Chem.*, 36, 477, 1944.
5. Cf. von Fuchs, Wilson & Edlund, *Ind. Eng. Chem. Anal.*, 306, 1941
6. Ministere de la Marine, Specn., 5044-165, 1933.
7. A.S.T.M., D-2, 1943.

8. Hatschek, *Trans. Far. Soc.*, 9, 80.

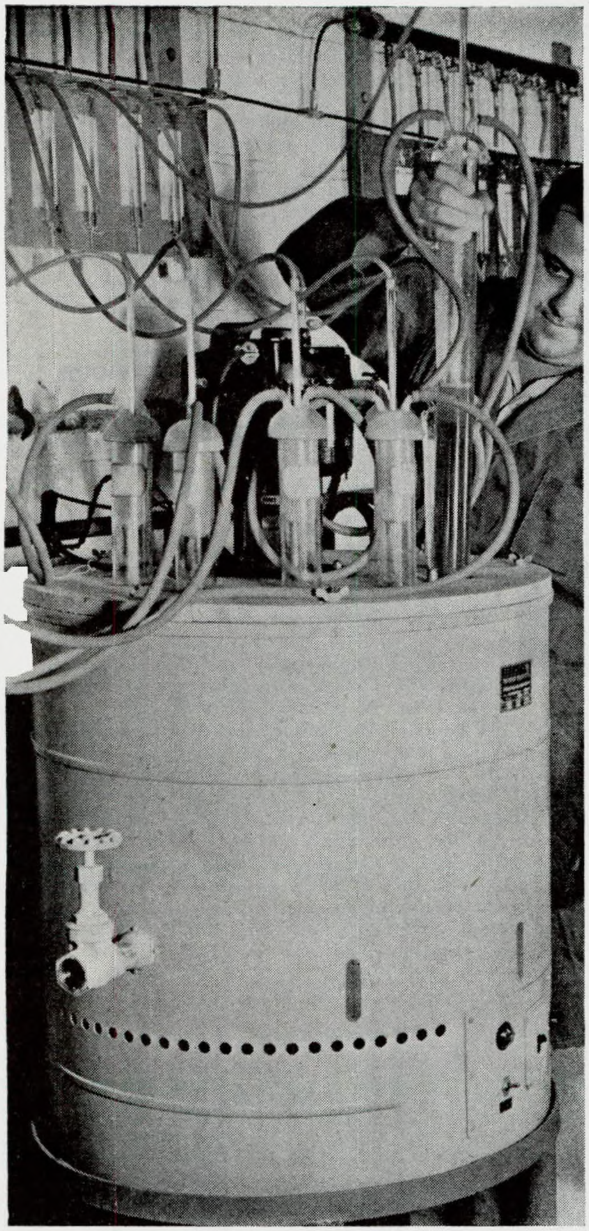

FIG. 2.—*Apparatus for proposed A.S.T.M. turbine oil oxidation test.*

emulsion, to the ratio A = Volume of Emulsion/Volume of Dispersed Phase as

$$A = \left(\frac{\eta}{\eta - 1}\right)^3$$

Increases of viscosity many times that of the original oil can take place. Troubles caused by such occurrences in practice will be referred to later. In practice also, the more viscous an oil the more liable it is to emulsification. This is due to the greater hindrance the heavier oil offers to coalescence of the particles of the dispersed phase.

The resistance of an oil to emulsification can be measured in a number of ways. The test methods may be divided into such as involve mechanical mixing and those in which emulsification is effected by steam. Of the former one of the best known is the Admiralty Test, in which the oil is mixed with water and simultaneously stirred and gear pump-circulated whilst heated to 160°F. The rate at which the mixture separates on standing, and the proportions of oil, water and emulsion left after centrifuging under standardized conditions, are measured.

The Admiralty test, the apparatus for which is shown in Fig. 3, has been used in naval contract specifications for many years and shows good repeatability in the hands of experienced operators, but it has never been popular, nor has it been adopted by other users. The requirements are too rigid and the test as a whole unduly sensitive. It can be upset by the slightest adventitious contamination. For this reason, even more than other emulsification tests, the results bear little relationship to the condition or behaviour of the oil subsequent to its introduction into the turbine system.

The steam emulsion test has now been standardized in identical form by the Institute of Petroleum[9] and the A.S.T.M. as the "Demulsification Number" and "Steam Emulsion Number" respectively. Steam is blown into and allowed to condense in the oil until the volume of water is equal to that of the oil. The rate at which the emulsion so formed separates is measured.

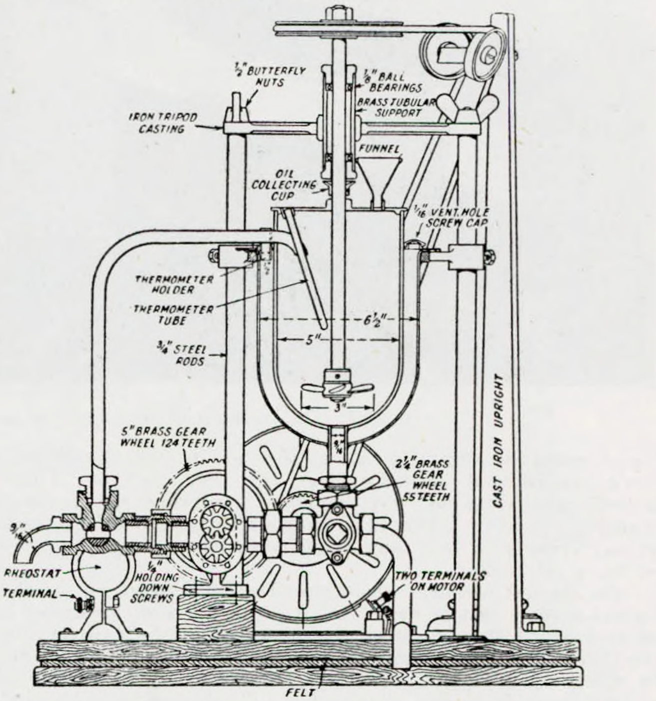

FIG. 3.—*Admiralty demulsification test.*

This test has some practical value in measuring the tendency of a used oil to emulsify besides that of indicating the demulsification characteristics of new oil. During the introduction of the steam there is a tendency in the initial stages to form water-in-oil emulsion which later on seems to invert to oil-in-water. Even in the most rapid separations, therefore, the oil layer frequently remains turbid. Such conditions, in the case of used oils containing oxidation products which act as emulsion stabilizers, may result in the formation of recalcitrant emulsions of slow-separating or even nearly permanent character which sometimes, though by no means invariably, correspond to the behaviour of the oil in the system.

The present tendency in the development of turbine oil specifications is to concentrate on the use of the standard steam emulsification method of test for new oils and at the same time endeavour to forecast the behaviour of the oil after use by carrying out a similar test on the oil artificially oxidized.

Prevention of Rusting.

Prevention of rusting in turbine systems depends primarily on the exclusion of water and, as such, is a problem of design, erection and maintenance. This aspect of the matter will be dealt with in a subsequent section. It is a fact, however, that serious potential rusting conditions can and do exist from the intrusion of water, and that the likelihood of rusting may be greatly augmented by the presence of salt-water, dissimilar-metal couples, electrolysis, soluble oil-oxidation products, and many other conditions.

Wartime troubles of this kind led to requests from the Services for rust preventives which could be incorporated in the oil. The success achieved in this direction has resulted in a continuance of the demand, although it is not really the oil's job. Turbine manufacturers and users have severally demanded the incorporation of rust-prevention behaviour in turbine oil specifications, and this characteristic must consequently be included under the heading of

9. I.P. Standard Method, 19/42.

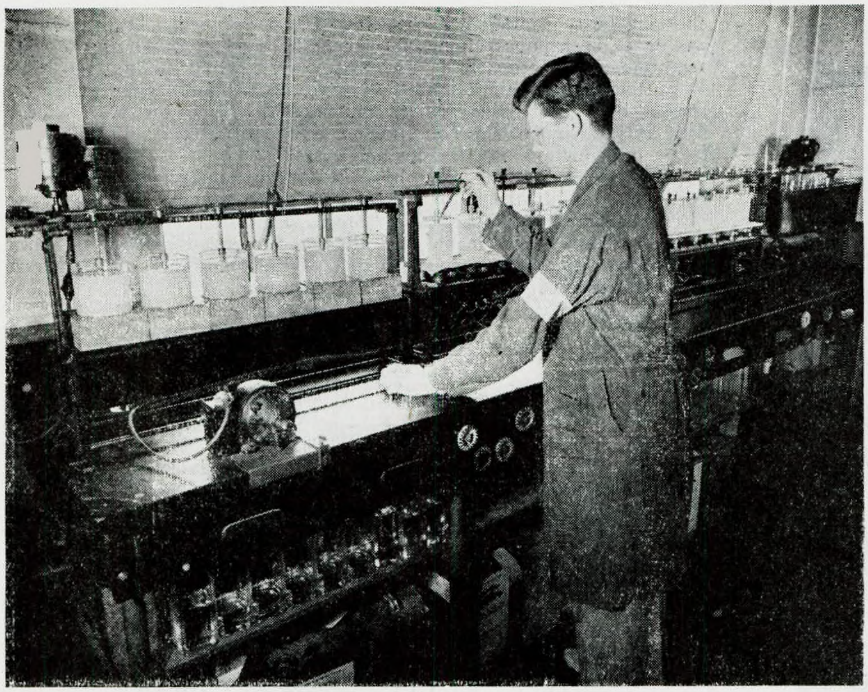

FIG. 4.—*Apparatus used in long-term rust tests.*

"requirements". What is more, the specification conditions laid down can be, and in many cases are, very onerous. They may include, for example, test methods specifying the presence of synthetic sea-water. This is to simulate such troublesome conditions as may arise from salt-water being taken into systems through vents or leaky oil coolers.

Of the test methods which have been laid down, one of the best known is again that of the A.S.T.M.[10] In this test, prescribed pieces of a standard shafting steel are immersed in the experimental oil, together with 10 per cent. by volume of distilled water. Stirring by means of a stainless steel stirrer at 1,000 r.p.m. is carried out at 140°F. for 48 hours. Similar but fully dynamic and lengthy tests in which the metal test pieces are used as stirrers and the distilled water is replaced by synthetic salt-water have been applied in the development of turbine oils used during the war by both the Admiralty and the U.S. Navy.

Illustrations of the apparatus used in such long-term tests and of test specimens showing degrees of rust prevention with various oils under standardized conditions are shown in Figs. 4 and 5.

Other Characteristics.

(*a*) *Specific Gravity.*

Specific gravity has no inherent significance of the behaviour of an oil. Its close delimitation in the Admiralty specification for special mineral lubricating oil was intended originally to ensure the oil's being wholly of Pennsylvanian origin. Superior oils of different nature were, of course, eventually developed from other sources and by improved methods of refining. The retention of the specific gravity requirement was restrictive and anachronistic. During the war the provision of the required type of stocks created unnecessary difficulties and at times interfered with the supply of other, more urgently needed lubricants. It was only towards the end of the war that the need for inter-Allied unification of oil or its inter-changeability led to a broader outlook being adopted.

(*b*) *Flash Point.*

This has little or no significance in use. Its introduction into turbine oil specifications should be for the purpose of ensuring suitable fractionation in refining and absence of volatile contamination.

(*c*) *Sulphur.*

Turbine oils must be chemically as inert as possible and without direct action upon the metals present in the system. There need be no limitation quantitatively on their sulphur content, but such sulphur must be non-reactive. This is determined by absence of staining effect upon copper in the form of bright foil or strip at elevated temperatures[11].

(*d*) *Frothing.*

As already mentioned, excessive frothing of a turbine oil is disadvantageous amongst other reasons because of the increased opportunity it creates for oxidation. As a rule, oils which froth badly in use are either contaminated or else prepared from unsuitable stocks. With the modern discovery of effective anti-frothing agents, it is now not unusual to require an oil to meet a test in which the rate of subsidence of an artificially-produced foam is measured. Such a test[12] has been standardized by the Co-operative Research Council for other purposes, and has been found suitable for application to turbine oils. It is readily carried out with simple apparatus and the results have fair repeatability.

III. TURBINE OIL BEHAVIOUR.

The trend of modern propulsion design being towards higher steam pressures and temperatures, higher speeds, decreased size and increased rate of oil circulation, the duty imposed on turbine oil becomes continually more severe.

The authors' main thesis is therefore to see in what manner the oil "requirements" are met in practice and the lines on which specific properties are being improved.

Viscosity and Viscosity Index.

As far as viscosity and viscosity index are concerned, the variation of different oils in lubricating and cooling value is not marked. In the past there has been, in practice, a particularly wide range in V.I., as, for example, from the paraffinic Admiralty S.M.L.O. with V.I. of 100 to Gulf Coastal oils of naphthenic character which though fully refined and giving satisfactory results may have had V.I. well below 50. In between have been the majority of successful Mercantile Marine turbine oils in which the extreme characteristics of the foregoing types have been merged and their behaviour safeguarded by chosen methods of refining. The trend at present is towards oils of higher viscosity index, chiefly because of their chemical behaviour in relationship to their origin and their response to special components now being introduced and not because of inherent lubricating superiority.

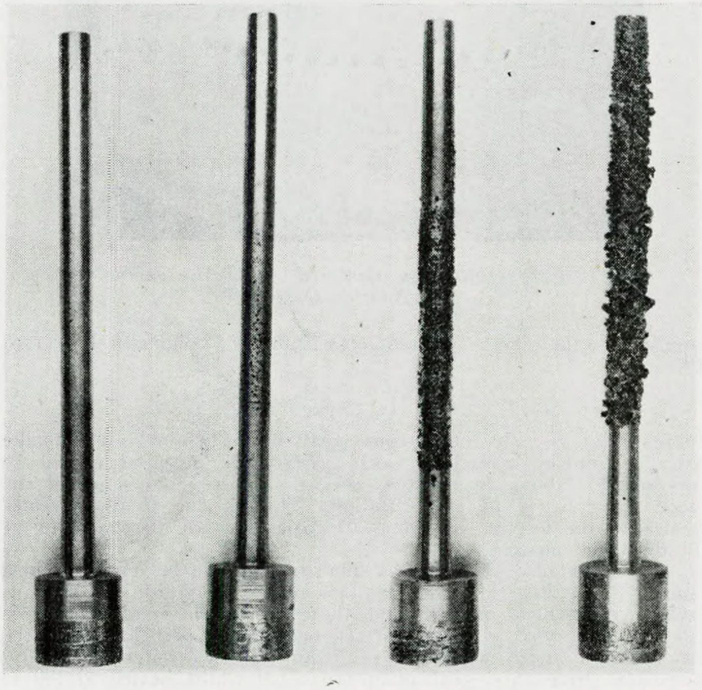

FIG. 5.—*Rust test specimens. Degrees of rusting obtained in oils with synthetic sea-water present.*

10. D, 665-44T.
11 I.P. Standard Method, 64/65.
12. C.R.C., L-12-445.

Resistance to Oxidation.

As will be already realized, resistance to oxidation is by far the most important characteristic of a turbine oil. In the past, the problem of deterioration from oxidation was dealt with by directing the unavoidable oxidation of the hydrocarbons of which the oil is composed into the most innocuous channels. In this connection it is as well to emphasize that the acidity of a used turbine oil, as measured by its neutralization value, may mean little unless the chemical nature of the oil is known. An N.V. which would rightly be looked upon with alarm in the case of a highly-refined paraffinic oil would be of little consequence in balanced blended oils or oils of naphthenic type. It is not possible, therefore, to answer the question frequently asked: "What is the maximum allowable acidity in a used turbine oil?" In the case of an over-refined oil of high paraffinicity, a desirable maximum for the N.V. may be as low as 0.2 or 0.3, whereas ten times that amount may be without adverse effect on a suitably-refined blended oil of medium V.I. The latter type of so-called "balanced" oils, are therefore highly esteemed.

The other, and growing, method of preventing dangerous deterioration is by the addition to the oils of inhibitors. These inhibitors are antoxidants of marked activity. They are frequently aromatic chemicals of the aminic, phenolic or disulphide type and are effective in quite small quantities—0.1 or 0.2 per cent., in preventing oxidation, even under difficult conditions of aeration, water intrusion, or metallic poisoning. They are, in fact, anticatalysts and probably act by breaking the peroxide chain-reaction previously referred to. They themselves are renewed continuously, and this is likely to occur by interaction of their own peroxidic form or combination with suitable chemicals present in the oil or formed in small quantities during use. These last-named materials, to which we suggest the name "co-inhibitor" might be given, are quite likely to be compounds of sulphur.

There are a number of conditions which must be safeguarded in the choice and use of inhibitors. In the first place, the stability of the mineral oil itself is of great importance. It has long been known that "white oils" respond readily to inhibitors, but that these oils by themselves are inherently unstable. Between such over-refined oils on one side and wholly unrefined oils on the other, there comes a wide range of stocks of varying susceptibility to oxidation and varying inhibitor response. Fig. 6 shows this clearly. It represents the artificial and accelerated oxidation of a number of oils under simulated field conditions to be described later. The white oil (*A*) shows a very short induction period and a very rapid rate of oxidation afterwards. The solvent refined light neutral (*B*), though having a shorter induction period than the light balanced blend (*C*), has the same rate of oxidation after the break. In the case of the heavier pair, which are more typical of marine turbine oils, the curves are approximately the same up to a neutralization value of 0.5 at which time they slowly diverge.

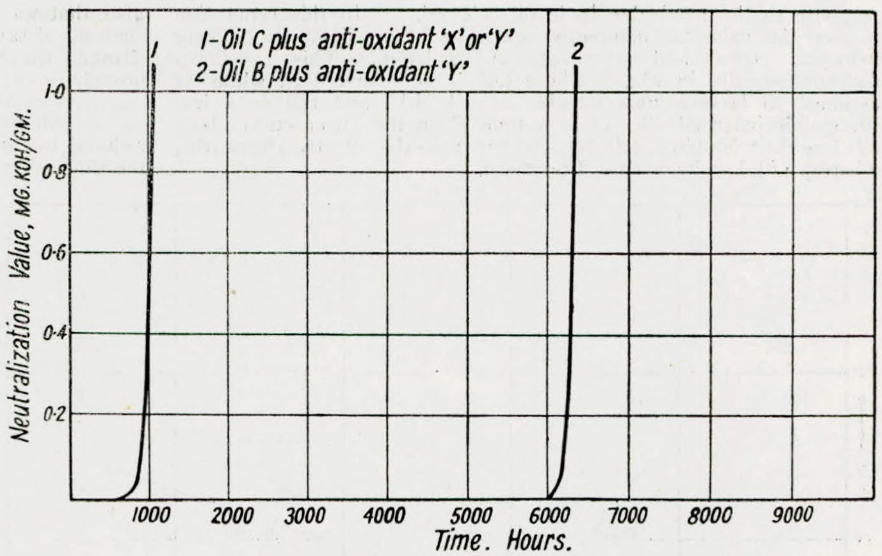

FIG. 7.—*S/V simulated turbine test.*

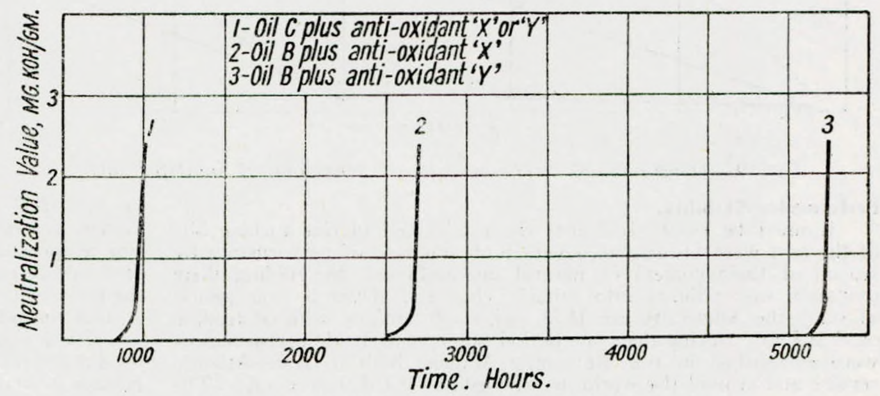

FIG. 8.—*A.S.T.M. turbine oil oxidation test.*

Inhibitor response varies markedly between different oils as also does the response of individual oils to different inhibitors. This is shown in Figs. 7 and 8, the former representing observations made in the simulated field test apparatus and the latter those made by the A.S.T.M. oxidation test. The similarity of the two sets of curves is striking and significant.

From these results it would appear to follow that inhibitors which are liable to destruction by heat or otherwise, or which may be removed from the oil by reason of their volatility, low solubility in hydrocarbons or solubility in water may be unsatisfactory in use. They may, indeed, be dangerous if the oils to which they are married are inherently unstable, since the rate of oxidation of the oil from which the inhibitor has disappeared is that of the original oil.

The requirements of the ideal turbine oil inhibitor thus appear to be (*1*) thermostability so that there is no reasonable upper temperature limit to its stability; (*2*) insolubility in water, so that it cannot be washed away; (*3*) ready solubility in oil so that it is not deposited when the oil is cold, or lost in the centrifuge or during cleaning; (*4*) response to all types of oils, if possible, but in any case maximum

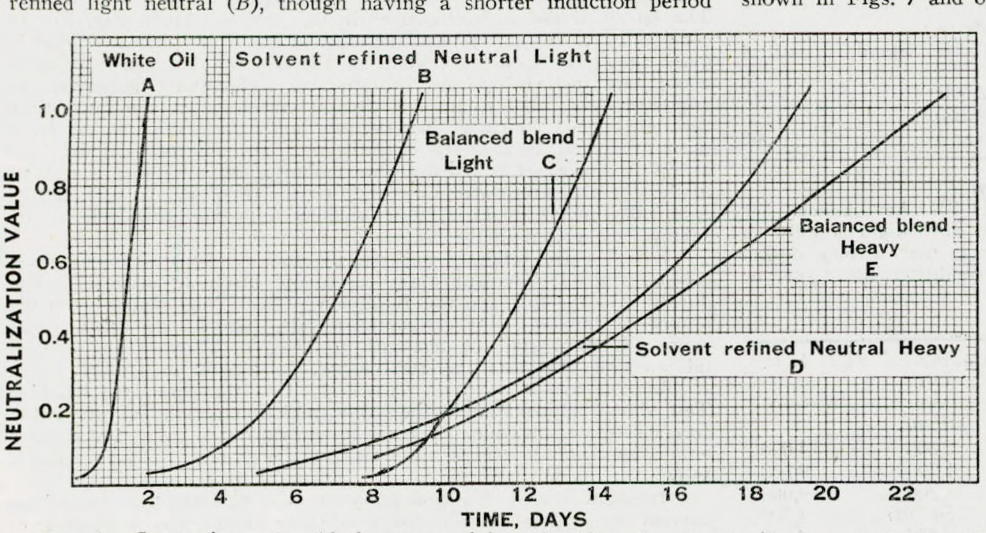

FIG. 6.—*Comparison of oxidation susceptivity of white oil, solvent-refined neutral oils and balanced blends.*

response to the particular basic oil selected. In this connection is seen the value of inherently resistance basic oil stocks of long induction period and slow rate of oxidation. This is shown diagrammatically in Fig. 9 where (*A*) is an over-refined white oil assumed to become unserviceable at 0.3 N.V. and (*B*) is a less susceptible balanced oil. If at a time *T* on the lower curves both oils lose their inhibitor, (*A*) becomes unserviceable shortly afterwards, whereas (*B*) has its normal life ahead.

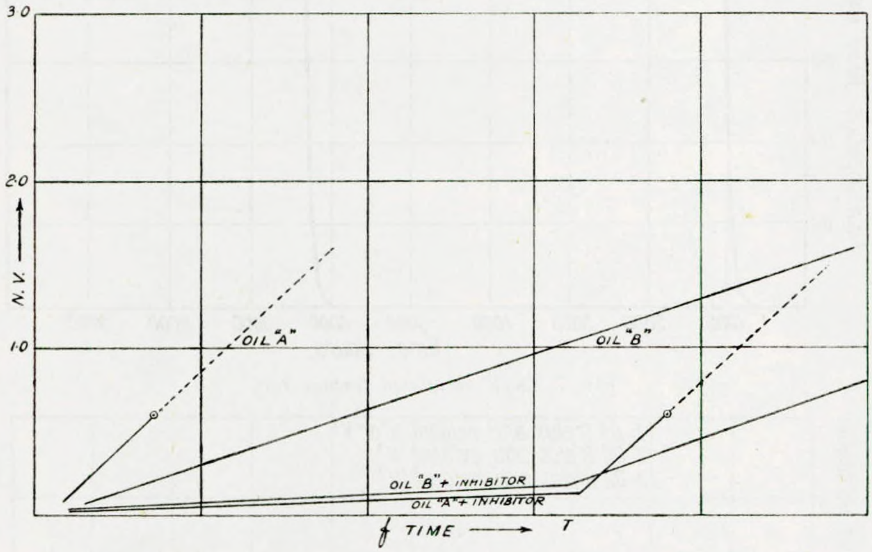

FIG. 9.—*Diagrammatic representation of behaviour of inhibited oils.*

Performance Stability.

It must be emphasized that the established marine turbine oils of the past were brought to a very high standard of performance by reason of their content of natural inhibitors and by guiding their oxidation susceptibility into suitable channels. Over a long period of years the Admiralty ran H.M. ships substantially without trouble on S.M.L.O. During the same period, some remarkable performances were established in the Mercantile Marine, both in trans-Atlantic service and around the world, using medium V.I. balanced oils. The interesting and diverse cases cited in Table II are typical of many which have been recorded.

TABLE II.

Vessel's Name.	System.	Oil in Circulation.	Maximum Temperature.	Milage	Viscosity	N.V.
		gallons	°*F.*	(*approx.*)		
Queen Mary	Forced	5,300	155/160	1,000,000	Standard	0.014
Mauretania	Gravity	—	120/130	1,990,015	,,	0.250
Guido	Gravity	500	130/135	462,000 (22 years)	,,	0.476
Gitano	Gravity	500	130/135	(23 years)	,,	0.306

Operating Conditions becoming more Onerous.

It may be asked after perusing Table II "Is there a need for inhibited oils at all?" It is a fair question and might loosely be answered in the negative. The true answer is that turbine design is becoming much more exigent and running conditions more severe; also, that war experience has shown the need for wider margins of operational safety. This is demonstrated by a review of the gradual changes which have been made in the conditions of lubrication brought about by the trends in design. Table III shows typical examples of installations built during the past 25 years.

TABLE III.

Vessel's Name.	System.	Amount of Oil.	H.P.
		gallons.	
Mahout	Gravity	2,000	4,000
City of Cape Town	Forced	1,700	9,700
City of Lincoln	Forced	1,200	9,000
Silverlaurel	Forced	750/980	4,500
Perim	Gravity	2,570	8,000
Empire Regent	Forced	720	6,800

It will be noted that the trend towards forced lubrication has reduced the amount of oil in circulation with consequent decrease in the time taken for the charge to circulate.

Earlier in the period referred to, conservatively-rated turbines were developing their power at speeds of 2,500/3,000 r.p.m. with transmission through single-reduction helical gearing. Just prior to the war, however, attention was being focussed on improving the efficiency of the H.P. turbine and this led to the introduction of working pressures of 450lb. per sq. in. with a total temperature at the first stage of the turbine of 750°F. This resulted in impulse H.P. turbines operating at some 5,000 r.p.m. and coupled through double-reduction gearing.

At the same time lubricating-oil systems were being modelled on naval practice and a cycle of lubrication of 2½ minutes was attained as compared with earlier practice of 15 minutes. To-day installations are coming into service similarly rated but with the added demand of double-reduction gearing throughout.

Conditions of lubrication will therefore be progressively much more arduous by reason of less oil in circulation, increased heat transfer due to higher thermal head, increased speeds of rotation which markedly influence aeration and, additionally, the increased thrashing the oil receives in a double-reduction geared train.

In this connection it is of interest to consider the effects of increased thermal head on the turbine. C. R. Soderberg[13] has stated that for steam temperatures up to 600°F. the transmitted and radiated heat losses to the oiling system are comparable with those of the frictional loss in the oil. For temperatures of 600°F. up to 750°F. the heat losses are doubled. It should be noted also that as steam temperatures and speeds increase, the turbine structure is made more rigid and the total length decreased so that the oil film is brought much nearer to the steam.

There is over and above all these requirements the mere matter of progression, for the inhibited oils have proved themselves to possess a stability outside the range of previously-known straight oils and as such they are to be commended and recommended.

Development of New Oils.

The development of new turbine lubricating oils along the lines indicated could not, of course, have been accomplished by test and trial in actual turbines, either land or marine. The need for an accelerated test procedure run under conditions corresponding in nature as closely as possible to those of reality, but so modified as to accentuate all effects, lead to the designing of the S-V Simulated Turbine Test[14] to which reference has already been made. The set-up of the apparatus used in this test is seen in Fig. 10. It consists of a vertical journal bearing mounted in such a way in a glass vessel containing six litres of the test oil that the bearing is about one inch below the oil surface. The shaft is driven at approximately 3,000 r.p.m. and the oil circulated at the same time through copper piping at 20 gals. per hour, the suction being from the bottom and the delivery near the bearing. The oil is maintained at 198°F. and water is added in the amount of 200 ml. daily. Catalysts in the form of iron wire exposing some 150 sq. in. of surface and Admiralty metal in 1½-in. tube sections approximating 300 sq. in. surface are placed in the bottom of the vessel.

Samples are removed periodically and examined for change in colour, viscosity, neutralization value and insoluble material. The duration of the test and the frequency of sampling depend upon the nature of the oil. For conventional oils, samples are taken about every 48 hours and the test run for two or three weeks. With inhibited oils the tests may run for several months to a year.

In comparison with the A.S.T.M. Test the Simulated Turbine Test shows approximately the same induction period but gives different rates of subsequent increase in neutralization value, and thereby emphasizes the differences in oxidation behaviour. This is clearly shown in Fig. 11.

In apparatus of this kind hundreds of long-term tests have been carried out, using a wide range of base stocks and a variety of

13. Inst. Mech. Eng., *General Discussion on Lubrication I*, 285, 1937.
14. Smith & Snyder, *Jl. Inst. Pet.*, 1946.

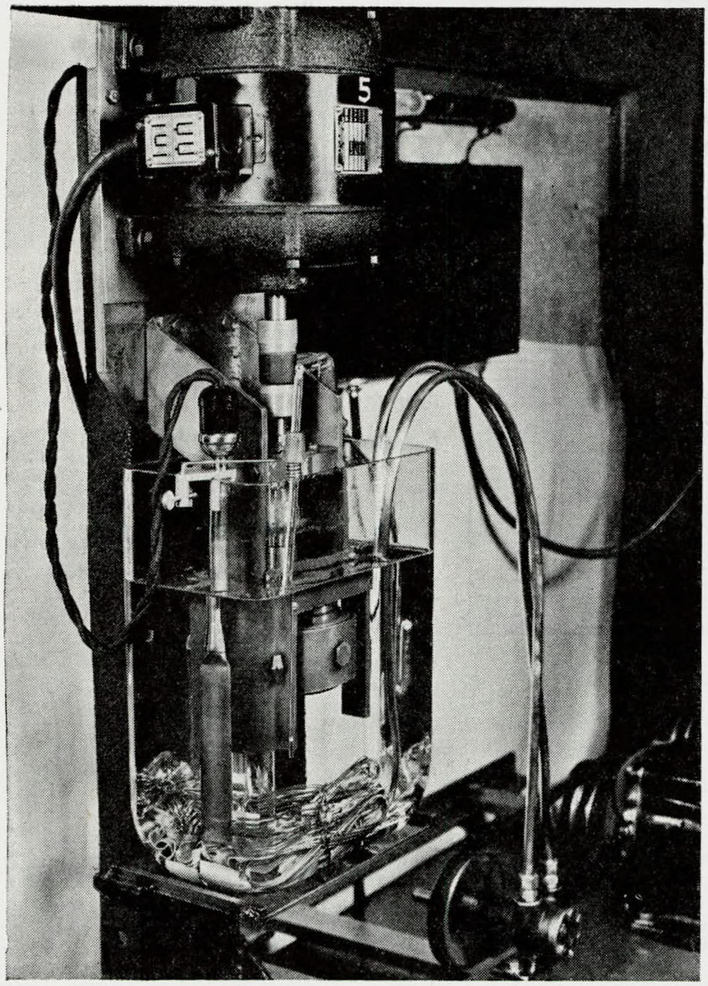

FIG. 10.—*S/V simulated turbine test.*

inhibitors. The most effective of the oils developed by this means, a light land turbine oil "X", has very high stability. In the Simulated Test it has shown over 6,000 hours as against the 300/400 hours for a heavy marine turbine oil of international reputation. Similarly, in A.S.T.M. Turbine Oxidation Tests, oil "X" has withstood 10,000 hours in comparison with the approximate 1,200 hours of corresponding standard grades. Fig. 12 brings out the comparison and shows the continued stability of the oil in the oxidation test after some 8,000 hours' service in the field.

The striking effect of this oil in a notoriously bad land installation, where conditions are so unfavourable that no previous oil had been in for much over 5,000 hours, is illustrated in Fig. 13.

To date, oil "X" has been in service in turbine No. 1 over 24,000 hours without showing any evidence of oxidation, or nearly five times the service life of the previous oil. Its further anticipated life cannot be calculated, for the data expressed in the curves of Figs. 11 and 12 seem to indicate that the A.S.T.M. test is likely to be of little value in making such predictions. None of the many cases of the use of the oils of this series in land and marine turbines has been of sufficiently long service to give an indication of the total life to be expected.

It should be noted that in the cases quoted, both in actual turbines and in the Simulated Turbine Test there has been no replacement of inhibitor and in the Simulated and A.S.T.M. tests no make-up of oil.

Rust Prevention.

Serious trouble from rusting is fortunately not unduly frequent in turbine systems despite the fact that rusting itself may be prevalent. Rust is most often confined to housings, the upper parts of tanks and horizontal pipe work, and indeed to all places not readily protected by the circulating oil. In such cases the ill-effects of the rust are generally secondary and consist (*a*) of its catalytic action in promoting oxidation of the oil, and (*b*) of stabilizing such emulsions as may have been formed.

There is always the possibility of intrusion of water into a turbine-lubricating system from condensation, leaky steam glands, leaky oil coolers, and so on, and every now and again real rust trouble supervenes on main shafting, gears or control mechanism. In marine turbines the effects may be intensified by the presence of salt in the water.

Ventilation.

Rusting does not take place without water being present, and the first thing is to ensure that steps are taken for its exclusion. Leaky glands are a major source of water contamination and must be given every attention. Pending their re-adjustment it should be possible to keep such water accumulations in check by systematic centrifuging and maximum ventilation.

Condensation is another fruitful source of water, and it must be remembered that the higher the temperature the more completely charged with water the air in the system will be and the more water will be condensed in the cooler parts. Gear housings are a particularly vulnerable region, and water charged with iron hydroxide dripping back from them into the gears may start serious trouble there or elsewhere.

The importance of ventilation cannot be over-emphasized. Not only does efficient venting remove moisture, together with volatile acidic degradation products of the oil, but by replacing the moist air with drier air it encourages the evaporation of further water from the oil. Tanks and gear housings especially should be ventilated and also, as far as possible, individual bearing housings and other dead spaces where moisture-laden air may be trapped.

Exhausters may be advantageously employed to aid ventilation, but the best type of venting is that which takes air from the system by suction, de-humidifies it through coolers and returns it dry. A diagrammatic layout of such an enclosed system connected with the oil tank is shown in Fig. 14.

Wherever possible, a complete suction system should be installed involving pipe-work bringing in all high spots previously vented to atmosphere. If this is not done such ventilators should be capped.

There are a number of contributory conditions which may encourage rusting. Experience during the war showed that fabricated covers were much more prone to rust than castings. Moreover, they were generally fitted snug with no opportunity of condensed moisture draining direct to the oil and away.

Salt-water and acidic oxidation products have already been referred to. Stray electrical currents are also dangerous. They may encourage electrolysis in wet systems, especially if the water contains appreciable quantities of electrolytes in the form of salt or acidic organic material.

Two bad cases of rusting in marine turbines may be cited as of interest. The first is that described by J. I. Hill[15] and deals with the turbines of an L.N.E.R. cross-channel boat. The other is that of one of H.M. American-built destroyers. In both instances the chief contributory factor was the intrusion of salt-water and when such leakage was remedied and the system cleaned the trouble ceased. The incidence of rusting in these cases of widely different origin was remarkably similar. Heavy rusting occurred on the shaft, particularly on or adjacent to the main bearing journals, and on gears and pinions. In addition there were heavy deposits on the shafts derived from iron oxide suspended in the oil. In the destroyer,

15. Auld and Lawrie, *loc. cit.* Discussion.

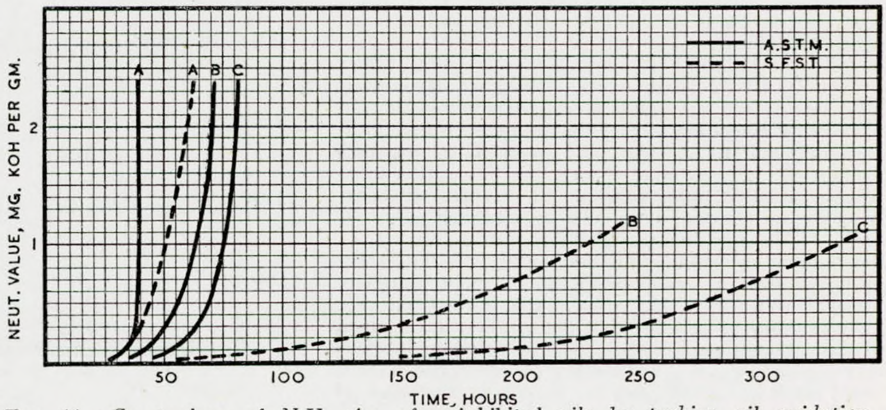

FIG. 11.—*Comparison of N.V. rise of uninhibited oils by turbine oil oxidation test (A.S.T.M.) and S/V simulated turbine test (S.F.S.T.).*

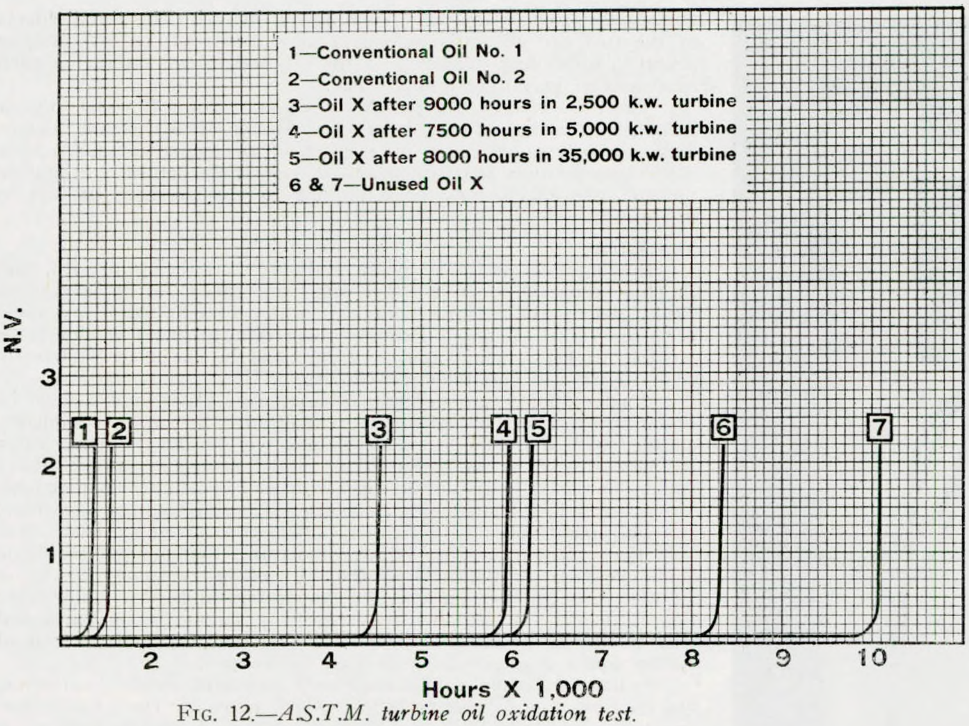

FIG. 12.—*A.S.T.M. turbine oil oxidation test.*

at any rate, these were chiefly derived from the cast-iron oil sumps. In the case of the packet, tests for electrical leakage were negative, but in the destroyer there was some evidence that leakage of direct current was taking place and was accentuating the rusting and corrosion. It must be remembered in this connection also that electrical stresses affect the oxidation of the oil. This was shown by Anderson for transformer oils[16] and has been confirmed by ourselves.

Although these cases were by no means unique, rusting trouble was not often met in H.M. ships. The whole situation is always liable to be dangerous, however, and calls for considerable vigilance. A sister ship of the destroyer mentioned, which was also leaking salt-water into the turbine system, was undoubtedly saved from trouble by the chief engineer keeping turbine and gearing turning by the turning gear during all periods when the vessel was not under way with full oil circulation. In the American Navy, for a variety of reasons, rusting trouble appears to have been much more frequent than in H.M. ships, and it was such experience which resulted in a call for treatment of the oil to aid in rust prevention.

Rust Inhibitors.

This position of calling for protection from the oil has since been widely adopted and both builders and operators are now demanding rust-inhibited oils. Such trend is probably more marked because of the increasing and widespread use of antoxidants which, it should be realized, prevent the formation of early oxidation products which under certain conditions act as rust inhibitors.

Rust inhibitors are surface-active agents which prevent rust formation by being preferentially adsorbed by the vulnerable metal surface and thereby preventing direct contact of the water with metal. It is not difficult to provide polar materials having such properties. The trouble is that the adsorption mentioned can also take place at the surface of water droplets in contact with oils so inhibited and this tends to destroy the demulsibility characteristics of the mineral oil stock. Surface activity to the extent required must be combined with sufficient inactivity towards water as would cause water-in-oil emulsions.

It is thus to be noted that the action of mechanism of rust preventives is closely akin to boundary lubrication conditions, and is not merely an interfacial tension effect seeking in that way to induce preferential oil wetting of the metallic surfaces.

Highly effective rust preventives have been designed having only minimum effect on the resistance of oils to emulsification. They are purely synthetic products of particular molecular structure and size and are referred to below in connection with demulsibility.

Notwithstanding the protection afforded by these new materials, it should be realized that water obtaining access to the system and freely circulated with the lubricant will be driven off in the form of vapour at the higher temperatures attained at the oil film. The importance of ventilation is therefore a factor which must again be emphasized and should engage the attention of all concerned in the design and operation of modern turbine machinery.

Demulsification.

As already indicated, the two chief dangers arising from the formation of emulsions in turbine lubricating-oil systems are (*a*) the building up of oil-in-water emulsions which do not lubricate properly, and (*b*) the formation of emulsions of either type which are so viscous as to interfere with circulation. Although severe emulsification trouble is not unknown in industrial turbine operation, it is of interest, again, to be able to take an outstanding instance of each kind from marine wartime experience.

The first case was one of the contamination of approximately 500 gals. of oil in circulation in one of H.M. destroyers by some 10 gals. of fatty drying oil, probably linseed. Analysis showed the turbine oil to have a saponification value of over 8.0 whilst its neutralization value was only 0.028. The whole charge was emulsified and sludged badly. Shellac-like deposits of treacly consistency were observed on gears and rotor bearings. Bearing wear was such that the shafts were resting on the gunmetal strips of the shells, and the journals were black. Severe wear also occurred in the circulating pumps and control gear, and indeed wherever the oil was in use as a lubricant. The ship was fortunate in not being called to action and in being able to make port.

The other instance was also that of a destroyer in which the oil suddenly emulsified so badly as to become unpumpable. The ship had to be stopped, but was eventually brought into port at slow speed after successive removal of suction and discharge filters to allow the buttery emulsion to be moved around. In this case bearings

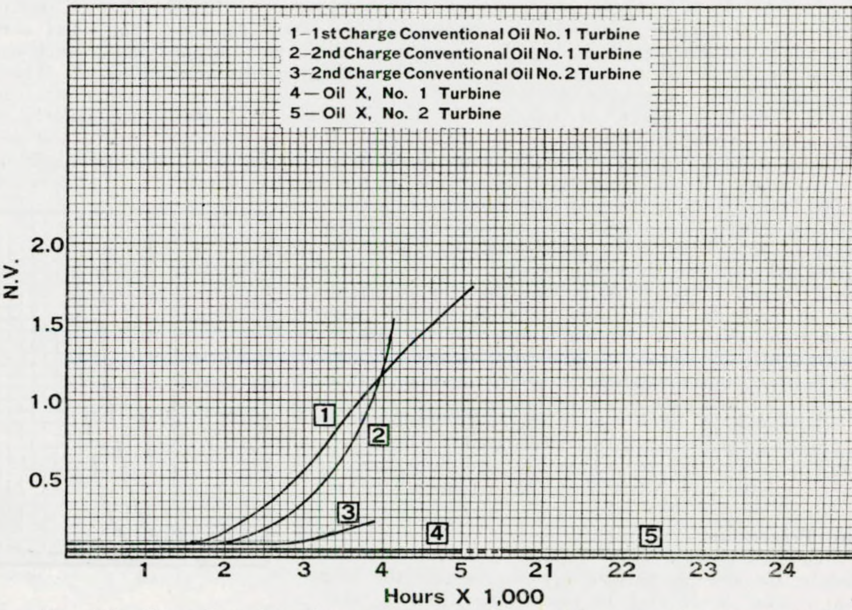

FIG. 13.—*Operating data for a difficult turbine with conventional and inhibitor-treated oils.*

16. *A.S.E.A., Journal*, 6, 137. 1929

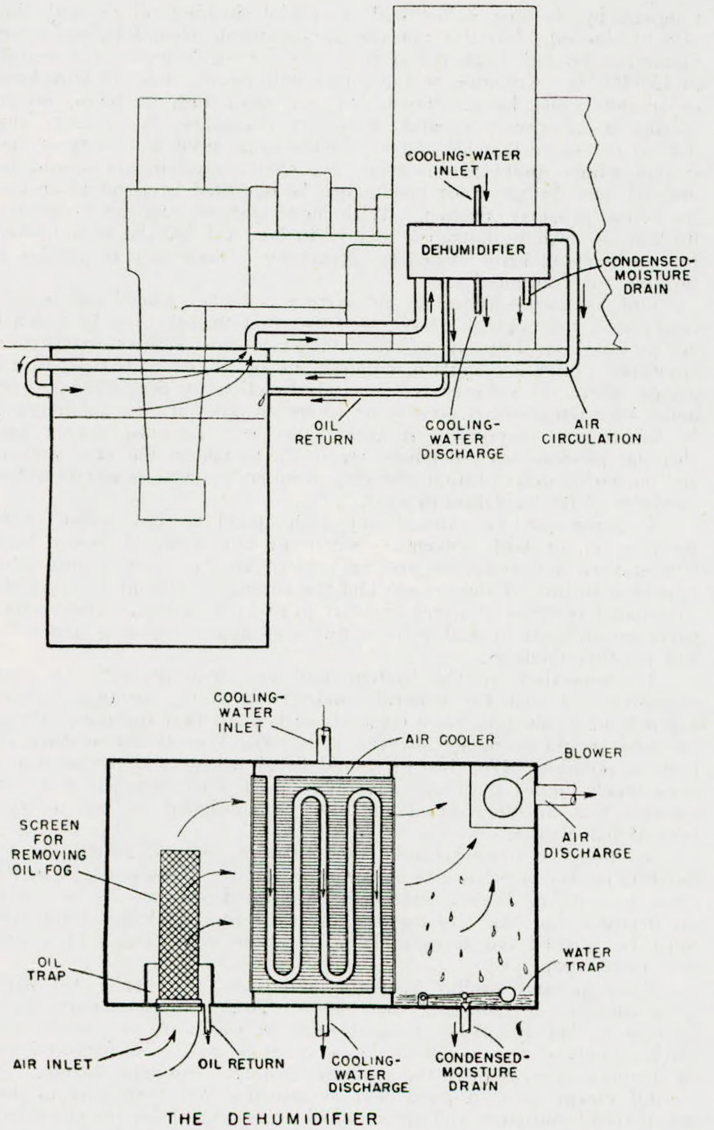

FIG. 14.—*Dehumidifier method for ventilating turbine oil systems.*

and journals were in good condition except for sludgy deposits, and no trouble was experienced with the lubricating oil pumps. It may be concluded, therefore, that the emulsion was of the water-in-oil type.

The cause of this emulsification was introduction in substantial quantities in a foreign port of a kind of oil different from S.M.L.O. The new oil in itself was quite suitable, but when introduced into the system loosened the accumulated deposits of past years. These caused the emulsification before they could be dealt with. The occurrence, however, draws attention to two matters which are not in general sufficiently appreciated. The first is the need for special care when, by force of circumstances, a different oil has to be used for topping up, especially in large quantities. The second is the need for periodical thorough cleaning of the system to remove old deposits. Both of these matters will be referred to later on. They are of particular importance in marine lubrication because of the suddenness with which emulsifying conditions can supervene.

Modern methods of refining have resulted in production of turbine oils of a high standard of demulsibility. The demulsification number of unused oil in the past was rarely over 120″, even for heavy marine turbine oils. With the advent of rust-inhibitor-treated oils, figures are likely to become higher for the reasons previously given.

In the interpretation of steam emulsification behaviour it may be desirable in the case of inhibited oils to increase the demulsification number requirements by 50 or 100 per cent. Some experimental results quoted in Table IV for different rust preventives show this need not always be the case however, and that it may be possible in the future to develop inhibitors having no adverse effect upon water separation.

TABLE IV.

	Base Oil.	Oil E.		Experimental Oil D.		
Oxidation inhibitor	None	No. 1	No. 1	None	No. 2	No. 2
Rust inhibitor	None	No. 1a	No. 1a	None	No. 2a	No. 2b
Demulsifier	None	None	Yes	None	None	None
Demulsification number	90	225	69	90	190	220

IV. TURBINE OIL SPECIFICATIONS.

Specifications are, in effect, minimum requirements, and as such are unsatisfactory guides to choice of products. This is particularly the case with lubricating oils whose intricacies of behaviour it is not possible to represent by simulative or arbitrary tests. This is seen from the complexity of modern Service oil specifications, most of which include detailed engine or machine tests. Turbine oils are perhaps more adaptable to specification than many others, for their lubricating value as such is not the requirement of greatest importance.

Based upon the current knowledge which has been described in Sections II and III, it is possible tentatively to indicate the lines on which turbine oil specifications might be laid down. These are shown in Table V.

TABLE V.

Property.	*Requirement.*	*Comment.*
Source, or method of refining	No restriction	Oil may be of any type and either conventionally or solvent refined.
Specific gravity	No restriction	To be quoted as indicative of nature of oil.
Flash point	Arbitrary	To be high enough to ensure freedom from volatile products.
Viscosity	Arbitrary	B.S.I. classification may be used[17].
Viscosity index	Not under 50	This tends to ensure stability of the base oil, but does not imply that oils of lower V.I. are necessarily unstable.
Demulsibility (unused oil)	Arbitrary	To indicate absence from contamination. Steam emulsion to be used.
Demulsibility (used oil)	To pass	Test to be elaborated.
Pour Point	25°F. max.	I.P. 15/42.
Oxidation inhibitor	To be present	
Oxidation test	To pass	Test to be prescribed.
Corrosion test	To pass	Test to be prescribed. (For marine specifications salt-water to be used.)
Foam inhibitor	May be present	
Foaming test	To pass	Test to be prescribed.
Sulphur content	No restriction	
Active sulphur	Copper strip test	I.P. 64/45.

V. CONDITIONS OF OPERATION.

Handling of Turbine Oil.

Insufficient attention is frequently paid to the storage and handling of turbine oils. Enough has been said to indicate how adventitious contamination, as, for example, with other oils, can endanger the whole set. According to Mr. P. Low as little as one part of an H.D. (heavy duty) Diesel oil in 40,000 of a turbine oil will impair the latter's ability to separate from water[18]. In refineries and oil-storage installations, therefore, turbine oils are handled with great respect. After a final treatment with activated earth to ensure stability, such oils are stored separately and dealt with in separate pumps and pipe lines. Similar precautions should be taken by the user.

At present it is common ships' practice to handle all oil stores through a single deck line, and the fact that this has caused little trouble speaks well for the care which has been exercised by

17. B.S.S., 489, 1933.
18. Personal communication.

engine-room staff. With much more specialized materials coming into use, however, the existing procedure becomes more dangerous. For example, it is reasonable to expect that in all modern tonnage a place will be found for a high-performance Diesel generator. This is the very type of equipment likely to use the H.D. oils just mentioned. It is clear that if the special characteristics and performance of modern turbine oils are to be unimpaired, provision must be made for separate piping arrangements whereby they can be passed to their respective storage tanks direct.

Such arrangements would be greatly facilitated if bulk fittings were standardized. At present there is a great deal of unnecessary complication from the multitude of different fittings in use. It is suggested that all builders agree to adopt a 2½-in. gas male fitting as standard. This should cater for all requirements and would promote rapid and straightforward handling.

In general, a plea must be entered with builders to give more attention than in the past to arranging oil-storage facilities aboard ship.

Lubricating Oil Fires.

Fires due to lubricating oil are not as infrequent as may be thought. Many authenticated cases are known and far more may have been overlooked because of the apparent unlikelihood of heavy oil being the cause. In view of the high steam temperatures which may be encountered in modern turbine practice, it may be valuable to indicate the probable mechanism of serious lubricating-oil fires which have arisen in turbine installations—land and marine.

The temperature at which an oil will ignite when in contact with flame, electric spark, etc. is its "fire point" which, in the case of turbine oils, is of the order of 450°F. The temperature at which the oil will burst into flame without the application of a spark or other source of high temperature is its "spontaneous ignition temperature" (S.I.T.). This for turbine oils is around 750°F. The temperature at which heavy petroleum oils begin to decompose is the "cracking temperature" and for turbine oils starts to be appreciable around 650°F. During "cracking" the oil is transformed into volatile products, including gas, and at the same time leaves a carbonaceous residue. The volatile products of cracking have fire points below atmospheric temperature.

Danger of ignition of lubricating oil in the open can therefore only arise when conditions are such as to raise its temperature above 450°F. Such a temperature might gradually develop if the cooling water failed, but the occurrence would have been apparent long before that from lubrication and bearing breakdown.

A normal source of high temperature in the immediate vicinity of the turbine is the steam line, and this may be carrying steam at 750°F. or over. As oil may seep from a cracked pipe or a leaky joint and come in contact with the steam pipes, the danger is apparent of its approaching or actually reaching the S.I.T. It may be regarded as doubtful, however, whether direct spontaneous ignition will take place. Under ordinary conditions, in a ship or power station, the presence of air currents greatly increases the amount of heat needed to effect the necessary rapid rise in temperature of the oil.

What is more likely to happen, and much less easy to observe, is oil from a slight leak coming in contact with the hot surface and undergoing "cracking" with the production of inflammable vapours and leaving a deposit of carbon on the surface of the pipe. Such conditions are liable to result in fire either from contact with a light, a short circuit or spontaneously. As regards the last-named, the carbon residue is an ideal surface for increasing the rate of pre-flame oxidation which may culminate in ignition of the vapours. The carbon itself, also has a very low S.I.T.

It is clear that proximity of high-temperature steam pipes to oil lines or storage is a potential danger of fire. The answer is correct insulation. Steam lines must be lagged in such a way that no bare metal is exposed throughout their length. Any flanges must be well boxed and the depth of lagging sufficient to bring the outside temperature below the fire point of the oil. In order to prevent oil soaking into the lagging and reproducing the conditions outlined, the insulation should be made impervious to oil so that none can reach the high temperature layers beneath. This can be effected by covering with a canvas jacket which is painted with fire-proof or, at any rate, oil-proof paint.

Cleaning Turbine Oil Systems.

New Systems.—When a new fill-up of oil is being supplied it is important that the lubrication system be thoroughly cleaned out.

New turbines are usually well cleaned by the manufacturers, a number of whom finish off by coating the surfaces with oil-resistant lacquers. Subsequent contamination of an insoluble nature is generally either abrasive or fibrous in nature and can readily be removed by flushing either with a special flushing oil or with the new turbine oil. For this purpose arrangements should be made for maximum flow through the system, and the oil is preferably heated to 150-160°F. Attention to the filters will clearly indicate how long circulation must be continued, but for most new turbines, either marine installations or land, it is not necessary to circulate the hot oil for more than 24 hours. At the same time any parts of the system which might act as traps for solid contaminants should be drained, and the governor mechanism be operated by hand to ensure its being properly flushed. With new systems the oil used for flushing is seldom damaged, and if turbine oil has been employed for the purpose little subsequent treatment is necessary to render it suitable for continued use.

Old Systems.—When an old system is to be cleaned out before receiving a new charge of oil, it is essential that the job be carried out thoroughly. Deposits of old oxidized oil must be given particular attention. They accumulate, either alone or mixed with rust, in all places where oil velocity is low and direction of flow changes, or under high temperature conditions where oil pipes are not submerged. If left behind, especially if they have been loosened during the cleaning process, such deposits are liable to poison the new charge and hasten its deterioration, for they frequently act as powerful auto-catalysts of the oxidation process.

Cleaning can be carried out with steam or hot water, with flushing oil, or with solvents. Steam or hot water at boiler feed temperature and pressure are very effective, but they require the near-dismantling of the system and the paying of special attention to subsequent removal of water in order to prevent rusting. Inaccessible parts are difficult to deal with in this way and recourse is generally had to other methods.

If inspection of the system indicates that deposits are not excessive and that the general condition is good, cleaning is best carried out by flushing with oil as described for new turbines. What can and should be done, however, is to raise the oil temperature as high as possible. 170°-180°F. should be aimed at, and temperatures even much higher than this have been used with success. For old systems the flushing oil should not be continued in use as the operational charge.

If there is considerable contamination and accumulation of deposits it may be necessary to resort to the use of solvents. Caustic soda and other alkaline detergents are good solvents of oxidized oil deposits, but they themselves are dangerous if left behind and must be washed out thoroughly with water after use. They are now rarely employed.

Creosote and similar aromatic materials have been used with some success for removing hard deposit from individual parts such as coolers, but for these accessible places steam or hot water are often equally effective. In any case creosote has to be followed up by flushing oil to remove the aromatic material from the system.

Of recent years a good deal of attention has been paid to the use of trichlorethylene and other chlorinated solvents for the cleansing of turbine oil systems. They can be used either in the liquid or the vapour form, and procedure for their application has been worked out on the basis that the operation is effected on site and with minimum loss of the expensive solvent.

Trichlorethylene is an excellent solvent for oxidized oil deposits and "varnishes". It is also very searching and can reach parts of turbine oil systems which might be difficult to approach by any other method. It must, however, be used with circumspection and under specialist control. Its chief danger from the point of view of the turbine is that its highly penetrative effect may soften or loosen, without removing, hard products which might otherwise be harmless, but which ultimately discharge into and poison the new oil. Chlorinated solvents must therefore be used thoroughly or not at all. Their vapours are, of course, non-inflammable, but are potent anæsthetics and must be guarded against in use.

Many other solvents have been proposed as turbine oil system cleansers, but the method most likely to come into use is the development of fluids of greater solvency than the ordinary petroleum flushing or turbine oils but which can be retained in the system for extended periods without adversely affecting the stability of the main lubricating-oil charge. Fluids of this kind now available have given excellent cleaning service, but have not yet been developed to the stage where they can be left indefinitely in the system.

Preparatory to cleaning, either by flushing or by solvent, all oil lines to gears, turbines or generators should be blanked off so that the fluid flows through sumps, pipe-lines, tanks, etc., but not through the lubricated parts. This eliminates the possibility of loosened deposit finding its way into bearings, governors or spray nozzles.

When using straight flushing oil, or an oil containing solventimprover, temperature should be as high as can be attained, for the reason that this greatly increases the oil's dissolving power and at the same time expands the metal and loosens the deposit. Circulation should be intermittent. Actual time involved will depend on the condition of the system, but a procedure which has much to commend it is to circulate the hot oil for one hour, then stop for an hour; circulate for two hours, then stop for half-an-hour; finally circulate till clean. This may possibly be completed within 48 hours.

Compatibility of Oils.

It is advisable in general not to mix lubricating oils of different origin in use, and this is of particular importance in topping up turbine oils. Oil from a different source may have a highly adverse effect upon a partially-oxidized used oil. This is especially so when a highly-paraffinic oil is added to a naphthenic one, since in that case precipitation of dissolved oxidation products may take place and serious sludging initiated. This is due to the lower solvent power of the paraffinic oil, and the reverse case is not so likely to be dangerous. It must be observed, however, that addition of too much naphthenic oil may loosen deposits previously firmly held on pipe-work, coolers and tanks and thus cause sludging and emulsification indirectly.

The ban on mixing does not equally apply to new oil, but it is nevertheless bad practice to mix oils, since mixing masks their individual characteristics and makes it difficult to follow the course of the oxidation changes which may occur. Compatibility in this respect is of particular importance in connection with inhibitor-treated oils. Different additives if present in the same oil must be compatible under all normal conditions of use. They must not by reason of chemical interaction cause deposits or the formation of metal soaps or result in metallic corrosion. Mixing of turbine oils containing unknown inhibitors is therefore especially to be deprecated.

In general, topping up should be limited to a maximum of ten per cent. of the charge at a time. With greater quantities of new oil, even from the same source, precipitation or some other disturbance of the oil-equilibrium may be caused and progressive deterioration of the charge thereby hastened.

Oil Temperatures.

The major purpose of the lubricating oil is the removal of heat which has resulted chiefly from frictional temperature rise in gears and bearings and heat conducted along rotor shafts. The oil, as we have seen, however, is susceptible to heat and it is to be noted that the chemical changes involved in its oxidation are doubled in velocity for each rise of 18°F. It is essential, therefore, that temperatures be controlled, and this may largely be effected by having an adequate quantity of oil in circulation. For marine turbines this may be suggested as 1 gallon per 2-3 s.h.p., depending upon the size of the power unit. For land installations a corresponding approximate guide is 1 gallon of oil per 15 kW. capacity. With sufficient oil in circulation, also, there is opportunity to get rid of the entrained air and so to minimize the adverse effects of aeration and frothing. This applies also to the quantity of oil going to the bearing, which is usually determined empirically from formulæ based upon bearing dimensions and speed. Factors are also applied to cover vibration, so that the quantity of oil must be greatly in excess of the theoretical minimum.

With the foregoing provisos, it may be said that the oil temperatures to be aimed at are a matter of choice within limits set by the conditions of operation. In this connection it is well to remember that should there be a tendency towards emulsification, a somewhat higher temperature may be advisable. Entrainment of water and emulsification take place more readily at low temperatures than at high, and turbidity due to slight water-in-oil emulsification is most likely to happen from wisps of h.p. steam leaking into a colder rather than a warmer oil. It is also to be borne in mind that too great an oil temperature drop within the coolers may result, in the case of used lubricating oil, in deposition of material from solution and the formation of sludges.

In general terms, it may be taken that a normal bearing return temperature at the oil outlet is of the order of 140°F., but this, of course, does not represent the temperature across the oil wedge, which is much higher and in a certain instance for corresponding outlet conditions was determined experimentally to be around 360°F. Alteration in the bearing return temperature resulted in correspondingly modified lubricating-film temperature. L. M. Douglas[14] refers to temperatures of 230/240°F. being measured at the face of pivoted thrust pads with pressures of 600 lb. per sq. in. and rubbing speed of 140 ft. per second. All such figures must be largely dependent upon the clearances as well as other factors, so that their meaning is still largely conjectural. Their importance to turbine oil behaviour is obvious, however, and detailed information on the temperature ranges to be expected should be sought.

Treatment of Used Oil.

Centrifuging.—Centrifugal separators are now standard ancillary equipment to both marine and land turbine installations. Their use for removal of water and solid deposits is well known. The nature and quantity of the solids removed should be closely investigated and this should largely determine the length of time during which the centrifuge is kept in use. The extent to which these deposits are composed of metals and metallic compounds has been drawn attention to elsewhere[19]. The catalytic effect of such substances on oxidation is high, and it is not possible to exaggerate the importance of their removal, or better still their avoidance. The carbonaceous materials also merit special examination, though their quantitative importance is often exaggerated in the earlier stages of oil deterioration. This is particularly the case with inhibited oils which give little or no deposit and where the organic material which collects is largely adventitious. Separation of the oxidized material is best effected with the oil as cool as is compatible with efficient handling. The reason is that the majority of the organic degradation products are more soluble in hot oil.

Water, on the other hand, is best separated at the higher temperatures which facilitates demulsification. Space, time and conditions of operation seldom permit successive centrifuging at different temperatures, and the greatest possible use must therefore be made of settling tanks. It follows also that in a dry turbine the centrifuging temperature of the oil should be kept low, whereas in one requiring appreciable separation of water, a temperature of 150/160°F. or over can be maintained with advantage, especially with heavier oils.

The oil suppliers should be consulted as to choice of temperature. They should also advise the specific gravity of the oil to enable the specific gravity disc or similar centrifuge fitment to be selected. This is important if churning of oil and water is to be avoided.

Centrifuging should not be carried out unnecessarily. If the quantity of suspended matter and water are low, the centrifuge should only be used intermittently. This is because the additional churning and aeration which the centrifuging process imposes upon the oil, combined with the higher temperatures liable to be used, may appreciably aggravate deterioration from oxidation.

Difference of opinion exists regarding the value of water-washing in the centrifuge. The facts are that water-washing can only be of value (*a*) if there is anything to wash out, *i.e.* material soluble in water; and (*b*) if the washing is properly applied. Water-washing may be of value in those cases where paraffinic type oils have given rise to corrosive acidic oxidation, and where by reason of water intrusion or poor venting the volatile acids so formed have been retained in the system. The same thing may apply less frequently to balanced oils whose oxidation has been strongly catalysed by contaminants; and also to certain inhibited oils from which the inhibitor may have been used up. Rise in neutralization value can sometimes be kept well in check by washing in the centrifuge, but it is important that sufficient water be employed and that it has the maximum opportunity to contact the oil. Washing must be from the bottom upwards. If these precautions are not observed and the oil is very acid, corrosion of the bowl may occur with consequent introduction of further catalytic metallic compounds into the oil stream.

Water-washing is naturally contra-indicated with inhibited oils containing inhibitor which is soluble in water.

Earth Treatment.—The refining of turbine oils is almost invariably completed by a treatment with activated clay followed by filter pressing. This improves stability, demulsification and colour. The same method is frequently applied to the correction and recovery of used oils and attempts have been made, without much success, to develop a procedure for use on the oil whilst in circulation. Treatment of used oil with earth results in the removal by adsorption of some of the oxidation products chiefly those of higher molecular weight. By this means it is frequently possible to reduce the N.V. of the used oil to a quarter or less. It is possible by certain alkaline treatment to reduce the acidity still further, but the soaps thus formed by chemical interaction are likely to be soluble in the oil and not readily removable. Treatment with alkali of any kind is therefore to be deprecated.

Recovered oils generally deteriorate more quickly than new oils, unless the treatment is, in effect, a complete re-refining.

Inoculation with Inhibitor.—It has already been pointed out that despite the existence or formation of "co-inhibitors" which largely protect the inhibitor itself from being oxidized, the oil-content of

19. Auld & Nicholson, Inst. Mech. Eng. *General Discussion on Lubrication, I,* 389, 1937.

antoxidant may gradually be lost or destroyed. Measurement of the amount of active inhibitor remaining in the oil is not always a simple matter, nor is re-inoculation invariably effective. The response of used oil to inhibitor varies amongst oils and amongst inhibitors. The nature, behaviour and past history of both must therefore be known before re-inoculation is attempted. In the majority of cases deterioration once it sets in is very rapid and quickly passes beyond the point at which the oil will still respond. This is another reason why the choice of the original oil stocks is so important, and why those having natural resistance to oxidation should be employed. Re-inoculation if carried out is done *in situ*, the circulation of the oil serving to dissolve and distribute the inhibitors throughout the system.

VI. GENERAL CONSIDERATIONS OF DESIGN.

The collaboration of petroleum technologists with design and research engineers has invariably been close and has resulted in a clearer view of the problems mutually requiring solution. This is particularly true in respect of lubrication, but we do not hesitate to suggest that the present paper indicates that the oil industry has anticipated the needs of turbine builders in producing oils of greatly improved resistance to deterioration. It is appropriate, therefore, that the designers should in their turn endeavour to ameliorate the working conditions of the oil, so as to ensure that, with the mechanical advances which may be expected, the length of oil life now achieved will be maintained. Apart from contamination, oil life is determined by oxidation which in practice is a resultant of aeration and heat and so can be expressed $L = fA{\cdot}H$. Intensification of either factor consequently governs oil life.

Taking this as a basis it may be suggested, for example, that more attention be paid to rotor bearing design and clearances as affecting skin temperatures and the temperature of the oil between journal and lining. This is probably the stage at which most damage to the oil is done and work of recent years on bearing losses is clearly indicative of this fact[20]. Anything in design which can assist oil escape after performing its true lubrication function is of importance. In this connection, length diameter ratios in particular may need closer delimiting. Similarly, with transmitted heat, the trend towards much higher steam temperatures intensifies the effects of decreased distance between the H.P. gland and bearing. This should be taken into account in its relationship to oil susceptivity as, also, the more direct influence of the high-temperature steam for gland sealing. Steam for the latter purpose might be expected with considerable benefit to be drawn from the saturated line.

As regards the aeration factor, the principal cause of air entrainment is particulation and churning of the oil by the gears and bearings. It has been suggested that it does not seem possible substantially to reduce this action by variation in design[21]. Nevertheless, it may be hoped to minimize the effect in this way or that advantage may ultimately accrue from separate lubrication systems with attendant wider field of choice of gear oil and consequently reduced aeration of the main circulating charge. In the meantime attention to streamlining and avoidance of splash must continue to be stressed. It is important, for instance, completely to submerge oil returns below working level in the double-bottom tank, especially where the latter is arranged under and open to the gear case. The very decided disadvantage of the air being charged with oil-water vapour and mist has already been pointed out in connection with ventilation.

The use of double-bottom space for clothing the lubricating oil on modern turbine tonnage has been discussed elsewhere[22], and while commercial considerations are against the adoption of an alternative plan, it is to be hoped some arrangement can be made providing greater protection from the effects of salt-water leakage through strain of shell rivets. It is conceded that trouble has not been appreciable, but while the arrangement exists it is considered important that provision be made for a line from the forced-lubrication pump to lead directly to the deck connection. In the event of bottom damage or when the oil is to be removed for processing ashore, work can then be effectively carried out with minimum inconvenience and danger of contamination.

20. Cf. Linn & Irons, A.M.E., 1941.
21. L. M. Douglas, *loc. cit.*
22. C. W. Cairns, *Trans. N.E.C. Inst. Engineers & Shipbuilders*, D.91 1942.

VII. TESTING AND RECORDS.

Analytical data are essential to the proper control of turbine lubricating oil in use. Arrangements should therefore be made for its periodical examination. For marine turbines, routine samples should be taken every voyage or at approximate intervals of twice yearly, whichever is the lesser. For land installations it has been found good practice to examine the oil four times during the first year of operation and three times yearly thereafter. More frequent routine examination is unnecessary and should be discouraged as being liable to concentrate attention upon minor variations in the analytical figures.

The information chiefly required is the rate of change of the oil rather than its individual test figures. Any sudden change, or any gradual change maintained at a different rate, may be indicative of operating conditions liable to affect the active length of life of the oil charge. On the other hand, individual figures can rarely be related to any arbitrary datum level, and this is particularly the case as between one oil and another.

Whilst all systematically acquired data are interesting, the really important figures indicative of basic change in an oil are neutralization value, viscosity and demulsificaton number. These must always be determined. Other characteristics such as saponification value, surface tension, Ph value, etc., are unlikely under present conditions of knowledge to give more information than that which can be deduced from the three first-mentioned tests when considered in conjunction with the origin, nature and past history of the oil.

In the case of inhibited oils, it is perhaps questionable whether measurement of the amount of additive remaining is a guide to the antoxidant efficiency. For one thing the activity is not a mass action and the placing of fixed limits upon efficiency is therefore a matter of great difficulty. For another, measurement of the amount of additive is not easy, nor is it always certain that the additive is present wholly in active form. For such reasons it has been claimed, at any rate for certain inhibitors, that the best measure of their continued presence is their effective activity in preventing oxidation. In practice a combination of these methods is likely to be most useful. The N.V. will tell whether the inhibitor is active, whilst attempted measurement of the inhibitor may give some indication of the reserves of activity.

Samples of oil for examination should be sufficiently large—say 1 pint—and taken in clean bottles previously rinsed out with the oil and immediately closed with clean corks. They should then be clearly and fully labelled and accompanied by as much running data as possible. Successive samples should be drawn from the same point in the system throughout the life of the turbine. Taking these precautions in sampling will tend to eliminate many of the inexplicable analytical variations which occur from time to time.

Apart from the analytical characteristics of the oil, observations are made of water content, sediment, colour and general appearance. From time to time it may be desirable to collect and analyse the centrifuge solids, but this is generally only done when some change of conditions requires checking or when the quantities appear excessive.

The maintenance of full turbine running records is very important and though power-station logs are generally admirably kept, the same cannot always be said of private industrial or the smaller marine installations. If and when lubrication troubles arise or when new charges or new types of oil are being introduced, it is of the greatest value to have the full past history of the units available.

Discussion.

Commander (E) L. Baker, R.N. (Visitor), opening the discussion, said it was difficult for him as a practical engineer to follow the excellent paper which the authors had presented, particularly as his experience was purely naval. He had recently returned from one of H.M. aircraft carriers, and he would like to place on record the shaft-horse-power to oil relationship for that ship. The shaft horse power was 37,000 per set, and normally 1,500 gals. were in circulation. Due to supply difficulties, the amount went down to 950 gals. on one occasion without any difficulties other than the normal ones.

As might be expected, aeration was a problem, and the cure was found to be twofold. The first thing to do was to avoid overcooling the oil; temperatures below 105° in the sump inevitably resulted in aeration. Secondly, it was necessary to avoid the use of fittings which entrained air. He referred particularly to the illuminated sight flow glasses usually fitted on the returns from turbine thrust blocks, gears, and so on. If the return pipe flowed full, those fittings would entrain air to a very large extent.

The use of inhibitors had not been widely adopted in the Navy. They had been used for supply reasons in the Pacific Fleet, but it would appear, subject to certain remarks which he would make subsequently, to be justified as an insurance policy against compulsory operation of the plant under bad conditions. He had returned home in H.M.S. *Sussex*, and that ship had had to continue operating after the lubricating system was flooded with salt water. Being unable to clean out properly, they used the American Navy 2190-T inhibited oil, and subsequent examination showed no rusting and no corrosion problems in any respect.

The proviso which he made was that before inhibitors could be widely used he would suggest that world standardization was required, because the marine engineer must be able to pick up his oil from any source and, if necessary, to mix it without the deleterious effects mentioned from mixing even new oils.

There was a small practical point which he would like to make for the benefit of engineers not familiar with advancing steam conditions. It had not been fully appreciated even in the Navy. One of the biggest problems would appear to be to determine the length of time for which the circulation of oil must be carried out on shutting down a plant. The normal practice in the Navy had been two hours, but that was definitely insufficient with steam temperatures of 700°, because a temperature of 210° had been recorded on a bearing one hour after shutting down the lubricating plant—*i.e.*, three hours after the steam was shut off.

In the specification no reference was made to colour. It was normally appreciated, of course, that colour was not important directly, but he would like to place on record that the American oil supplied in Australia to the British Pacific Fleet was frequently as colourless as medicinal paraffin, and a number of engineers refused such oil on the ground that it was not what they had been used to having. He felt that that point should be emphasized, particularly if different refining processes were going to be more widely adopted in marine practice.

Finally, he would like to throw a small problem to the scientists —the question of ship's tests of oil in service. It was not always possible to call in an expert, and some sort of guide other than what it looked like was most desirable. What was required, he thought, would appear to be a simple viscometer and a simple acidity test. The acidity test should involve no problems for the most modern ships, because the reverse of that, the alkalinity test, was in common use for boiler water testing.

Mr. H. Mackegg (Member) said that the handling of turbine oil was a feature which needed to be strongly emphasized, both from the point of view of the remarks made by the authors and also from the installation angle.

Quite recently the speaker had seen specifications for vessels with main propulsion turbines and Diesel auxiliaries where a proposal had been made to use one of the centrifuges for the purification of the turbine lubricating oil or alternatively for the Diesel oil. This, of course, was very bad practice and it could not be too strongly emphasized that turbine lubricating-oil systems must have independent pipework, pumps and centrifuge arrangements, which would preclude any possibility of external contamination.

Under the heading "Cleaning Turbine Oil Systems"— subheading "New Systems", he would strongly advocate that the oil should be centrifuged at low temperature immediately after the system had been filled and before the turbine, and therefore the gearing, was started up, and assuming that the feed to the centrifuge was taken from the lowest point in the system, the oil would then be circulated and all deleterious matter removed, so that the lubricating oil system would be in the cleanest possible state from the very commencement of the operating life of the machinery.

Similarly, when oil systems were cleaned out and flushing oil was used, the centrifuge could serve the same useful purpose, and here again when the system was re-filled the same procedure should be followed as in the case of the new installation, even though the flushing oil also had been so treated.

The foregoing remarks were made bearing in mind the comments of the authors regarding the effect of centrifuging upon turbine lubricating oil generally, because aeration produced by centrifuging was negligible as compared with the aeration and agitation produced in the turbine system, and he therefore suggested that centrifuging should be as continuous as possible.

He agreed that to remove oxidised material which was soluble in hot oil, as low a temperature as possible (consistent with good separation) should be used, but he would repeat that the oil should be centrifuged immediately it was put into service, because separation could then be more easily achieved at a lower temperature, and it was better to do this than to wait until the oil had become contaminated and then try to retrieve the position by centrifuging at high temperatures.

Water washing had proved to be beneficial in the United States, where a rather more complicated process was adopted, and in this country where the water-washing process was the simple addition of water at a low rate of flow and at correct temperatures to the oil before centrifuging. This use of a continuous feed of water removed the separated acidic materials from the bowl of the separator and also helped to prevent any corrosion in the bowl; tests carried out in co-operation with the oil companies had shown that anti-oxidant inhibitors were not generally removed by centrifuging and water washing. The oil companies realized that oils were normally subjected to such treatment, and their choice of inhibitors took this factor into account. In any event, it was advisable to have a water-wash connection, which in many instances could be conveniently arranged from the condensate drain of the steam heaters, because it was then a simple matter to water seal the centrifuge bowl when starting up, and a further point of very definite importance was that the use of wash water had the effect of continuously replacing the water seal, because if wash water was not used and the water seal was therefore comparatively stagnant, except for any water normally separated from the oil, the water would then become highly contaminated by the absorption of acids picked up from the oil in its passage through the separator, and it was under those conditions that serious corrosion troubles generally arose.

The wash water used should preferably be condensate, this having the best solvent properties. If hard water containing much lime was used, lime soaps might be formed, thus stabilizing water-in-oil emulsions, which were difficult to separate.

The authors had correctly stated that a difference of opinion existed regarding the value of water washing in the centrifuge, and he did not wish to be too dogmatic upon this point, but the success of this method of treatment depended very largely upon the method of application and the intelligent operation of the centrifuge equipment.

The foregoing comments were made on the assumption that the capacities of the centrifuges used were adequate. This particular point was dealt with in a paper* submitted to this Institute on "Oil Purifying with Continuous Lubrication", by Professor E. Forsberg, and he would only like to emphasize that operating results had proved that the largest capacity centrifuge which economic circumstances would allow should always be fitted, and it should be operated at approximately half its normal throughput capacity, under which conditions it would give its highest effective separating efficiency.

In that particular connection the first two vessels mentioned in Table II had been operated under precisely those conditions, and it might be added that similar results had been obtained in the case of the *Queen Elizabeth* and many other geared-turbine installations.

Mr. S. E. Laxton (Associate) congratulated the authors on the very able manner in which they had covered all the developments which the industry had achieved in recent years. There were one or two small points which occurred to him which he thought might be of interest. The figures given for the old *Mauretania* might reasonably be compared, as a matter of interest, with those of the new *Mauretania* which had been running for the last seven years, and for the last three years on an inhibited turbine oil. The neutralization value had never exceeded 0·15 mg. of caustic potash per gramme of oil, and was now less than 0·10. The *Franconia* was another interesting example, having been run on an inhibited oil for the last five years, and having at the present time a neutralization value of 0·06.

He was very pleased that the authors had emphasized that the greatest possible care was necessary in both the production and the selection of the basic oils which were used for incorporation with inhibitors, and to note their emphasis on the matching of the inhibitors to those particular selected oils.

Another point of interest was that as a result of war-time experience, notably in conjunction with the United States Navy, and development work in this country, the modern oils forecast in the paper could and would be produced in the United Kingdom.

There was so much in the paper with which he was in agreement that he did not like to pick out anything in particular, but he would very much like to endorse the plea made by the authors to shipbuilders and superintending engineers for the standardization of bulk fittings for the delivery of lubricating oil. The suggestion was made that a 2½in. gas male fitting connection should be standardized and that, he thought, would be acceptable all round. He would also like to endorse the plea that a connection should be made from the forced feed pump to the deck level to facilitate the discharge of the system in case of need for cleaning.

The third and final point among the many with which he was

* Vol. LII, Part I, February, 1940 issue of TRANSACTIONS.

in agreement and which he would like to mention was that steam for gland sealing should be drawn from the saturated line.

Mr. W. D. Jarvis (Visitor) said that the authors had discussed the causes of turbine oil deterioration in service and had shown that the chief cause of ageing was the oxidation of the hydro-carbons of which the oil was composed. The factors which influenced the rate of oxidation were shown to be:—

(*a*) Aeration and heating.

(*b*) By the intrusion of water, the formation of stable emulsions and/or the corrosion of metals in contact with the oil.

The degree of aeration and the changes in temperature which occurred in a turbine-oil system were dependent upon turbine design, and although much had been done in the past few years by turbine designers to relieve the strain imposed upon the oil from these causes, there was room for more improvement.

The resistance of the oil itself towards direct oxidation and oxidation induced by the breakdown of water-oil emulsions and by oil-metal catalysts, was a problem which was the concern of oil technologists and the preparation of turbine lubricating oil.

As a power station chemist the speaker had been able to observe the performance of oil in service in direct-coupled turbo-alternators during the past 20 years. An examination of the routine oil tests carried out on oils over this period showed that by a change in oil refining the amount of oil-insoluble decomposition products formed by oxidation had been reduced, but that the insoluble products now formed appeared as varnish-like films which might develop where clearances were fine, as on relay pistons, and cause operating troubles. The tendency to form stable emulsions with water was more marked, the amount of copper found in centrifuge deposits had increased, and the appearance of rusting had been more frequently recorded. The rate of rise of the neutralization value of the oil with hours in service showed a considerable increase.

It was suggested that, by the change in the refining of the oil, those naturally-occurring hydro-carbons which themselves were resistant to oxidation and acted as inhibitors, had been removed, and that simultaneously the property of wetting metallic surfaces had been impaired. To increase the resistance of highly-refined oil to oxidation, inhibitors had been developed. Thus, a condition had developed in oil preparation which might be compared with the treatment of boiler feed water, where the raw water was evaporated, distilled and treating re-agents were added finally to the distillate to control scale formation and corrosion. There was some doubt, however, at the present stage whether the inhibitor added was a complete substitute in behaviour for the hydro-carbons removed during the refining processes. Evidence to show that the more highly-refined oils did not wet the metallic surfaces as completely as less-refined or oxidised oils was given in "Lubrication of General Electric Turbines", Dantsizen, Transactions A.S.M.E. Vol. 63 (1941) 491. Some warning was necessary, therefore, against the indiscriminate use of chlorinated organic solvents for cleaning out oil systems. By the use of such solvents the metallic surfaces were left dry and free from oil. If a highly-refined oil was to be used in the turbine, it was suggested that a flushing oil containing a surface-active reagent should be circulated prior to filling up with a new charge of oil.

On page 129 four requirements of an ideal turbine-oil inhibitor were enumerated. To these he suggested might be added (*5*) the oxidation products of the inhibitor should not act to stabilize oil-and-water emulsions and should be preferably water soluble, and (*6*) should be resistant to attack by metallic corrosion products.

He would like to see the development of a method of testing inhibited oils whereby the activity of the inhibitor might be estimated by the oil users. By the addition of an inhibitor to oil the initial induction period of oxidation was considerably prolonged, during which period the inhibitor was itself by selective oxidation being used up. The subsequent rate of oxidation would vary with the intensity of the influences, aeration, heating, and water content present in the individual system, and there were instances where inhibited oil had failed completely in several hundred hours after the induction period.

In order to support the authors' claim that by present-day methods of turbine oil preparation the exacting demands of modern turbine lubrication were being met, he gave as an example the following:—A 30,000-kW. turbo-alternator with a shaft speed of 3,000 r.p.m. and supplied with steam at a pressure of 650lb. per sq. in. and a temperature of 825°F. at the stop valve, had been lubricated with a balanced inhibited oil for 22,000 hours. The neutralization value was 0·06 mg. KOH per gramme and the inhibitor was still active.

Dr. Alan Wolf (Visitor) said he was particularly interested in the points raised partly because he had specialized in that direction during the war, principally in the United States, and partly because he had had the privilege of communicating a paper* to the Institute some twelve years ago on marine steam prime movers including turbines, and that had emboldened him to take part in the present discussion. In the paper in question he had prophesied (by inference) that one of the major developments in turbine lubrication would be the increasing use of solvent-refined oils, or, as they were sometimes termed, non-sludging oils. He thought that experience since then had shown that the prophecy had been amply fulfilled.

Commander Baker had referred to the very pale colour of some of the inhibited turbine oils, and especially those used by the United States Navy, and to the prejudice which that aroused in the minds of some users because of its abnormality compared with the appearance of the turbine oils previously used. One reason for the pale colour was that many of the oxidation inhibitors used were much more efficient when employed in conjunction with oils refined to a very high degree by fuller's earth treatment, so that the pale colour was incidental to the obtaining of an oil which gave the maximum degree of inhibitor response.

The authors recommended that samples of the oil should be examined at intervals of three to six months, according to the type of turbine under consideration, and whether it was the first or subsequent year of use. He assumed that the recommendation was intended to apply only to oils which had been protected by oxidation inhibitors, because all his own experience in the United States, especially with marine turbine lubrication, showed that if one were to confine oneself, in the case of the non-protected uninhibited oils, and especially uninhibited heavily solvent-refined oils, to such lengthy intervals between examinations, one might in a number of cases run into severe lubrication troubles before anything wrong was detected. He would suggest that for the non-protected oils an examination at least at monthly intervals was highly desirable. Incidentally, such examination could be confined to the determination of neutralization value and, using a shortened form of the test, could with a little practice be conducted in a few minutes by ordinary turbine operatives.

With regard to the incidence of trouble, when he went to the United States he had been staggered to find the extreme frequency with which trouble occurred both in land and in marine turbines when the oil was uninhibited against oxidation. He was not exaggerating when he said that, for example, in a fleet of about a dozen vessls in which the main propulsion turbines were of about 6,000 h.p., and where each vessel also had two auxiliary 300 h.p. turbines, the incidence of the trouble was, in terms of percentage of steam turbines which showed serious lubrication difficulties and very rapid oil deterioration, of the order of 75 per cent., and it was impossible in his experience to be certain of satisfactorily lubricating modern turbines driven by medium to high steam pressures and temperatures unless the oil was inhibited against oxidation. By that he meant that if an uninhibited oil was used one might be lucky and have no trouble at all over even a few years of oil life, but the likelihood of having trouble was so great that it became almost compulsory, and certainly highly desirable, to use an oil inhibited against oxidation.

Incidentally, with regard to the proportion of trouble in land installations, he found that in the case of those of which he had kept a lubrication log in the United States—about 100 turbines, varying in size and output from 1,000 up to 50,000 h.p.—the percentage was of the order of 25 when the turbines were operated with steam at medium to high pressure and temperature. The danger point as far as the steam conditions were concerned seemed to begin at about 400 to 500lb. per sq. in. steam pressure and 400°F. to 500°F. steam temperature at the hot end of the unit. When one got much below these figures, the incidence of trouble did not seem to be anything like to high, and when it did occur it was usually due to some mechanical defect or abnormal operating condition.

That puzzled even a good many experienced turbine engineers, and it had been argued that there seemed to be no valid reason why the general tendency towards higher steam pressures and temperatures should be accompanied by such a marked increase in the rate of oil deterioration and consequent lubrication troubles, because the mean temperature of the oil returning from the bearings was not very much higher than with turbines operated with steam at much lower temperatures and pressures; in other words, it was usually of the order of 140°F. He suggested, however, that one of the main reasons for the difference—and the authors had really already referred to it in the paper—was the high skin temperature of the shaft. In other words, although a typical *mean* temperature of the oil returning

*"Lubricants for Marine Steam Prime Movers", Trans. Institute of Marine Engineers, Vol. XLVI, Part 7, August, 1934, pp. 197-209.

from the bearings might be only 140°F. or less, the molecules of oil in immediate contact with the shaft were at very much higher temperatures indeed, and in fact not far below those of the high-temperature end of the turbine itself.

With regard to rusting and corrosion, there seemed to be a good deal of confusion of thought in this connection. There certainly was when he was in the U.S.A. and South America. To his mind, there were two entirely different kinds of rusting; one which might conveniently be termed "primary rusting", and the other which could be referred to as "secondary rusting". Primary rusting, in his experience, occurred only in *new* turbines which were filled up with highly-refined *new* oil, not containing an anti-rust inhibitor, and the recommendation of a number of American turbine manufacturers was that there should be added to the oil something like 15 to 25 per cent. of old oil from another turbine. The idea was that the old oil had already developed sufficient acidity and consequently sufficient wetting properties and polarity to give protection against globules of water piercing the oil film, attaching themselves to the metal surface and causing this primary rusting, which could be very severe indeed. It should be clearly pointed out that oxidation as distinct from anti-rusting inhibitors afforded no protection whatever against this primary rusting in new turbines, as this type of rusting occurred long before the oil had undergone any appreciable oxidation at all. Thus, an oil might behave excellently in any sort of oxidation test in the laboratory involving the blowing of air through the hot oil in the presence of water and catalysts, but nevertheless give severe rusting when in a new turbine. It was only tests of the Westinghouse type in which a polished ferrous surface was immersed in a stirred mixture of oil and water which would evaluate the oil from that point of view. Conversely, oils giving excellent results in such steel corrosion tests gave very poor oxidation test results unless containing oxidation inhibitors.

Secondary rusting, which was quite distinct from primary rusting, appeared to occur chiefly above the oil level, and particularly on the ceiling and on the walls of the oil reservoir above the oil level. Most members of the audience had probably observed in turbines in which the oil rapidly became acid, what appeared to be a fairy grotto of stalactites suspended from the roof of the oil reservoir, and this phenomenon was always a warning of trouble in store. Each of those stalactites consisted of a thin skin of rust (both hydrated ferric oxide and black magnetic oxide of iron) and was filled with a dilute aqueous solution of the iron salts of volatile oil oxidation acids such as acetic. A clear drop of this acid aqueous solution could often be seen suspended from the tip of the stalactite, and in due course fell back into the oil. That type of rusting was not like the former, due to absence of polar bodies from the oil, but to the formation of highly corrosive water-soluble volatile organic acids as the result of a particular type of oil oxidation. These acids evaporated along with any moisture which had entered the oil and condensed on the cooler and unventilated portions of the oil reservoir above the oil level. Such corrosion or secondary rusting could be guarded against by the use of an oil efficiently inhibited against oxidation, but the primary type of rusting in new turbines could in his view be guarded against only by ensuring that the oil also contained an inhibitor of a "polar" type specifically designed for this particular purpose.

The objection to the device of adding used to new turbine oil for the initial fill-up of new turbines was that, although it often effectively prevented primary rusting, it involved a risk of infecting the new oil with harmful oxidation products, particularly iron soaps of oil oxidation acids. Thus, the life of the new oil might thereby be considerably shortened. Similarly, attempts to reduce the acidity of an oil which had suffered rapid oxidation in use by the addition of large amounts of new oil, only afforded a very temporary relief. The rate of oxidation of the mixture was as high as before the addition of the new oil, due to the presence of iron soap catalysts in the old oil.

Mr. A. T. Wilford (Visitor) said that after listening to Dr. Wolf he felt that he was present on false pretences, because he could not claim to have any large experience in the lubrication of turbines, although the concern with which he was associated had recently adopted the use of inhibited turbine oils. He had, however, had much experience on inhibited turbine oils in quite another application, and a curious one, namely, the use of such oils as the lubricant in pre-selector gear boxes of motor omnibuses. In that case normal lubricating oils of various types of refinement, used in quantities over a period of years, failed utterly. They increased in acidity, with figures of about 60 mg. per gramme or even higher, and the viscosity increased sometimes to three or four times that of the original oil. That sort of thing occurred after some 6,000 miles use. They were then persuaded to test an inhibited turbine oil, and such oil had been in use in an identical type of gearbox, exactly similar to that in which the uninhibited oil had been used, and in which it could not have been used for more than 6,000 miles, for as long as 120,000 miles without being changed. Actually that was an exceptional case, because the gear boxes did not generally last for that length of time before being overhauled; but the oil was capable of lasting for that time.

Within recent years for various reasons uninhibited oils were tested again on a very limited scale, and almost as a cross-check on the fact that it was the oil and not any change in design or operating conditions, and they at once ran into trouble again. There was no doubt therefore that an inhibited oil was essential for this purpose and the viscosity requirement happened to coincide with that adopted for turbines. He was very interested in a point which was raised by the authors and also by Commander Baker, that of the compatibility of the various oils. It was very desirable to be able to purchase lubricating oils from more than one source of supply, and therefore that those oils should be compatible with one another. In the case of the United States Navy turbine oil specification, 2190-T, that specification in effect called for or allowed oils of various types to be delivered, as long as they were inhibited oils. He had been told that one could not expect that an oil complying with specification 2190-T should come from any particular source of supply, so that in the case of the United States specification it was definitely expected that inhibited oils of different kinds should nevertheless be compatible with one another. He thought that from the point of view of the user of turbine oils, either for their proper purpose or for the peculiar purpose to which he had referred, the question of compatibility was very important.

A matter of equal importance was that of specification. This was a matter of extreme difficulty at the present moment. He thought that probably every user of inhibited turbine oil would agree with him that it was impossible at the present time to draft a specification setting out exactly what was wanted. The A.S.T.M. oxidation test described by the authors showed some promise perhaps, but from the data given in Fig. 12, it was evident that an exceedingly long period was required to obtain a conclusive result. The sort of time before any change in the oil took place was perhaps of the order of 6,000 hours' running, and 6,000 hours running at 168 hours a week—day and night operation—meant a thirty-six weeks' test. From the point of view of a motor omnibus, one could get the result in service in a not much longer time and this being the case a laboratory test of such long duration was not very attractive. Nevertheless the A.S.T.M. test might be of immediate value in sorting out those oils which would be likely to fail under service conditions.

Dr. D. Clayton (Joint Admiralty and Ministry of Supply Advisory Service on Lubrication) (Visitor) said he had been privileged to attend meetings which Colonel Auld and his colleagues of the Lubricating Oil Pool had held on the subject, and therefore necessarily agreed with many of the statements made in the paper.

He agreed that co-operation with the designers was very desirable, and that was particularly the case with the additive type of oil. So far the turbine designer had been able to use an oil which was relatively inert and almost any metal could be used (the oil technologist preferred not to have copper); but with inhibited oils it was very necessary to choose the metals carefully, indeed as carefully as the oil technologist chose his inhibitors.

Co-operation with the designer was necessary also in the case of gears. The authors said that an oil of 120 seconds Redwood viscosity at 140°F. might not be thick enough for gears, but Admiralty experience with S.M.L.O. showed that in spite of many rough teeth, some badly corroded, satisfactory lubrication seemed in fact to have been obtained, very few cases of scuffing having arisen. However, if something had to be done, it seemed to him that it was the designer who must take the next step by improving the gears; and from what he had seen of gears they could do with a good deal of improvement.

The authors gave a warning about the deposition of sludge in coolers. That warning might also have been given with regard to the effect on viscosity in cold climates; with over-cooling, the rise of viscosity could be very serious and lead to considerable loss of power in the bearings and difficulty in pumping. It seemed that the cooling should be adjusted to suit the particular conditions.

The question of whether the viscosity was too low for the gears brought up the question of the load-carrying capacity, to which the authors referred in one little paragraph and then did not pursue further. They said that increase of lubricating properties or load-carrying capacity was desirable if the same oil were to continue to be used for the gears as for the bearings. He wondered whether they did not really mean running-in compounds rather than materials to give increased load-carrying capacity, so that the high spots would rub down quickly and allow fluid conditions to be set up between the teeth. Additives increasing the load-carrying capacity often did act as running-in compounds, but he thought that it was necessary to be clear on this point. Would friction reducers serve in the same way? He thought that it was very doubtful, for it did not seem that mechanisms could run continuously with boundary lubrication to any serious extent if the speed were high.

In these connections, he would like to mention phosphating as a process which might deserve attention. As far as he knew, it had not been applied to large gears such as turbine gears, though it had to small gears. It had been found to increase load-carrying capacity. It was also a way of avoiding the increased accuracy of finish by machining to which he had referred earlier as one of the ways of improving gear lubrication; the layer was about 0·0003in. thick, and it therefore served to cover up many of the inaccuracies of the gear teeth. It facilitated quick running in; it wore away quite quickly at the high spots of the surfaces, and so tended to promote a smoother tooth surface. It could be applied cold, which was an important point for marine gears of large size. Another feature was that it increased corrosion prevention; even with plain mineral oils a considerable improvement in corrosion resistance was conferred on the surfaces. A small point which was of interest in that connection was that the low spots on the surfaces would be protected against corrosion, whereas with plain steel corrosion would tend to accentuate the differences of level between the different points of the surfaces by a pitting action.

With regard to bearings, the authors made some reference to the aeration which resulted from the churning in bearings. He thought that it was possible to be more specific in one respect. Air entrained in the oil would be taken into solution in the convergent part of the film where the high pressure developed to take the load. As the oil came out in the diverging part there was a negative pressure region and the dissolved air would come out of solution; but it would come out in an extremely fine form, often making the oil look like milk, and the fineness of the bubbles meant that the rate of separation was extraordinarily low. He recalled that Samuelson* utilized the negative pressure region of a turbine bearing to feed the lubricant. The authors referred to the evaporation of water from the oil in the bearing film. He had found it difficult to believe that that was possible even though the temperature was high enough. Any oil coming from the ends of the film was immediately swamped by the flood of oil for cooling purposes.

Should the return pipe to the tank be submerged or kept above the oil level? The authors said that it should be submerged, but there had been an instruction from America during the early period of frothing trouble with 2190-T oil that the return pipe should come out above the oil level, to give any air carried along in the stream with the oil a chance of escaping.

He would like to support the lead the authors gave to specifications on p. 133 as against the discouragement in the opening phrases of that section, in that there was much to be said for specifications in the sense that they were minimum requirements. The latter did not need to be so low as not to provide satisfactory behaviour; they could always be revised to take advantage of accepted advances in technology. The minimum requirement that represented the economic optimum was very desirable, in his view, so that the supply was not too critical or too narrow—a point referred to by Commander Baker, and particularly important for naval purposes. Too close a fitting of the oil to the job was to be deprecated; when it did occur it was again the turn of the designer to improve the mechanical conditions so that a fairly common, though not necessarily poor, oil could be used. He was inclined to agree with the authors that the new turbine oils had rather outstripped turbine design.

Regarding the last paragraph on p. 127, the move to rust-inhibited oils was not nearly so direct in this country as the brief statement might imply. The first step to remedy rusting was to recommend the stoppage of leakage. It was only after the United States rust-inhibited oil had been adopted at a later stage for the sake of common supply that a rust-inhibited oil was sought, to secure permanent benefit from that type of oil. Salt-water was certainly the worst enemy in his experience in avoiding ship turbine corrosion troubles. On the last page of the paper, reference was made to the testing of oil, and he would certainly recommend that the test for salt should be added to the list, even though the trouble was not likely to be so great in peace-time as during the war when leakage resulted from strains caused by near misses in bombing, severe operating conditions, and so on. He was not sure that the present rust-inhibiting oil could deal with salt-water leakage; it might with adventitious salt spray and small deposits from salt-laden air. His department had been experimenting with a water-soluble inhibitor with some success as a means of dealing on the spot with leakage *which* had been detected.

He had been interested to see the cases quoted by the authors of actual ship trouble due to salt-water corrosion leading to rusting, the rust then acting as a stabilizer to emulsion. He had been concerned with several other cases of a similar kind. In what he thought was the second case quoted by the authors, it had been found, subsequently to the examination of the oil, that the turnings from the journals contained a good deal of salt, showing why the journal corrosion was so severe, and suggesting rust again as a cause of emulsification. In that particular case the oil itself, after centrifuging, gave a demulsification number of 120 seconds, showing little deterioration.

In considering rust-inhibited oil for the preservation of turbines for storage it had been disappointing to find that in a conventional humidity chest test the behaviour of the inhibited oil was very little different from that of the plain mineral oil. That was in complete contrast with the behaviour in the 2190-T specification test; in the latter there was a constant sweeping of the steel specimen by the oil and water mixture, and it appeared that the frequent opportunity for the removal of the oil film led to very much better protection than in the humidity test. It should be noted, however, that in the gear casings the tops were subjected to condensation of moisture and acid products. To what extent was the inhibited oil effective under those conditions? He had referred to work for the designers to do, and he wondered whether this was not a case where the paint people should be encouraged to produce a really well-adhering paint, oil and acid-resisting, for the casings, tanks, etc.

If there was such emphasis on the volatile acids—and he agreed that they were important—should not the oxidation test be followed by an estimation of the volatile acids as part of the total acidity, or should not a corrosion test be done with a steel specimen hanging in the return from the condenser where this was used to return volatile products to the oil?

On the proposal of **Mr. S. E. Laxton** (Associate) a vote of thanks to the authors was accorded with acclamation.

BY CORRESPONDENCE.

Mr. L. J. Davies (Director of Research, The British Thomson-Houston Company, Ltd.): The writer was in substantial agreement with the various views expressed in the paper, and was very conscious of the need to ease the duty performed by the oil both as regards lubrication and cooling on modern high-speed turbine sets. Hence the following comments might be of interest.

In order to prevent too much work being done on the oil it was his company's practice on large sets operating at temperatures of the order of 850°F. not to circulate the oil more than 8-10 times per hour, although in the case of small sets operating at lower temperatures, and where the peripheral velocities on the journals were not so high, it might be possible to circulate the oil at a higher rate than the above.

Carbonization of the oil due to its coming into contact with surfaces of the pedestals near the H.P. gland was prevented by the use of what they termed "radiation shields". These "shields" reduced to a minimum the radiation from H.P. gland into the pedestals.

There was no need to dwell upon the ill-effects of water in the oil, as these were well known, and consequently the designer took all possible steps to avoid such contamination. The water was derived from condensation of steam leaking from the gland packings and to reduce this they were now fitting sealing fans on large sets. These sealing fans cut down to a minimum the possibility of steam leaking from the gland packings into the space between the housing and the pedestal and should have a very marked effect in reducing the quantity of condensed steam in the oil.

He agreed with the authors that rusting could be a very serious matter, particularly in return oil pipes which were not running full, due to condensation of water vapour (possibly containing water-soluble low-molecular-weight corrosive organic acids) upon the upper surfaces of the pipes which were not covered with oil. His company were giving some consideration to the suggestion that return oil ducts should be coated with vitreous enamel in order to overcome the very excessive rusting which did occur in certain cases.

There was no doubt that ample venting was extremely important to allow the escape of moisture and volatile acids to the atmosphere, and the scheme shown in Fig. 14 was very interesting. He would also mention that all boiler plants were not run under ideal conditions, judging by the condition of some of the steam rotors returned

*Proc. I.Mech.E., Gen. Disc. on Lubrication, 1937, Vol. 1, p. 269.

for overhaul, and the harmful effects of "dirty" steam, containing chlorides, etc., leaking into the oil system would be appreciated.

In regard to the danger from lubricating oil fires, it had been suggested that the pipes conveying the high-pressure oil should be inserted inside the return oil pipes, so that if leakage should occur or a pipe burst, the possibility of high-pressure oil being sprayed out and becoming ignited was absent. This arrangement, however, was obviously a complicated one to carry out, and if reasonable precautions were taken, as suggested by the authors, the danger from lubricating-oil fires should not be great.

He could not agree with the suggestion that desuperheated steam should be used for gland sealing, particularly at the high-pressure end of the turbine, for the following reason. If the load on the turbine should be reduced, comparatively cool sealing steam would be drawn into the casing by the vacuum on the turbine side of the gland, and travel across the face of the 1st-stage wheel disc, giving rise to the danger of the wheel being dished due to the cooling effect of one side of the disc as compared with the other side. For this reason, therefore, it was their practice to seal with steam at the initial temperature in the case of the high-pressure end of the turbine.

The authors mentioned the length-diameter ratio of bearings in connection with the question of assisting the escape of the oil after performing its lubrication duties; the writer's company were prepared to consider a ratio of length to diameter of the bearings down to 0·75. Not only did this assist the quicker exit of the oil after it had done its lubricating work in the bearings, but it also reduced any tendency to oil-film whipping, due to the increased specific loading on the bearings, particularly in the case of light rotors.

Mr. L. M. Douglas (The Parsons Marine Steam Turbine Co., Ltd.): The authors were to be congratulated on the careful study they had given to the requirements of their clients, the turbine designers, builders and operators. Such co-operation between suppliers and users was unquestionably next in importance to technological improvement, and it was only by such co-operation that such improvements could be brought into practical use. Judged by the satisfactory results attained in general practice it was, he thought, beyond doubt that improvements in the quality of lubricating oil had at least kept pace with the increase in severity of service requirements.

The authors showed that with oils having inhibitors to meet the more rigorous conditions, greater care in their handling and use would be necessary, and in this connection it occurred to the writer that if the injunctions and instructions given in the paper as to handling, etc., were epitomized, they would form a very useful *vade mecum* for operating engineers. It had also occurred to him that it would be helpful if it could be stated by the vendors at what maximum N.V. an oil could safely be used. The reference to the use of exhausters for ventilation led to the suggestion that long vertical vent pipes might with advantage be used in some cases in order to obtain chimney effect.

Regarding the ingress of water into the oil system, particularly in the form of superheated steam from the turbine shaft glands, the suggested packing of these glands by saturated steam would involve some loss, as usually sufficient steam leaked over the high-pressure turbine glands to pack the remaining glands, and if this highly-superheated steam was not so used it would be wholly or partially wasted since it would not be possible to utilize, at all events fully, its potential energy in power production. However, a promising development in this connection was the use of aspiriting systems to prevent egress of steam from the turbine glands, and this was proving so successful in preventing humidity of the engine-room atmosphere that it bade fair to be generally adopted. It might be stated, therefore, that the means were at hand for preventing contamination from this source. Ingress of salt-water into the oil system from a leaking oil cooler should be an exceptional occurrence, and it could hardly be expected that the oil should continue to function properly with such pollution to any considerable extent.

As pointed out by the authors, the tendency was for the initial temperature of the steam to rise as the general search for higher turbine efficiences proceeded, and the designer was compelled, again in search of higher turbine efficiency, to bring the bearings as close as possible to the steam belt in order to enable the maximum rotational speed of the turbine to be attained. There did not seem to be any practical way of insulating the journal or bearing respectively from the parts of the rotor and casing which were in contact with the high-temperature steam and, apart from the necessarily small air gap between gland and bearing, there was no room for the introduction of any cooling means. The heat transmission from the steam to the oil seemed therefore to be inevitable, and it was not likely to be less severe with the gas turbine but fortunately it was confined in its severest degree to one bearing. The oil passing through the film wedge would probably attain almost the full temperature of the journal plus a further increase in temperature resulting from the frictional heat generated in the bearing, and since the amount of oil passing through the bearing was normally limited to the side leakage through the bearing clearance spaces, the cooling effect of the oil upon the shafts was small and the increase in temperature of the oil in the film wedge fairly considerable. Here, however, there was some scope for the designer and means were at present being considered and would shortly be tested for increasing the amount of oil flowing over the bearing and journal surfaces and also for increasing the side leakage of oil which had passed through the film wedge, both of which would be effective in reducing the maximum temperature to which the oil was subjected.

It was true that despite the figures quoted in the paper, temperatures at bearing faces were largely conjectural, but these figures did show that frictional heat could produce considerable rise in oil temperature. It was only with cylindrical bearings that the temperature was dependent upon the clearance. Pivotted thrust bearings were usually able to take up their own clearance and inclination according to the load, speed, viscosity, etc., whereas with a cylindrical bearing the shape of the oil wedge was, for given conditions of load, speed, viscosity, etc., determined by the relative shape of the journal and bearing, that was by the clearance.

In regard to churning and aerating of the oil, while it was certainly desirable to streamline the piping, etc., and reduce the amount of churning and aeration to the minimum, the greatest amount of churning was unquestionably caused by the inter-engagement of the gear teeth, and here again the designer was limited in scope for ameliorating this condition. The gears acted as a pump; to be effective the oil must be delivered to within the common tangent of the engaging gears on the approach side, and it was consequently strongly impelled by centrifugal force towards the intermesh and expelled axially by the engaging teeth with the axial speed of the tooth contact which, with the usual 30° helical angle, was about 75 per cent. greater than the peripheral speed of the gears. This axial velocity could be reduced by increasing the helical angle of the gears if other considerations of design would permit. An increase in the helical angle to 45°, which would no doubt be the absolute limit to which the gear designer would in any circumstances be prepared to go, would reduce the axial speed of the tooth contact to the same value as the peripheral speed. This axial velocity of the oil was at present arrested by a surface normal to its direction and only a very short distance away—something like 1in. to $1\frac{1}{2}$in. There was therefore not much room for any streamlining or guiding, but it should be possible to provide small deflecting vanes which would turn the oil jet through 90° and reduce very considerably the churning and aeration of the oil.

It would seem possible therefore to alleviate to some extent the effects of all of the three major causes of oil deterioration—water contamination, excessive temperature and aeration caused by churning.

The authors raised again the question of the desirability of having separate lubricating-oil systems for bearings and gears. This would, of course, involve considerable complication both of the installation and its operation. If the oil technologists could produce two oils of quite different characteristics, one especially suitable for withstanding high temperature and the other for withstanding churning and aeration, there might be some justification for this additional plant, but if the object was merely to enable oils of different viscosities to be used in the two systems the complication could not be justified. The choice of viscosity for the gear teeth was in any case a compromise, an increase in viscosity involving an increase in frictional loss as well as an increase in load-carrying capacity. The oils in general use were probably as good a choice in this respect as could be made. The bearings could with safety be supplied with oil of a lower viscosity. (As evidence, many years ago a partially-geared destroyer was put through some trials using a light spindle oil of only about one-eighth the viscosity of a usual turbine oil, the reduction in bearing friction being indicated by the remarkable coldness of those bearings unaffected by conducted heat). However, the only advantage to be derived would be a reduction in the frictional losses in the bearings and these losses were small, ranging from less than $1\frac{1}{2}$ per cent. of the power in a large power installation to about $2\frac{1}{2}$ per cent. in a small power plant. Obviously the saving could only be very small even in a small power plant where it would be most desirable to avoid complication. There was the further point that whichever punished the oil more severely, the bearings or the gears, this punishment was shared by all the oil in the common system, whereas with segregated systems it would be concentrated on a smaller quantity of oil. It might be that in the future recourse to separate systems would become necessary, but the writer thought that they had not yet arrived at that stage of development.

Mr. J. I. Hill (Chief Chemist and Metallurgist's Dept., London and North Eastern Railway): The authors referred to the corrosive influence of water-soluble acids of low molecular weight produced by oxidation of certain types of hydrocarbon present in varying amounts in turbine oils: the formation of acids containing the carboxylic group had been explained and was in agreement with the authors' view point that it was the highly-refined paraffinic type of hydrocarbon that was the most liable to develop corrosive acid. The views of the authors would be welcome as to whether it was possible to produce turbine oils from mineral oil base containing little or no paraffinic hydrocarbons of the type prone to active acid development. It would also be valuable to have the authors' experiences as to the frequency with which cases of corrosion due to this cause had been met.

In their remarks on resistance to emulsification of turbine oils, the authors referred to the inversion of water-in-oil type of emulsion to the oil-in-water type and *vice versa*. This interesting observation might go some way towards elucidating cases of shaft corrosion that had been recorded where no excess acidity, either of the harmless type or volatile carboxylic acids, had developed in the oil. In the case of severe rusting of shafts and scuffing of gears in a marine turbine, referred to in the discussion on the paper on "Trends in Marine Lubrication", by the same authors, the neutralization value of the lubricating oil, even after long use, was not seriously high and the seat of the corrosion trouble was in no way associated with the possible sphere of activity of volatile acids; but a large amount of water was always present in the oil system, together with salt-water leaking from a cooler, in amount sufficient to render the water corrosive to mild steel. In the absence of evidence of acid corrosion the only conclusion could be that the shafts and gears in use became wetted with a saline water and, therefore, the emulsion carried with the oil stream was of the oil-in-water type and not the water-in-oil, as described by the authors as the primary product of reaction at the water-oil interface.

Although methods of test were largely the concern of the Institute of Petroleum, the views of the authors would be welcome on the present I.P. method of carrying out the steam emulsion test; it might be thought that merely to bubble steam through an oil, either new or used, without any attempt to introduce suitable factors of time and environment of practical use, was somewhat far removed from the conditions that the oil had to face in service, and that a better test would be to introduce agents accelerating emulsification and to extend the test to a much longer period than the few minutes required in its present form.

Amongst many observations of practical value in this encyclopaedic paper, there was none probably of more value to engineers than the statement that analytical data were essential not only to the proper control of turbine oils whilst in use, but also in regard to the development of oils to meet new and more exacting conditions. Such control was, of course, regularly carried out in large land installations, but was a more difficult problem with the marine turbine of small or medium size, though it was a possibility in ships working cross-channel or coastal services. A case might be pleaded for the more frequent routine examination of the oil whilst in use than the three samples per annum suggested by the authors, though it could be argued that frequent routine testing was, in effect, simply a test in service of an oil of unproved characteristics and, therefore, an inappropriate burden to lay upon users of turbines. Such frequent testing could be considered the responsibility of oil producers, but was it to be expected that they could maintain large machines purely for experimental purposes? There was a clear case for co-operation between turbine users and the oil industry.

It was suggested that wherever possible maintenance engineers would find a close liaison with the chemist or other technical investigator to be a valuable aid in the efficient maintenance of their machines. A particular value of such collaboration would be quickly to detect unexpected mechanical breakdowns or other sources of intrusions of harmful substances. Typical cases would be similar to those referred to by the authors, of accidental mixing of totally unsuitable oils with the turbine stock, a sudden increase in the amount of water in the lubricating system or the appearance of corrosive salts in significant amounts. Doubtless other cases of human error and of the unpredictable factor would have come to the notice of engineers.

One form of control of turbine lubrication which had been practised and was available to users of small turbines in which the lubricating oil was strained through fine cotton cloths for the purpose of removing coarse particles, would be the periodic examination of the nature of the particles strained off by the cloth. In one case a disturbing scuffing of the gears had been observed and it was essential to know the conditions which affected the rate of flaking of the metal and, if possible, to find a corrective. The cloths were changed every fourth day and examined in the laboratory: the oil was washed out with solvent and the metallic particles carefully removed, weighed and examined; the work was continued for several months though in the aggregate did not amount to a heavy load on the laboratory.

Interesting and useful results were obtained by this examination One associated the rate of scuffing of the gears with heavy weather, and another was that by increasing the viscosity of the lubricant the amount of metal particles removed from the gears was substantially reduced. This latter observation had some bearing on the suggestion made by the authors that in some circumstances it would seem that bearings and gears should be lubricated separately.

Mr. J. E. M. Payne (Member): Mechanical failure due to an inherently faulty lubricant was of rare occurrence. The reason doubtless was that the technique of oil refining had always been well in line with the progress of mechanical development.

The paper would be of assistance in enabling the professional engineer the better to appreciate and interpret the diagnosis of the chemist—so essential when investigating the cause of failure.

The varnish-like films described on the first page of the paper were commonly observed and tended to adhere mainly to bearing flanges. They were harmless, but indicated need for cleaning tanks and centrifuging the oil and a chemical check.

It was to be doubted whether the oil temperature was raised by friction, as such, so much as by work done on the oil in the gearbox and by the laminary flow between journals and bearings and turbulence in pipes, etc.; in other words, it was suggested the specific heat of the oil which was not usually specified was not so important as its viscosity. If the viscosity was too high, too much work would be lost by hydraulic frictional work done on the oil with resultant high temperature. and if the viscosity were too low the film would break down.

Oxidation, stability and neutralization value were factors to which engineers paid more attention to-day than heretofore, as the result, no doubt, of closer contact with the chemist brought about by the development of modern engineering technique. The term acid in this connection seemed unfortunate, as corrosive tendency was not implied.

It would appear that professional opinion was divided as to whether rise of neutralization value in service due to oxidation was harmful *per se* or, as the authors stated on the first page, innocuous, and it would be interesting if the authors would elaborate this point for the guidance of the engineer.

The apparatus in Fig 1 was interesting, not as simulating running conditions but as being capable of faithful reproduction—a feature essential in the propagation of any standard testing device, and it was surprising to learn that the use of oxygen or air was not determined; was it not a fact that the effect of the inert nitrogen in air was not fully understood and also that the function performed by catalysts was still in doubt, though not its effects?

Turning to the authors' comments on rusting, it might be observed that rusting in the generally accepted sense did not occur in turbine journals and gears. In the event of a vessel lying idle say for several months, surface marks were subsequently observed on journals at points where discontinuity of contact occurred, for example in way of oil recesses or oil grooves in the bearing surface, the contour of such grooves being clearly marked on the journal. The cure lay in rotating the engines by hand every day.

The authors' remarks on the danger of salt-water in turbine oil were welcomed. The writer had observed in particular one very serious case due primarily in the first instance to enemy action and lack of subsequent after care. Gear wheel shrouds, pinions, thrust shafts and all journals were uniformly pitted. In the case of a marine casualty where danger of contamination of oil was even remote, a safe plan was to call for an analysis immediately, and act accordingly.

Oil tanks in cellular double bottoms were potential sources of danger and to be avoided.

The case of the L.N.E.R. cross-Channel boat cited on page 131, called for elucidation in the absence of Mr. Hill's context. The culminating feature of this case was a collision, as the result of which the engine-room was flooded and the gears and journals became blackened with oxidation. Following the refitting of the main engines and repair of the hull, no further trouble was experienced, although the journals always retained a tarnished but polished oxide film.

Drain tanks should not be built as an integral part of the hull structure. In this connection, cooling coils submerged in sumps and circulated by sea-water were a potential source of danger and called for frequent examination. The result of an undetected leakage was rapid pitting of mild-steel machined forgings; cast iron and non-ferrous metals and also, for a reason unknown to the writer, journals in way of the bearing surfaces, were unaffected.

In conclusion, and having reference to the call by some users for rust inhibitors, the writer would ask whether the chemical effects would be to make the oil more sensitive to oxidation, in which case it would appear that such a property was not called for?

The Authors' Reply to the Discussion.

Lt.-Col. S. J. M. Auld, replying on behalf of his co-author and himself, said that it was manifestly impossible to deal completely with all the points which had been raised during what had been a most helpful discussion, but an endeavour would be made to do so when the remarks which had been made were before them in writing. There were, however, many points which could be discussed at once with mutual advantage. Commander Baker referred particularly to matters which had come up on one or two occasions since, in stating the success which he had had with the 2190-T after the penetration of a great deal of salt-water; but it must not be imagined that because salt-water got into the system there was necessarily going to be trouble. There were many cases where a great deal of water had got in. He had heard it stated by one or two engineers that they would for a period be willing to run their ships with water alone for the lubrication and coolant. It was entirely a question of the approach of the water to the metal.

That was connected with a point raised by one or two of the speakers—Mr. Jarvis in one aspect and Dr. Clayton in another—regarding the getting of the water to the surface, which was a most important point. Dr. Wolf had also referred to this. It had to be remembered that the rust inhibitors were not merely affecting the surface tension; they were really in themselves producing a surface, and that was why Dr. Clayton's water-soluble inhibitors or rust preventers had a chance, because if there was any normal approach to the bare metal they had a chance of getting there first and digging their toes in, so to speak, in much the same way as the polar molecules did in boundary lubrication. He thought that it all depended, therefore, on the conditions under which one was operating as to whether one got rust or not. If one got an approach to a bare surface one would certainly get trouble, but it was possible to look after a considerable amount of water, especially if it came in gradually, although it might be troublesome in other directions by raising the viscosity to such an extent that the circulation was reduced. The question of salt corrosion was one to which a good deal of attention must be given in individual cases, and it must never be overlooked.

The authors agreed entirely with the point made, to which he did not think that they had given enough attention in the paper, of the importance of the circulation of the oil after shut-down. It applied equally to land and to marine installations. There was so much heat about that unless care was taken to use the oil as a coolant until the danger was passed, there might be considerable trouble.

The question of testing equipment on board ship had been raised. There was no reason at all why it should not be done, and he thought that all that the authors had wanted to imply in the paper was that too much attention could be paid to individual tests. It was true, as Dr. Wolf had pointed out, that if there was going to be trouble with certain types of oil, it might come suddenly, but then one should not use that type of oil; one ought to know more about it to start with, and after that, if one kept an eye on what was going on, the change in direction of one curve or another would indicate what was happening. There had not been a discussion of the peroxide test which had been recommended, but if it were possible to have a test which gave information before the induction period finished and the direction of oxidation had gone upwards it would be valuable. It was desirable to find out well in advance what was going to happen. The observations that were normally taken of N.V. and viscosity increase and so on were, he thought, sufficiently well looked after if they were done regularly, whatever the intervals were; it was the first stages that were generally the most troublesome. They had only been concerned to deprecate spending all one's spare time doing N.V. tests, instead of playing hockey on deck.

Mr. Mackegg was most illuminating in his reference to centrifuging. There were very many points on which the authors were completely in agreement with him, and personally he did not feel inclined to cross swords with him about anything. The fact was that it was not possible to use centrifuging without continuously exposing surfaces, and if that was done the whole time it might give more chance to the oil to oxidise than it would otherwise have.

The water-washing of inhibitor-treated oils was another matter which should, he thought, be looked at from an entirely different aspect. With a properly inhibited oil it was not likely to matter. It would be noticed from the curves given in the paper that the change was relatively rapid; in other words, if one was going to have trouble, one was going to have it. By the time that the stage was reached where in an inhibited oil the water-washing was going to do any real good in respect of the removal of acidic products, the damage was likely to have been done. With the inhibitor-treated oils the rate of change was generally so slow that the sudden movement indicated that there would not be a recovery. Although they did not normally deprecate water-soluble inhibitors, it was more from the point of view of adventitious water accumulation.

Mr. Jarvis referred to what was probably a perfectly true tendency in his twenty years' experience of various oils from a good many sources, namely that they became more and more "tender". Personally, he thought that that was quite likely to be the case. He did not know whether it applied to the war years or not, or whether the Petroleum Board should take that as a compliment or not, but he thought that even without the war years it was just such a tendency which indicated the need to move towards inhibitors; it was not the odd cases where real trouble happened and individual cases went completely wrong by emulsification or corrosion trouble in the system or the centrifuge.

He was inclined to agree that it was information of that kind which should be put on record. All kinds of lubrication experience were needed, because it was experience in the field which counted in the long run. The laboratory workers were trailing along behind and trying to express what was known to the man in the field or on board ship.

Dr. Wolf and Dr. Clayton had given the authors so many points to deal with that he could not do more than promise that they would be dealt with. They were both men of such wide experience that almost everything they said required a very considerable amount of thought to be given to it before one would venture to disagree with them. Dr. Wolf referred to two types of rusting, and it would be of interest if he would elaborate that point in the written discussion. Personally, he thought that he was right, but to what extent one should fear the initial rusting due to bad preparation, due to bad flushing out of the system and so on, he was not sure, whereas the second type of rusting was a matter about which one should definitely be frightened. If it occurred, and if one got these volatile acids forming stalactites such as he described and coming back into the system, there was very great likelihood of trouble developing.

Dr. Clayton mentioned the reference to load-carrying capacity in the gears. That was something which had a definite implication, and it was to be feared that it had rather grown of recent years. When reference was made to load-carrying capacity, one at once thought of V.P. materials, but that was not what the authors meant. If it was necessary to use V.P. materials for gear lubrication, it would be a confession of considerable failure in design, and it was the duty of the designer to provide gears which would not produce any trouble. He thought that what he and his colleague had had in mind more than anything else was viscosity, and that was implied by their tilting gently at the viscosity of the oil that it was possible to use if one were going to have a circulating system. It would be better if they could get what they felt to be the right oil for the gear lubrication separately, but that might be overcome by the third aspect of the load-carrying capacity, namely giving the metal surfaces a chance to carry their normal loads. That type of gear was not a very difficult job to do. It was very much a sliding form of lubrication, and the point which Dr. Clayton raised about phosphating really covered the other aspect of it, the use of wear reducers. Those things, when they were of the phosphatic type, almost invariably meant that the gear did carry its load more easily than otherwise. If it were possible to use material of that kind which would go into circulation it would be ideal, and would have a large effect on what was never a great trouble in the actual lubrication, but more a nasty thing that one did not like to see, where there was any sort of pitting or wear in the gears.

He hoped, too, that in his written contribution Dr. Clayton would bring out more clearly the point he had illustrated by a sketch, because it was very important. Everybody was looking for some means of reducing aeration in turbine oils in circulation, and this was something to which he agreed with Dr. Clayton that not sufficient attention was given. He hoped that it would be as conducive to good practice as were other matters to which Dr. Clayton had directed attention in the past.

The Authors in written reply wished to thank all who had taken part in the discussion, and to express their appreciation of its high standard. The discussion had given opportunity in many cases to supplement important points in the paper, and they wished in the first instance to amplify the replies given to certain points raised at the meeting.

The question of compatibility and standardization of inhibitors, raised both by Comdr. Baker and Mr. Wilford, was very important. Fortunately, in the case of the low-temperature antoxidants there seemed little likelihood of chemical interaction. The response, of course, would vary from one oil to another, but laboratory experience seemed to indicate that in mixtures the effects were likely to lie somewhere between the individual effects of the mixed additive. It was naturally important that there should be no physical incompatibility such as might cause precipitation by "salting out" or otherwise. The case of rust inhibitors was rather more complicated, and close observation of the effects of mixing was essential.

Mr. Jarv's' reference to chlorinated solvents was very much to the point. Surfaces cleaned with such materials were liable to rusting if exposed to moisture. This might be due to the complete lack of protective surface envisaged by Mr. Jarvis, but it might, under certain conditions, be due to the chlorinated material being slightly decomposed. It was essential for both reasons to get the surfaces thoroughly cleaned and oil wetted as quickly as possible. It would be all to the good to use for this purpose oil containing the surface active materials described as rust inhibitors. This might be effected with some of the charge to be introduced, or with a special flushing oil, according to circumstances.

In amplification of the reference to Dr. Clayton's remarks on phosphating, it would seem likely that conditions were created by this process somewhat similar to those well explained by Beeck, Givens and Williams for the use of organic phosphates. The phosphatic layer originally formed underwent reduction, and the metallic phosphides thus produced melted or softened under the local high temperature conditions, more readily than the metal itself, thereby flowing and forming a new and smoother layer.

The authors wished to associate themselves with Dr. Clayton's plea for the inclusion of a test for salt in any scheme for used turbine oil analysis, or for that matter marine lubricating analyses in general, and with his view that salt-water under conditions where water wetting could take place was one of the most dangerous of all contaminants. Dr. Clayton's references to the absence of protection offered by rust inhibitors under conditions of condensation might be ascribed to finer particulation than in the case of mixtures of oil with water in "bulk". In the case of dispersion there was opportunity for the rust inhibitor to be adsorbed at the droplet interface, and thereby to prevent access, at least for a time, to the metal. With an incomplete inhibitor layer there was obviously more opportunity for the water to by-pass the rust inhibitor and attack the metal.

The authors replied to the written discussion as follows:—

Mr. L. J. Davies. The authors were pleased to note that Mr. Davies was in substantial agreement with the views expressed in the paper. They were, of course, aware of the close attention his company had given to ameliorating the rate of oil circulation in modern turbines, and the benefits which had arisen therefrom in increasing oil life. There was no question also that the radiation shields he described had had a substantial influence in reducing the thermal conditions of the high-pressure bearings, while the dry condition of the turbine charges was a true reflection of the effectiveness of the sealing fans incorporated on large turbines.

It was good to note the consideration being given to protecting the surfaces of return oil mains and those parts of the system which were not completely oil wetted. There was much to be done along these lines, particularly as steam temperatures increased and there was little doubt that improved protective coatings would become available.

In suggesting the use of saturated or desuperheated steam for gland sealing the authors had in mind the high-pressure end of the turbine, and while the conditions Mr. Davies described could produce vacuum, they thought this would not be a frequent occurrence on a large turbine, and under light load running the same temperature would be employed. Pressures would, of course, be similar under all load conditions, and under practically all conditions of load there would be a steam leak from the turbine side into the gland. The desuperheated steam in the gland would be raised in temperature by this leakage, but this heat transfer would undoubtedly minimize that along the shafting to the bearing oil film. There were indications that temperatures of 1,000° F. would not be uncommon, and if such steam were employed for gland sealing, other means entailing further complications would have to be found to minimize the heat passed to the bearing. On these lines of thought the employment of lower temperature steam for gland sealing purposes seemed worthy of further consideration.

It was appreciated that the insertion of high-pressure oil pipes in return oil mains might involve some complication in pipe arrangement, but the authors felt the benefits so derived would far outweigh higher initial outlay and the slightly increased maintenance cost. It was true, however, that as fire hazard increased as a result of higher thermal conditions, all precautions must be taken to minimize the risk of outbreak which might jeopardise the whole installation.

Mr. L. M. Douglas. The comments made by Mr. Douglas on the collaboration between turbine designers, builders and operators, and the oil industry were most welcome. The authors were in complete agreement that the progress made in developing new oils to withstand modern conditions of service could only have been made possible by such co-operation.

With regard to the maximum permissible neutralization value, it was not possible, as already indicated in the paper, to ascribe a maximum figure without knowledge and experience of the nature and history of the oils in use. Neutralization value was not so important as a knowledge of the type of change taking place and the rate of such change. It was a fact, however, that with inhibitor-treated oils there would be no substantial change in neutralization value until such time as the inhibitors were rendered inactive. Thereafter the oil would follow its natural curve in terms of neutralization value rise. For some oils the allowable rise in N.V. would be much higher than for others.

The authors were pleased to note Mr. Douglas' points in support of the use of saturated steam for gland sealing. Experience had shown that on difficult turbines it had been possible by this means to reduce bearing temperatures by 8° F. to 10° F., thus making a substantial reduction in the heat-oxidation attack on the oil. His reference to the investigation now being made by designers to increase the amount of oil flowing over the bearing and assisting its escape by more generous clearances was welcome, for any reduction in maximum bearing temperatures would be of great value as steam temperatures increased.

The authors were also in substantial agreement with all that had been said regarding the churning the oil was subjected to on meshing gears, and they welcomed the indications that these service conditions would be eased.

With regard to the separate lubrication of bearings and gears, it was appreciated this would involve considerable complication, but the thought in mind was to emphasize that turbine lubrication was of necessity a matter of compromise; and notwithstanding the advances made, it was still not possible to have ideal gear and bearing lubrication in one common system. As had been previously mentioned, slight viscosity increase alone would not afford any appreciable protection. The ideal would appear to be retention of the present viscosity range with incorporation in the oil of suitable additives which would not impair the stabilty of the turbine requirement. As Mr. Douglas rightly pointed out, however, gears as applied for marine purpose had not yet demanded lubricants with these characteristics; but, again, this was a matter engaging the attention of the oil industry, so that as the needs of the designer were made known oils of particular characteristics might be made available.

Mr. J. E. M. Payne. The authors were glad to note Mr. Payne's agreement with them on so many points. He had raised a number of very interesting features regarding fluid friction of oil and temperature, though this appeared to be of relatively small importance in so far as turbine bearings were concerned. Gear losses, and heat transmitted and radiated from the steam end were the principal factors in oil temperature increase. Specific heat in oils did not vary to any degree and in general was of the order of 0·5.

The authors were in substantial agreement on the appreciation of chemical and physical change existent in the minds of resident and operating engineers to-day. This was an indication and reflection of their knowledge of the increased selectivity of lubricants by modern power units.

So far as neutralization value rise was concerned, the authors had attempted to make clear that neutralization value in itself should not be employed as a yard stick in measuring an oil's suitability for further service. In highly paraffinic oils, neutralization values of quite low order might indicate ability to produce just that corrosion which Mr. Payne had in mind, whilst in more naphthenic oils the "acidity" to the same extent might be innocuous. Knowledge of the product, together with wide experience, was of the utmost importance before attempting to correlate mere neutralization with suitability for continued service.

His comment on rusting was opportune, but it was not clear whether in the case mentioned there was any appreciable amount of fresh or salt-water contamination. Nevertheless, it was possible under certain conditions, such as poor ventilation and the possibility of vapour return circulation from the reception tank, to produce rusting conditions without such intrusion, when not only rotor bearings but pinion bearings and gears could all show quite a serious degree of attack.

So far as machinery lying idle was concerned, the authors felt that by rotating the machinery by hand every day there was always the possibility of squeezing out some of the protective film of oil, and under such conditions they would advocate either priming each bearing prior to and after turning by hand, or, if possible, the employment of a hand pump to flood all bearings prior to moving the engine.

The authors were glad to have Mr. Payne's further contribution regarding the Channel packet and were pleased to note his agreement on all that had been said regarding the employment of double-bottom tanks for the reception of lubricating oil.

So far as rust inhibitors were concerned, they had no effect or influence on the oil's sensitivity to oxidation.

Mr. J. I. Hill. This contribution raised several important matters, and so far as the production of turbine oils containing little or no paraffinic hydrocarbon of the type prone to active acid development was concerned, the authors believed that in oils now available some success had been achieved in this direction. Without attempting to be too precise regarding numbers of cases where bad corrosion due to high active acidity had occurred, the authors could state that due to the advances made this was now an infrequent occurrence. It should also be remembered that precautionary measures were such to-day that the oils were removed prior to damage being sustained.

So far as shaft corrosion troubles were concerned, the authors agreed with the theory propounded by Mr. Hill that rusting and scuffing of gears and shafts was due in many cases to the preferential wetting of the surfaces by salt-water. With oils now available containing rust inhibitors, which could give protection even against salt water, the incidence of such trouble should be drastically curtailed.

The authors were also in complete agreement with all that had been said regarding laboratory testing methods, but it would be appreciated that great difficulties existed in attempting to reproduce actual service conditions in the laboratory. This was the principal reason for the introduction of the S.V. simulated turbine test. While it was admitted that difficulties existed in servicing marine equipment in such a manner that would ensure the closest possible liaison between operators and research workers, it was also true that development had now reached the stage where marine application did not impose service conditions as arduous as those on land. With the present type of facilities available for observation, therefore, needs could be more adequately catered for.

It was for this reason the authors had suggested three samples per annum being drawn from turbine systems. They felt that with proved products in use it was not necessary, and in fact had some quite serious disadvantages, to suggest more frequent testing. There were signs that with the growing appreciation of the importance of maintaining first-class lubricants in condition for prolonged service, maintenance and superintendent engineers were working in close harmony with technical representatives of the oil industry. Understanding, for example, of the disastrous effects which could be produced by accidental mixing had brought about a degree of care which some few years ago would not have beeen thought possible.

Mr. Hill's reference to a gear scuffing problem was most interesting and the authors were in complete accord regarding the necessity for the closest liaison between laboratories and operators when troubles of the nature described had to be resolved.

CORRESPONDENCE.

"Some Wartime Examples of Repairs to Merchant Ships", by C. Bartlett, B.Sc.

The Secretary,
The Institute of Marine Engineers.

Dear Sir,

With reference to the above paper, which appeared in the April, 1946 issue of the TRANSACTIONS (Vol. LVIII, Part No. 3), the following notes on ship repairs carried out by troops under the writer's command in North Africa may be of interest.

In one case the hatch in the 'tween decks of the damaged compartment was sealed off by welding plates over the beams, the 'tween decks also being made tight. Air was then pumped in until the vessel floated with the hole below the waterline, when she was able to proceed for permanent repairs.

A second vessel was of the Ocean type and had torpedo damage in the port side of No. 1 hold. A large hole bordered by damaged and broken plating extended from the 'tween deck to the double bottom and was approximately 55ft. wide. Owing to the demands for berthing space the ship was not laid alongside a berth but was moored stern to a breakwater. Suitable plates, sections, plant and tools required were brought out to the ship on flat deck pontoons of local construction made of timber (deck size 60ft.×40ft. approximately). The ship was trimmed by the stern and at the same time listed to starboard to 12 degrees angle of heel until the damaged shell was clear of the water down to the tank top plating. This was achieved by pumping tanks and the use of sand ballast. The bulkhead between Nos. 1 and 2 holds was shored up with 12in.×12in. and 9in.×9in. timbers.

The plating was laid out on the barge and butt-welded to suitable lengths so that it would overlap sound plating on each side of the damage by a minimum of three frame spaces. Rivets were cut out of these sound frames and corresponding holes drilled in the new plating. Two lifting eyebolts were welded at the top of each strake of plating. The strake was then lifted into position on the ship's side by a gun tackle rigged overside from the gunwhale bar and led to a winch. Bolts were passed through corresponding holes and nuts drawn up until a faying surface was obtained at the top and each side (plates were fitted in succession, clinker fashion, starting from the strake next to the sheer strake). At the lower levels the curvature of the waterline forbade the use of this method in the initial stages, so eyebolts were welded to the inside surface of the plating which was then pulled into place by tackles, the standing ends of which were fastened to suitable frames opposite the opening. Ropes from the tackles were led to other winches and to the windlass. The strake nearest the tank top was fastened to it by knees welded to both.

Two T-shaped stringers were welded to each plate and carried through from three to six frames each side of the damage. Additional knees were welded to frames and 'tween decks, and from beams to stringers in way of the damaged portion. The plating was continuous welded round all faying surfaces with one run of 10 S.W.G. and three runs of 8 S.W.G. electrode. The T-stringers were built up of two flat bars welded together and to the plating with intermittent fillet welds. A cement box was built on the tank top against the lowest strake of plating and extended for the whole length of the hold. This was done as it was found impossible to make a watertight joint between the plating and the tank top. Efforts to make No. 1 hold watertight in this way proved fruitless, as a diver's preliminary examination had failed to note damaged bottom plating about six feet outboard from the keel plate. Water came up through holes in the damaged tank top plating after the ship had been returned to an even keel and all efforts at pumping failed to keep the water under control. It was considered imperative to return the ship to U.K. as soon as possible, partly owing to the danger of further damage from enemy air attack; the time required to heel the ship again would have been too long, and since it was considered inadvisable to send the ship to sea with a large quantity of slack water in the compartment, large holes were cut in the shell plating (about 2ft.×3ft.) on both sides to allow the water free ingress and egress.

Work was started on 3rd March and finished on 28th April. Three heavy gales prevented all but minor work for about 14 days of that time. Further, the ship had been carrying cased petrol in the damaged compartment, so that burning away of damaged plating, etc., was interrupted at frequent intervals by fires. The ship sailed the day she was completed and subsequently returned to U.K. with a cargo of oranges for permanent repair.

The third vessel was of the Fort type and had torpedo damage in No. 2 hold but somewhat lower down than was the case with the second vessel, so that a large portion of the double bottom was extensively damaged but the 'tween decks were intact though slightly buckled. The aim in this case was to fit some kind of temporary strengthening to the ship to make up for the lost area of the equivalent girder. It was, of course, impossible to make the hull watertight, but some means had to be found to prevent the water washing into the hold in any force and pounding against the after bulkhead with the resulting danger of its failure. The damage occurred at approximately the position of the LWL, so that there was a natural tendency for the water to move inside. To break up the force of the water the opening was plated over down to 3ft. below the normal trim LWL in the light condition, in the same way as outlined above for the second vessel, but there was, of course, less difficulty in obtaining faying surfaces. T-stringers were also fitted as before.

To make up for the loss of strength T-shaped girders were built up. The angles ($3\frac{1}{2}$in.$\times 3\frac{1}{2}$in.$\times \frac{3}{8}$in.) and flanged plates ($8 \times \frac{3}{4}$ F.B.) were riveted to the web plate (1in. thick) with $\frac{3}{4}$-in. rivets, by a local French firm ashore and brought aboard in sections. Gusset plates were placed and 6×3 RSC's joined the 'tween deck to the upper deck. A built-up longitudinal girder was welded across No. 2 'tween deck hatch and the hatch beams were halved and welded in position to this girder and to the coaming brackets. Welding was used throughout in this repair except as above-mentioned.

On all these repairs about 20 men were employed, including two senior N.C.O.'s.

Yours, etc.,
E. F. J. PLOWDEN,
Major, R.E. (Graduate).

ADDITIONS TO THE LIBRARY.

Presented by the Publishers.

British Standards Institution.

P.D. 529. Amendment No. 2 to B.S. 665 : 1936—Vertical Cross Tube Boilers.

B.S. 1312 : 1946—Fuel Fired Regenerative Tank Furnaces for Melting Glass, 67pp., price 5s. net, post free.

Journal of the Institute of Petroleum. June, 1946, Vol. 32, No. 270.

Transactions of the Newcomen Society. Vol. XXII, 1941-1942.

The Operation of Gas Producers. Fuel Efficiency Bulletin No. 44, July, 1946. Prepared by the Fuel Efficiency Committee of the Ministry of Fuel and Power. 32pp., illus. This Bulletin can be obtained free on application to the Ministry of Fuel and Power, Queen Anne's Chambers, Dean Farrar Street, Westminster, or from the Ministry's Regional Offices.

Electric Power Engineers' Handbook. (Second edition). By W. S. Ibbetson, B.Sc., A.M.I.E.E., M.I.Mar.E. E. & F. N. Spon, Ltd., 57, Haymarket, London, S.W.1. 1945. 295pp., 126 illus., 15s.

German Piston Manufacture. British Intelligence Objectives Sub-Committee Final Report No. 499—Item Nos. 18, 19 and 26. H.M.S.O., London, 119pp., illus., price not known.

Marine Engineers' Handbook. By J. M. Labberton, Editor-in-Chief. McGraw-Hill Book Company. 1945. 195 pp., profusely illus., $7.50.

The Editor-in-Chief of the first edition of this handbook has compressed into one volume the work of many specialists in the increasing and expanding branches of Marine Engineering and Naval Architecture.

The first chapters of the book are devoted to the usual mathematical tables and engineering fundamental knowledge. The field covered in fundamental knowledge of mathematics, mechanics, materials, heat engines, etc., is more lucid and comprehensive than is generally found in handbooks of this type and supplies the reader with up-to-date information.

Into the subsequent chapters dealing with the various types and details of marine and auxiliary engines, the author has compressed most of the latest available information on current practice. In addition to the information on marine engines, there is much information on hulls, propellers, heating and ventilation for the naval architect. The book fittingly ends with a chapter on ships' trials which should prove a most valuable refresher for responsible persons taking part in these momentous occasions and a chapter of instruction for the uninitiated.

This is an up-to-date authoritative reference book of the highest order. It should be noted that it is an American product and in some details varies from current British practice. Even these variations are stimulating. As a handbook it can be recommended to all persons engaged in the science and practice of marine engineering and naval architecture.

The Mid-Twentieth Century Atom. By Martin Davidson, D.Sc., F.R.A.S. Hutchinson's Scientific & Technical Publications, Ltd., London. 1946. 124pp., 15 figs., 8s. 6d. net.

Since the use of the atomic bomb a considerable amount of interest has been aroused in the nature and structure of the atom. It is safe to predict that the energy of the atom will some day be utilized for commercial purposes and that its release, under conditions permitting the energy to be controlled, will revolutionize our industrial system. Meanwhile people's attention is focused on the use of the atom for purely destructive purposes, and there is a feeling of apprehension, with a certain amount of justification, about its terrible possibilities in the event of another war.

This book deals primarily with the modern conception of the structure of the atom—not with the atomic bomb. It is specially intended for those whose knowledge of physics and chemistry is very limited or non-existent. It shows that there is latent an enormous store of energy in the atom—not only of the heavier elements like uranium, plutonium, etc., but also of the lighter elements—and describes how this energy can be released under certain conditions. In addition, it deals with the source of the prodigious amounts of energy emitted by the sun and other stars in the form of heat and light, showing that the emission of this energy is due to the transmutation of certain elements under the conditions of high temperature and pressure existing in stellar interiors. It describes what the final fate of our sun will be when the complete transmutation of its hydrogen content has taken place.

A number of illustrations assist the reader in understanding certain points connected with atomic disintegration, and the Appendices are specially intended for those whose knowledge of physics, chemistry and mathematics is beyond that of the mere novice.

Mechanical World Monograph (21).

Finance for the Engineer. By Gordon Lowe. Emmott & Co., Limited, London and Manchester. 1946. 50pp., 2s.

Too often enterprising company promoters succeed in securing opportunity to provide finance for clever engineers, on terms which favour those who put up the money, rather than the engineer who has provided the root stock of a potentially successful business.

Every engineer of ideas will be well advised to read and digest "Finance for the Engineer" before he attempts to build up a business of his own. This little Monograph is very interesting and helpful. That it must not be regarded as covering the whole ground will be fully appreciated by engineers already launched upon business enterprises—to whom, however, the book can be well recommended as containing some useful ideas, suggestions—and warnings.

Electrical Technology for Beginners. By G. W. Stubbings, B.Sc., F.Inst.P., A.M.I.E.E. E. & F. N. Spon, Ltd., London. 1946. $7\frac{1}{4}$in.$\times$5in., 152pp., 48 figs., price 6s. 6d.

This, the second edition of this book, has been corrected and revised; additional matter has been incorporated on metal rectifiers, electricity supply regulations, cables, and installation testing, and some additional numerical questions have been included.

On its title page this book is described as "a simple non-mathematical textbook on the supply and utilization of electricity up to matriculation standard". It is very many years since the reviewer took "Electricity and Magnetism" as one of his matriculation subjects, but he does not recollect that it included "supply and utilization", and very much doubts if it does to-day. Again, in the preface to the first edition the author stated that "This book is intended to assist those who have have had no regular training in physical science and mathematics . . . " and " . . . is primarily intended to meet the needs of students preparing for the elementary electrical engineering examinations of The Chartered Insurance Institute and of apprentices preparing for The City and Guilds of London Institute in Electrical Installation Work". But most, if not all matriculations require some knowledge of mathematics, and the "B" course of The City and Guilds contains a subject "Calculations and Drawing" which appears in all three years of the course, and in the electrotechnology paper some knowledge of general science is expected, so there is no point in trying to avoid the mathematical issue. In any case, one can go quite a fair way in the study of electricity without any more elaborate mathematical equipment than the ability to do correct arithmetic, including the manipulation of fractions and decimals, the ability to state and solve a simple equation, and a smattering of trigonometry. One feels that the author never quite made up his mind for whom he was writing.

Having expressed this opinion, and it is but an opinion, one hastens to add that the author has presented a considerable amount of sound electrical information in a precise and concise form—perhaps sometimes too concise for the reader who is anticipating being confronted with an examination paper.

There are a number of good line diagrams, but one of these, Fig. 6, where directions are of primary importance, is not too clear. One has to invoke the very principle which the diagram purports to illustrate, to interpret the diagram. For the type of student for whom the author is avowedly writing, he should avoid such expressions as "integral submultiple". The reviewer can assure him that not one in a hundred will have the faintest idea as to what it means.

On page 70— sixth line from bottom of page—the word "current" is obviously meant to be "circuit". This correction should have been included in the errata slip at the beginning of the book.

Despite all of the above criticism, there is much that is extremely good in this book. It avoids "sloppiness" and imprecision in statements of physical facts and in definitions, and the method of treating R.M.S. values for non-mathematical students is quite ingenious.

The Installation and Maintenance of Boiler House Instruments. Ministry of Fuel and Power Efficiency Bulletin No. 45, August, 1946. 24pp., 9 figs., can be obtained free on application to the Ministry of Fuel and Power, 2, Little Smith Street, Westminster, or from the Ministry's Regional Offices.

Presented by the Author.

Our Indebtedness to China and **Russia's Great Opportunity.** By H. E. Metcalf, M.I.Mech.E., M.I.N.A., M.I.Mar.E., author of "On Britain's Business", "Beware Japan's Leaders", "India's Glorious Future". Printed in England by Waynford Press, Ltd., Grove Road, Eastbourne. 1946. 2s. each.

Purchased.

British Intelligence Objectives Sub-Committee. Final Report, No. 509. Item No. 29. Voith-Schneider Propeller. H.M.S.O. London. 9½in. by 7¼in., 5pp., 1s. net.

Presented by the Publishers.

Practical Hydraulics. By Thomas Box. (Seventeenth edition, new impression). E. & F. N. Spon, Ltd., London. 1943. 109pp., 48 figs., 9s.

The Sixteenth Edition of this book now being exhausted, the opportunity has been taken to produce a new edition, which has involved a considerable amount of alteration. The illustrations which were all at the end of the book have now been inserted in the text adjacent to matter referring to them. Many of the tables have been re-arranged so as to bring them as close to the descriptive matter as possible, and in a more convenient way to the reader. All known errors have been corrected and many additions and modifications of the text have been effected.

New tables, formulæ and illustrations have been added for the discharge of water over the 90° V notch or weir in gallons per minute. The index has been re-arranged to refer to items under paragraph numbers which will greatly facilitate reference.

It may be anticipated that this new edition will by its increased usefulness and ease of reference be as well received as its predecessors.

Metallic Corrosion Passivity and Protection. By Ulick R. Evans, M.A., Sc.D. Edward Arnold & Co., London. Second edition 1946. 814pp., 144 figs., 50s. net.

To all engineers metallic corrosion is of importance and it would be difficult to find an example of such corrosion in any branch of engineering which is not referred to in the 814 pages of this excellent book. Whilst the book contains beneficial information for the student, the designer and the research worker, it is of particular value to the marine engineer.

Every chapter is divided into three sections; the first being the scientific basis for the subject in question; the second—practical examples of the particular problem, and the third a quantitative treatment of the subject.

Several chapters deal with the factors which influence the corrosion of ferrous and non-ferrous materials. The sections dealing with ships, hulls, oil tanks, propellers, riveted and welded joints, etc., are of particular interest to the marine engineer. The corrosion of boilers and turbine blading is mentioned.

The various methods of protection against corrosion are fully described and one chapter is entirely devoted to protection against corrosion by paints and enamels, with a section dealing with marine painting.

In the chapter dealing with oxidation at high temperatures a section is devoted to the oxidation problems of the melting shop and foundry and a complete chapter is devoted to protection against corrosion by inhibitive treatment of water which includes a section on boiler water treatment.

Throughout the book there are copious references to technical articles on the various subjects.

OBITUARY.

Mr. David Goodsir.

It is with deep regret that we record the death of Mr. David Goodsir (Member 4348 and Past Member of Council), which took place at his home at Ilford, Essex, on Saturday, 13th July, 1946.

Mr. Goodsir was born at Kirkcaldy on 22nd August, 1881, and served his apprenticeship with Messrs. W. M. Melville, Kirkcaldy, from 1896 to 1902, and was subsequently for a short time with Messrs. Barry, Ostlere & Shepperd, Ltd., of that town.

In 1905 he joined the Peninsular & Oriental Steam Navigation Company as a junior engineer and was on board the "Delhi" when she went ashore off the coast of Morocco in December, 1911. From 1914 to 1919 Mr. Goodsir was foreman engineer at the Mazagon Dock, Bombay, afterwards returning to sea. He was promoted chief engineer of the s.s. "Mooltan" in 1930, subsequently serving in the

"Viceroy of India" and the "Strathaird". In 1934 he went to Barrow-in-Furness for the building of the "Strathmore", in which he sailed for the maiden voyage when the vessel made a record run to Bombay.

Mr. Goodsir was appointed assistant superintendent engineer in the Company's London office in January, 1937, and he became superintendent of maintenance and personnel in 1939, a post which he held until his retirement through ill-health in March, 1945, after almost 40 years in the service of the Company.

A Member of the Institute of long standing, Mr. Goodsir was elected to the Council in 1940 and served in this capacity until 1942. His death is keenly regretted not only by his colleagues on the Council, but by his many friends amongst the membership and in marine engineering circles where he was so well known and esteemed.

MEMBERSHIP ELECTIONS.

Date of Election, 16th July, 1946.

Members.

Anthony Joseph Bradford.
Alfred Norman Bramald.
James Charles Buchanan.
Royston G. Ferguson.
William Peter Glen.

Dudley Gualbert Hogan.
Reginald John Keough.
John Munro.
Percy R. Owens.
Stanley Paul Quenet, Temp. Lieut.(E.), R.N.R.
Bruce Graham Sherratt.
George Henry Strong.
Norman Turner, Major, I.E.M.E.
Simon Servaas Ulrich.
Frederick John Ward.
George Crawford Watson.
Sergey Zinoviev, Eng. Capt., U.S.S.R.N.

Associate Member.

John William Greener, B.Sc.

Associates.

Kenneth William Berry, Ch. E.R.A., R.N.
Thomas Brydon.
Edward Frederick Butler.
Henry Castles.
Richard Doling.
Robert Fairweather.
Harry Hatfield.
Kenneth Hebb.
Walter Laurence Hughes, B.Eng.
Frank Carvell Love, Comm'd. Eng., R.N.(ret.).
Frank Ronald Marriner.
Alan Pentney.
Gordon Pybourne,, Lieut.(E.), R.N.V.R.
John Mackie Walker.
Laurence Charles Webb.
Anthony John Wharton.

Graduates.

Thomas Derek Aldwell, A/Lieut.(E.), R.N.
Donald John Spruce Ashley, A/Lieut.(E.), R.N.
Jagoish Mitter Bazaz, Lieut.(E)., R.I.N.
Robin Moore Inches, Lieut.(E)., R.N.
John Charles Mardon Longley, A/Lieut.(E.), R.N.
William John Prowse, A/Lieut.(E.), R.N.
Walter Hugh Stead, A/Lieut.(E.), R.N.
Ronald Sidney Trowell.

Students.

Paul Eric Bass, A/Lieut.(E.), R.N.
Norman Probert Elson.
Peter Grimley Evans, A/Lieut.(E.), R.N.

Transfer from Associate Member to Member.

Arthur Charles Efford.
Thomas William Ross.

Transfer from Associate to Member.

Ivor Wilton Shelly.

Transfer from Associate to Associate Member.

Cyril Raymond Charlton.

Transfer from Student to Graduate.

Myles John Nash McLachlan, Lieut.(E.), R.A.N.
Frederick Miguel Shaw, A/Lieut.(E.), R.N.
Michael Trounce, A/Lieut.(E.), R.N.

PERSONAL.

D. G. Alcock (Member) has been appointed an engineer surveyor to The London & Lancashire Insurance Co., Ltd.

Lt. (E) K. J. Bateson, R.N.R. (Associate) has now been demobilized from the Royal Navy.

T. W. Burt (Associate) has been demobilized from the Royal Navy and is now employed as assistant engineer with Messrs. Kemball, Bishop & Co., Ltd., Bromley-by-Bow.

A. C. Butcher (Member), who for 21 years has been surveyor of machinery to the Royal National Lifeboat Institution, has been promoted to the post of superintendent engineer.

J. W. Coulthard (Member) has been appointed superintendent mechanical engineer to Messrs. K. L. Kalis, Sons & Co.

John Craig (Associate) is at present engaged as superintendent and consulting engineer to several shipping companies in Aberdeen.

C. G. Crook (Associate) has been appointed to the staff of the Ministry of Works.

Eric Davies (Member) has been decorated by the Representative of the French Government in China with the Cross of a Chevalier of the Legion d'Honneur.

A. C. Efford (Associate Member) has been appointed a surveyor to the British Corporation Register of Shipping and Aircraft.

Lt.-Cdr. (E) C. R. English, B.Sc., R.N. (Associate Member) has been released from the Royal Navy and has been appointed H.M. Inspector of Technical Schools and Colleges under the Ministry of Education.

Lt.-Cdr. (E) P. Fondeur, F.N.R. (Member) has been awarded the Cross of Knight of the Order of the Legion of Honour and the Cross of Knight of the Order of Merit (Merchant Navy) for outstanding services with the Free French Navy and the Free French Merchant Navy from 1940 to 1945. Cdr. Fondeur was a surveyor in France to Bureau Veritas before the war and now, on his release from the French Navy, has been appointed an inspector on the French staff of the Society. At present he is attached to the London office on temporary duty in Great Britain.

A. Gamble (Member) has been engaged by the Crown Agents for the Colonies as 2nd engineer for the Uganda Harbour and Railways.

Maj. R. T. Gardiner, I.S.E. (Member) has been awarded the M.B.E. for services rendered during operations in Greece in 1944/45.

A. D. Hayward (Member) has left the Air Ministry Directorate of Works to take up an appointment with the Ministry of Works.

J. Henderson (Member), who held the rank of temporary acting Lt.-Cdr. (E), R.N.R., has been demobilized from the Royal Navy.

B. Hill (Associate) has been appointed an engineer surveyor to Lloyd's Register of Shipping.

W. J. Hipwell (Associate) has been appointed assistant superintendent engineer, Port and Marine Department. Trinidad.

A. M. Keith (Member) has been granted the rank of Lt.-Cdr. (E) R.N.R.

F. R. Lawrance (Associate)has joined Messrs. Gow, Harrison & Co. as second engineer.

W. Maddock (Member) has been appointed a technical assistant to The Chesterfield and Bolsover Water Board.

R. A. MacDonald (Member), who has been awarded the D.S.C. for distinguished service in the European theatre during the war, has now joined the staff of The British Electrolytic Condenser Co. of Ilford.

A. D. Marshall (Member) has been released from the Royal Navy, retaining the rank of Ty. Lt.-Cdr. (E), R.N.R.

J. A. Matthews (Member) has been appointed chief engineer of The Eagle Star Insurance Co., Ltd.

Group Capt. H. Nelson, R.A.F. (Associate Member) was awarded the C.B.E. in 1944 and this year he was decorated with the American Legion of Merit (Degree of Officer). Capt. Nelson is the author of a dictionary of aeronautical terms.

John Patrick (Member) has been elected an Associate Member of the Institute of Industrial Administration.

Sir Frederick E. Rebbeck (Past-President and Member) has been awarded the honorary degree of Doctor of Science by Queen's University, Belfast.

A. Simmons (Member) has joined the Gas Light & Coke Co., Ltd. in the capacity of safety officer.

Sub. Lt. (E) C. E. Strugnell (Associate) has been released from naval service and has joined Messrs. Brown Bros. & Co., Ltd. as plant manager.

J. B. Stuart (Member) has secured an appointment in the specification office of Messrs. Harland & Wolff, Ltd., Glasgow.

D. Turner (Member) was recently appointed chief engineer of The Ship Carbon Co. of Gt. Britain, Ltd.

J. C. Wallhead (Member) has been released from the Royal Navy and has resumed his former employment with the Port of London Authority.

J. R. Ward (Member) is leaving his appointment as senior works manager of The Middle Dock & Engineering Co., Ltd., to become marine superintendent of Messrs. Coastwise Colliers. Ltd. of London.

G. Ridley Watson, B.Sc., (Member), who is London technical director of Messrs. Henry Robb. Ltd., has been appointed a director of Messrs. Jacobs, Barringer & Garratt, Ltd.