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SOME ASPECTS OF STANDARDIZATION IN OIL MEASUREMENT.

By H. Hyams (Fellow).

Chairman of Standardization Sub-Committee No. 1—Measurement and Sampling.

It is pleasing to be able to report that close co-operation on oil measurement matters has been established between the A.S.T.M. Committee on Gaging, and the Institute's Sub-Committee No. 1, the first-fruits of this being the joint publication of two documents entitled respectively " Principles Governing Oil Measurement Procedure " and " Tables for Converting Metric Tons in Vacuo to Long and Short Tons in Air." These are published in the current issue of A.S.T.M. Committee D2 Report, and in the 6th edition of the Institute's " Standard Methods for Testing Petroleum and Its Products."

The standardization work of the Institute of Petroleum's Standardization Sub-Committee No. 1 has been divided into seven sections, each dealt with by a separate Panel. These Panels cover the following subjects :

(1) Tank calibration.
(2) Measurement of oil depths.
(3) Measurement of oil temperatures.
(4) Measurement of oil gravities.
(5) Sampling.
(6) Calculation of volumes and weights.
(7) Apparatus for oil measurement.

A further Panel has recently been formed, including members nominated by the Standardization of Tar Products Tests Committee, to deal with measurement of blends of coal-tar and petroleum products.

In submitting their draft methods to the Sub-Committee for confirmation, the Panels draw attention to any points of doubt or difficulty, or on which there has been division of opinion.

In this paper it is proposed to discuss a few of the problems which have been or still are occupying the attention of the Panels.

(a) *Tank Calibration.*

New types of storage tanks continue to appear, and although various authorities have recommended methods of calibration, no comprehensive publication on the subject is yet available. Panel No. I is working on the preparation of such a document, but among other difficulties the following thorny questions confront them :—

(i) Is the external strapping method to be preferred to the internal diameter method for vertical tanks, or should both methods be approved, if they are geometrically equivalent ?

(ii) Should allowance be made for expansion of the tank under oil head, and, if so, how should fully or partially supported buried or bricked-in tanks be treated?
(iii) To what extent should water-filling be used in calibrating small tanks or parts of large tanks?
(iv) Should both water-filling and strapping methods be accepted as standards for the preparation of tables for horizontal tanks, and how are these methods affected if these tanks are tilted?
(v) What procedure should be used to calibrate tanks with floating roofs, ship and barge, rail-car and road-wagon, spherical and spheroidal tanks, and other bulk containers?

These are a few of the questions which the Tank Calibration Panel must answer before their work can be considered as complete.

(b) *Measurement of Oil Depths.*

Panel II has made substantial progress in standardizing methods for measuring the depth of oil in containers, a tentative but complete set of procedures for these measurements having been published in the February, 1945, issue of this Institute's Journal. The Sub-Committee invites comment and criticism on these, so that an I.P. Standard Method may be put forward. There are difficult problems here also, such as, for example :—

(i) What methods are to be used to determine the quantity and oil-content of emulsified sediments on tank bottoms?
(ii) What are the real merits of the hydrostatic gauge and the meter for measuring oil quantities?
(iii) What are the best means of gauging a pressure tank containing a highly volatile gasoline where no gauge glasses are available?

(c) *Sampling and Average Tank Temperature.*

Panel IV is preparing a standard procedure for obtaining the average temperature of the oil in storage vessels; this is obviously important, since an error of 2° F. in the average oil temperature leads, in the case of the lighter oils, to an error of over 0·1 per cent. in volume calculations. Any proposal to circulate a tank's contents because the gauger wants an accurate average temperature is usually looked on with disfavour by the installation manager, so that oil in storage is seldom uniform in temperature throughout its depth. Careful attention therefore must generally be given to the number of samples drawn, and the levels from which they are taken, as well as to the apparatus and procedure used for drawing the samples and for taking their temperatures.

(d) *Apparatus.*

Specifications for recommended types of dip tapes, dip weights, ullage rules and water finders have been prepared by Panel VII and appear in the paper by Panel II on "Measurement of Oil Depths" referred to above. Much comment on these is expected, because the oil gauger undoubtedly has very strong likes and dislikes where oil measurement apparatus is concerned.

Interest has recently been aroused in the materials to be used for measuring water depths and ullage levels in storage tanks.

Hydrometers and samplers are now carefully specified in Standard Methods, and it is hoped to produce before long recommended standards for thermometers to be used in oil temperature work.

(e) *Standard Temperature in Oil Measurement.*

It is not out of place to recall here that a short time ago the Institute aligned itself with the A.P.I. and the A.S.T.M. by confirming its acceptance of 60° F. as the standard temperature both for specific gravities of petroleum oils and for correction of oil volumes. This declaration of policy on standard temperature in the petroleum industry was necessary because adherents of the metric system proposed to have 20° C. recognized as the international standard temperature in the petroleum industry.

(f) *Units of Measurement and Tables.*

This difference of view on standard temperature leads naturally to a discussion of the systems of weights and measures which are widely employed, and the necessity for inter-relating them for commercial usage; the prospect of the adoption of any international system of weights and measures would seem to be as remote as ever. In the oil industry the three principal systems are the American, the Imperial or British, and the Metric. By its publication in 1932 of " Standard Weights and Measures," a booklet which laid down authoritative conversion factors in the three systems of measurement, Sub-Committee No. 1 made a valuable contribution towards standardization of conversion factors in oil measurement calculations. The tables in that book have been accepted in the United States, and international status may be claimed for them. But that is only a fraction of the problem. So long as oil is handled both by volume at standard temperature and by weight, we have to guide those concerned in the simplest and most accurate methods of computing quantities. An important contribution in this connection is to be the publication by the Institute of Petroleum in the near future of a book of oil measurement tables. The production of this authoritative book of over 300 pages is perhaps the biggest standardization task which Sub-Committee No. 1 has so far undertaken. It provides a set of tables which will allow the correct conversion of weights *in vacuo* in the metric system to weights in air in the British and American systems. The tables will be in very close alignment with the American Bureau of Standards tables, so widely used in the American oil industry, but as a British Standardizing body the Sub-Committee has naturally constructed the tables so that they will facilitate weight and volume computations in British units. It is realized, however, that this new production does not complete the work under this heading.

In the not very distant future a wider variety of commercial products will be available, and it is not certain that the present tables for correcting specific gravity and volume for temperature change will be satisfactorily applicable to these new products. It is possible that the changes necessary may involve reconsideration of the whole basis on which the present tables are computed.

Again, tables are needed which will allow reduction to 60° F. of the specific gravities and volumes of the liquefied gases—propane, butane, and the like. These tables should, of course, be based on or correlated with some simple physical property of these products, one which can be measured easily in a small installation. Tables for blends of petroleum products with coal-tar products and with alcohol must also be provided, but, as already mentioned, steps towards this have been taken. Preliminary investigation shows that the problems which the new Panel will have to consider are not likely to be easily solved.

This paper shows that much has already been done on the standardization of oil measurement procedure, although the Sub-Committee's Panels are likely to have heavy programmes of work for a considerable time yet. Valuable co-operation has been received from all members of the Sub-Committee in the work on which we have been engaged and, since the bulk of that work has been carried out under war-time conditions, the progress which has been reported speaks for itself.

SULPHUR ESTIMATION BY LAMP METHOD USING I.P. TEST 107/45 (T).

By A. R. Javes, B.Sc., F.R.I.C. (Associate Member).

In the sixth edition (1945) of " Standard Methods for Testing Petroleum and Its Products " the Institute of Petroleum has adopted, as a tentative standard, an additional lamp method for the measurement of the sulphur content of petroleum products.

The previous lamp method (I.P. 62/42) is limited in scope, not being suitable for sulphur contents of less than about 0·01 per cent. Also, the apparatus does not permit of the combustion being carried out in purified air.

It is now frequently necessary to measure sulphur contents much lower than 0·01 per cent. and to burn the test sample in an atmosphere substantially free from impurities. In the case of the volumetric method the impurities include, not only sulphur compounds, but also acid vapours and materials which form acids when in contact with the flame. The gravimetric and turbidimetric procedures, based on measuring a precipitate of barium sulphate, are affected only by sulphur-bearing impurities.

A blank test is usually made for these impurities by burning a sulphur-free material, such as alcohol, in another apparatus and subtracting the titration of the blank from the titration obtained with the test sample. If the sulphur content of the test sample is low, then it is possible for it to be almost equalled by the blank, in which case the results obtained for the sulphur content of the test sample are very unreliable.

There was, therefore, a need for a standard method in which the procedure for working-up the test solution could be chosen to suit the magnitude of the sulphur content of the sample, using a form of apparatus suitable for carrying out the combustion in purified air.

The new lamp method I.P. 107/45 (T) is designed to cover the full range of sulphur contents which are likely to be met, and is suitable for materials ranging from gases to gas oil. The apparatus is suitable for burning the sample in purified air, or in a mixture of oxygen with nitrogen or carbon dioxide from cylinders.

While this procedure does not eliminate the need for a blank test, in general it ensures that the amount of sulphur found in the blank test is not excessive. A large part of the blank can come from the reagents.

The lamp is so designed that primary air is injected into the wick tube 30 mm. from the top. This gives a very rapid rate of combustion, and even highly aromatic materials can be burned without smoking. It is customary to use enough primary air to produce a steady and smoke-free flame, but not enough to produce a bunsen-burner effect. Materials in the gasoline range can often be burned at a rate as high as 8 ml./hr.; kerosines at about 5 ml./hr. Gas oils will burn at just over 1 ml./hr., if previously mixed with a sulphur-free diluent.

The lamp is constructed with the burner and the oil flask sealed together, so as to prevent the loss of vapour which might occur if the burner were corked into the oil flask. A T-piece burner is used for gases. The wick is introduced through the filling hole into the oil flask and then pulled into place with a hook-ended piece of wire.

The chimney is large enough to provide a sufficient reserve of air to prevent the flame from going out while the lamp is being corked in. The water jacket is fitted to the outlet tube so as to cool the flue gas passing to the absorber. Without the water jacket, the heat from the burner is sufficient to melt the rubber tubing joint between the chimney and the absorber and to evaporate the solution in the absorber. The chimney is quite easy to wash through with distilled water at the end of a test.

The absorber is a modification of the absorber specified for use with the previous I.P.T. G.4 method, the enlarged top allowing for the increase in volume of liquid in the absorber, due to the condensation of the water formed by the combustion of the sample, and also helping to prevent the absorber solution bubbling over into the Drechsel bottle. A drain tube is also provided so that the absorber contents can easily be transferred to a beaker at the end of a test, in preparation for working them up by the gravimetric or turbidimetric procedures.

The Drechsel bottle is used purely as a catch-pot for any absorber solutions which may bubble over.

A flowmeter is used at the exit end of the Drechsel to facilitate lighting and control of the lamps, and in addition it enables all the lamps and the blank to be adjusted to take the same quantity of air. The purity of the air is less critical if this adjustment is made.

This apparatus has been in use for the last three or four years for gravimetric and turbidimetric sulphur contents. Two operators can handle up to twenty lamps between them. When the lamps were first put into use it was noticed that operators preferred them to the old style (such as those used for the I.P. volumetric method) on account of the ease of operation.

The method allows the test solutions to be worked up volumetrically, gravimetrically or turbidimetrically. The volumetric procedure is substantially the same as that for method I.P. 62/42, the advantages of the new method being an improved control of the flame, burning in purified air and a more rapid combustion of the sample. It suffers from the same disadvantage as I.P. 62/42, in that nitric acid formed in the flame is recorded as sulphur, with the result that it is not suitable for sulphur contents of less than 0·01 per cent.

The gravimetric and turbidimetric procedures do not suffer from this limitation, as the sulphur compounds are measured after precipitation as barium sulphate. The gravimetric procedure is quite conventional. It is not suitable for sulphur contents of less than 0·001 per cent., but there is no upper limit. The repeatability of results is of the order of 0·001 per cent.

The turbidimetric procedure is suitable for sulphur contents down to 0·0001 per cent., with a repeatability of 0·0002 per cent. There is an upper limit for the use of this procedure, which depends upon the make of turbidimeter used and which is usually between 0·005 and 0·01 per cent. sulphur, but this range can be extended by burning less sample or by taking an aliquot part of the test solution. Measurement of the turbidity produced by the barium sulphate is a very quick operation, and can be made within a few minutes of adding the barium chloride. This procedure is based on that given by Zahn [1] for the measurement of low sulphur contents in petroleum products.

The sulphur content range between 0·001 and 0·005 or 0·01 per cent. is covered by both the gravimetric and turbidimetric methods, but the turbidimetric method is the more accurate of the two in this region.

The efficiency of the lamps and apparatus, and of the gravimetric and turbidimetric procedures, has been examined very thoroughly.[2] The work included measurements to ascertain whether high boiling sulphur compounds were likely to remain behind on the wick of the lamps; whether errors were likely to be caused by the sulphur content of the wick itself; a comparison of blank tests made without a flame, with an alcohol flame and with an electric heater; the effect of sulphur in the rubber-tubing joints; the effect of tetra-ethyl lead on test results, etc.

The method of test specifies that if the gravimetric or turbidimetric procedures are going to be used to test a leaded fuel, then the lead must first be removed by washing the sample with fuming hydrochloric acid. The reason is that, if a leaded fuel is burned, part of the lead is deposited on the wick and a larger part on the chimney. A portion of the sulphur content of the sample is deposited with this lead. This is not all dissolved when the chimney is washed through with water into the beaker of test solution at the end of the combustion. This effect is not peculiar to the lamps used with this method of test, though the error introduced is larger than it would be with a lamp with a plain wick tube.

The order of magnitude of the effect of lead on the results of a sulphur determination is shown by the following values taken from a graph correlating the results of just over a hundred tests made on various classes of motor fuel before and after leading.

Sulphur Content, %.	Sulphur Found, %.		
	Deleaded.	Slow Lamp.	Fast Lamp.
0·0001	0·0001	0·0005 *	0·0002 *
0·0010	0·0010	0·0008	0·0004
0·0040	0·0035	0·0026	0·0016
0·010	—	0·0076	0·0041
0·100	—	0·094	—

* The reason for these high results is obscure. It may be caused by the co-precipitation of lead with the barium sulphate.

It can be seen that quite serious errors can arise, particularly when the sulphur content is low, if no precautions are taken to avoid errors caused by the lead.

An alternative to deleading is being tried. This consists of washing the lead film off the chimney with acid into the beaker of test solution. Preliminary information shows that it is very effective, but a final decision on the procedure has not yet been made.

The blank test is always very important when testing materials with a low sulphur content, and it is useful to have some information as to the

[1] Zahn, V., *Ind. Eng. Chem.* (*Anal.*), 1937, **9**, 543.
[2] Javes, A. R., *J. Inst. Petrol.*, 1945, **31**, 129.

contribution which various factors make to the overall magnitude of the blank. The method to be adopted for purifying the air will depend largely on local circumstances. Experience in a rural district has shown that scrubbing with a continuously renewed supply of tap water is as good as any other purifying treatment. The purity of the air so obtained gives a blank test which is substantially the same as that obtained when working with a mixture of oxygen with nitrogen from cylinders.

Provided that the blank is not too large relative to the sulphur content of the fuel, its actual magnitude does not matter, as long as it is a constant quantity for all the lamps. A recent analysis showed that the greater part of the blank came from the reagents and distilled water. The reagents were all used in measured quantities, so their contribution was fixed, and the quantity of distilled water used was kept as constant as possible by topping all the beakers up to the same level after washing out the apparatus. A graduation mark was painted on the beaker to facilitate this. The results of the analysis were :—

Blank Determination.	Sulphur Found, mg.
Average of 14 blank determinations using the electric heater in place of a flame	0·170
Blank due to distilled water and reagents	0·158
Blank due to air by difference	0·012

The portion due to reagents and distilled water was then examined for the contribution which each made to the blank, with the following results :—

Reagent.	Quantity Used in a Normal Sulphur Test.	Sulphur Found, mg.
Distilled water	say 400 ml.	0·039
Sodium carbonate N/4 . . .	20 ml.	nil
NaOH/Br N/4	10 ml.	0·053
Hydrochloric acid N/1 . . .	19 ml.	0·013
Phenolphthalein	1 drop	nil
Caustic soda, 20%	1·4 ml.	0·030
Alcohol/glycerol	20 ml.	0·001
Barium chloride crystals . .	0·3 g.	nil
Total	—	0·136

This total differs from the value of 0·158 mg., when they were all bulked together, by only 0·022 mg., and this difference can be accounted as being well within the experimental error of the procedure employed.

The fact that the barium chloride was also tested may seem strange, but it must be remembered that it is in the form of small crystals. A batch of sieved crystals will last for a very long time, during which it might become contaminated with solid impurities (*e.g.*, dust). These impurities might be insoluble and recorded in the turbidity, or they might contain sulphate which would be converted to barium sulphate when the barium chloride crystals went into solution during the test.

STABILITY OF FUEL OIL.

By W. E. J. Broom,* Ph.D., B.Sc. (Fellow).

Chairman of Stability of Fuel Oils Panel of Standardization Sub-Committee No. 4—Gas, Diesel and Fuel Oil.

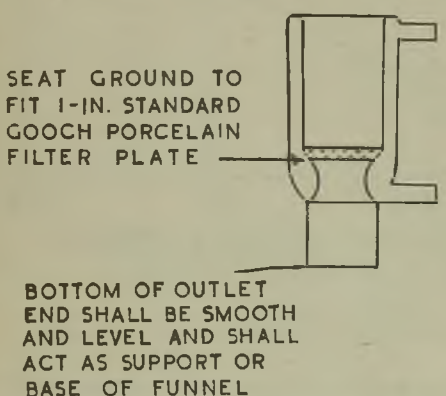
During the past two years the Stability of Fuel Oils Panel of the Institute of Petroleum's Standardization Sub-Committee No. 4—Gas, Diesel and Fuel Oil—has been studying the stability of fuel oil, and a brief account of the work of the Panel is given here.

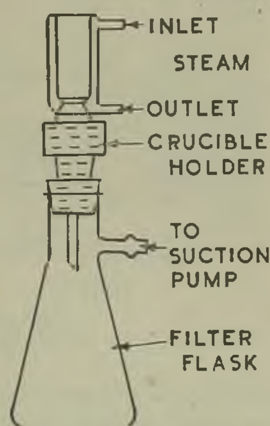
Due to the complexity of the problem it was considered that progress could best be made by sub-division of the subject into three main heads :—

(1) Stability of fuel oil in storage,
(3) Stability of fuel oil in blending operations,
(3) Stability of fuel oil when heated to the temperature of use.

Stability in Storage.

For the purpose of investigation of the storage stability of fuel oil it was decided to investigate the Sediment by Hot Filtration test. The primary





Sedimentation by Hot Filtration Test.

Fig. 1.
Steam-jacketed filtering funnel.

Fig. 2.
Assembled apparatus.

object of the Panel was to ascertain if good reproducibility could be obtained using the test in various laboratories and, secondly, if the results could be correlated with the behaviour of fuel oils under normal storage conditions.

The method of test consists of the filtration of the oil sample through an asbestos filtering medium in a steam-jacketed funnel. A diagram of the funnel is given in Fig. 1.

* Esso European Laboratories.

To carry out the test, 20 grams of the oil are weighed directly into a weighed filter funnel and, with the apparatus assembled as in Fig. 2, filtered under a pressure of 10 in. mercury. At the end of the filtration the accumulated sediment on the sides of the funnel is washed down with a prescribed quantity of high-boiling naphtha of specified properties. After a final washing with A.S.T.M. precipitation naphtha, the funnel is dried out at 105° C. and the weight of sediment determined.

The particular merit claimed for the Sediment by Hot Filtration test is that it discloses and measures types of suspended matter which may eventually deposit, and which are normally dissolved by the boiling benzol used in the older method I.P.—53/42(T)—Sediment in Fuel Oil by Extraction.

Experience in regard to this test has not been entirely satisfactory.

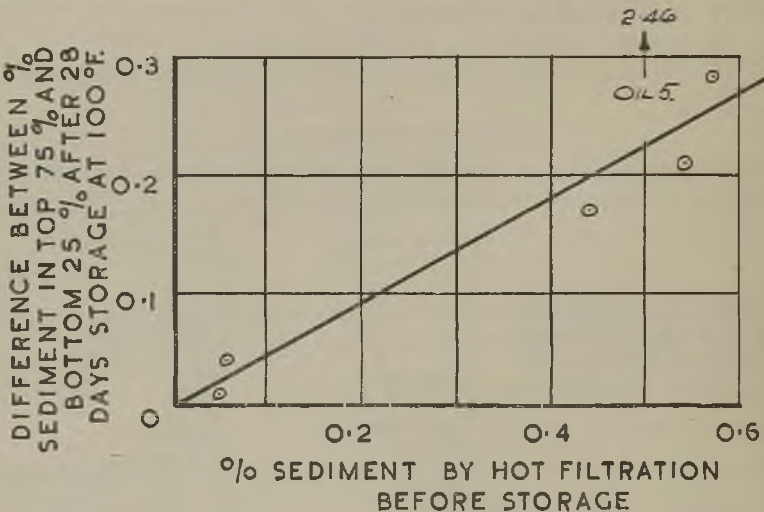


Fig. 3.

CORRELATION OF SEDIMENTATION WITH SEDIMENT BY HOT FILTRATION.

While the six co-operating laboratories obtained good reproducibility for the sediment present in certain of the oils before storage, the determinations of sediment in the top 75 per cent. and the bottom 25 per cent. of samples stored at 100° F. for 28 days were not so consistent. In general, determinations on the stored samples showed that some increase in total sediment had occurred during the storage period, but these increases were not large.

The difference between the sediment in the top 75 per cent. and in the bottom 25 per cent. is taken as an indication of sedimentation during storage. An attempt to correlate this with the amount of sediment before storage is shown in Fig. 3. In the case of oil No. 5, a cracked 500-second type fuel oil cut back with gas oil, the proportionately higher sedimentation during storage may be due to the low viscosity and specific gravity of this oil. This view is supported by the curve in Fig. 4. A similar curve is obtained when the difference in sedimentation is plotted against the logarithm of the viscosity.

Unfortunately, the work has been hampered by filtration difficulties due to the inability to obtain the correct type of asbestos, and such alternatives as a No. 3 sintered glass funnel have not proved satisfactory. Experimental difficulties in determining the sediment in the bottom 25 per cent. of the stored samples have also been experienced.

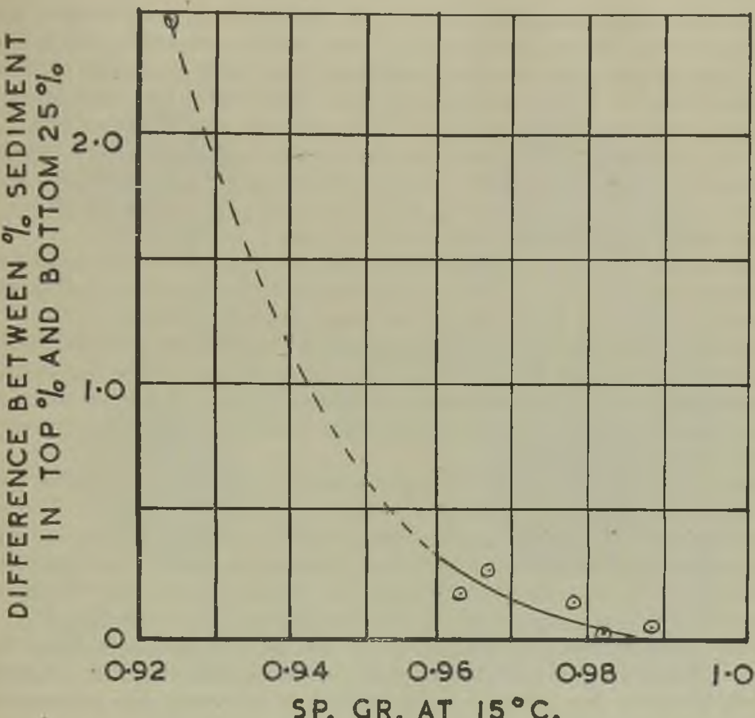


FIG. 4.

RELATION BETWEEN SEDIMENTATION AND SPECIFIC GRAVITY.

While, therefore, it is believed that this test may be of considerable use, it is obvious that further work must be done before it can be put forward as a standard method or even as a tentative standard. It is also very desirable that some correlation with normal storage conditions should be established.

STABILITY ON BLENDING.

In regard to the stability of fuel oil in blending operations it was decided to examine the possibilities of the Xylene Equivalent test. This is based on the Oliensis Spot test, and is carried out by heating, on a boiling water-bath, 2 grams of the fuel oil with 10 ml. of a trial mixture of xylene and Oliensis solvent. After heating for 8 minutes with agitation at the end of each minute the flask is removed from the water bath and allowed to cool. A drop of the mixture of oil and solvent is then removed from the flask by means of a pipette and placed on a No. 50 Whatman filter paper. After 10 minutes the drop is examined and, if the nuclear ring is still visible, the procedure is repeated using solvent mixtures with progressively increasing xylene contents, in 5 per cent. increments, until the stage is reached when the nuclear ring just disappears. This procedure is illustrated in Fig. 5.

The lowest percentage of xylene in the solvent to give no nuclear ring is reported as the Xylene Equivalent. Thus, for the example given in Fig. 5, the Xylene Equivalent is 41/45, indicating that, with a mixture containing 40 per cent. of xylene, the nuclear ring still exists, but that when the xylene content had been increased to 45 per cent. there was no ring.

A fairly satisfactory degree of correlation was found between co-operating laboratories, most of the oils examined showing a reproducibility of ± 10 units. In some cases, however, this limit was appreciably exceeded, and in one particular instance results varied from 0 to 100 +.

The method does not appear to be unduly sensitive to the composition of xylene or Oliensis solvent used, within the specification limits, nor to the temperature to which the oil-solvent mixture is cooled.

Further work will be necessary to define the interpretation of the results. It is probable that a Xylene Equivalent of 0 indicates that the fuel oil is compatible with a paraffinous gas oil, whilst a value of 100 probably indicates incompatibility. More information is needed on the interpretation of the intermediate figures.

One criticism of the test is that the procedure ignores the possible peptising influence which one oil may exert on other oils in a blend. The argument has been advanced that blending stability cannot be dissociated from the particular constituents which it is required to blend. In other words, the instability of a blend should not be considered peculiar to any constituent, but as a property of the combination of oils in the blend.

The problem certainly seems to be one of colloidal chemistry which cannot be dissociated from the physical conditions which exist. A method which involves the use of a light solvent in assessing the occurrence of sediment is, therefore, not viewed with entire satisfaction.

Stability to Heat Treatment.

The stability of oils to heat treatment has been examined using the N.B.T.L. or U.S. Navy Heater test. This test, which was developed in the U.S. Naval Boiler and Turbine Laboratory, Philadelphia, and is incorporated in the U.S. Navy Specification No. 7-0-1 f. is stated to have given good results in correlating the behaviour of U.S. Navy fuel oils with deposits in pre-heaters under conditions applicable to U.S. Navy steam plant practice.

The test is regarded highly by the U.S. Navy, but as yet there is no evidence available to the Panel to indicate that the Royal Navy or the British Mercantile Marine have found it necessary to apply such a test to their fuel oil. This may be due to the particular steam-raising technique used by the U.S. Navy or to the wider variety of fuel-oil types employed by it for steam raising.

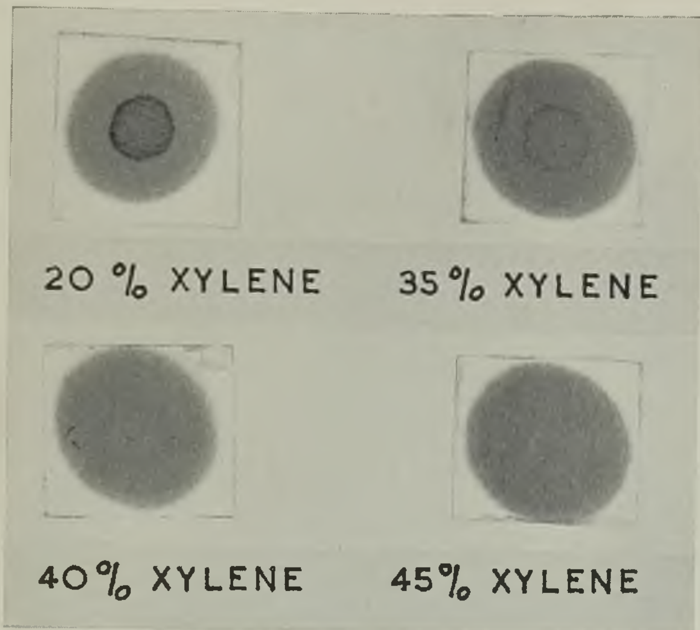


FIG. 5.

NUCLEAR RING TEST—XYLENE EQUIVALENT 41/45.

[*To face p.* 350.

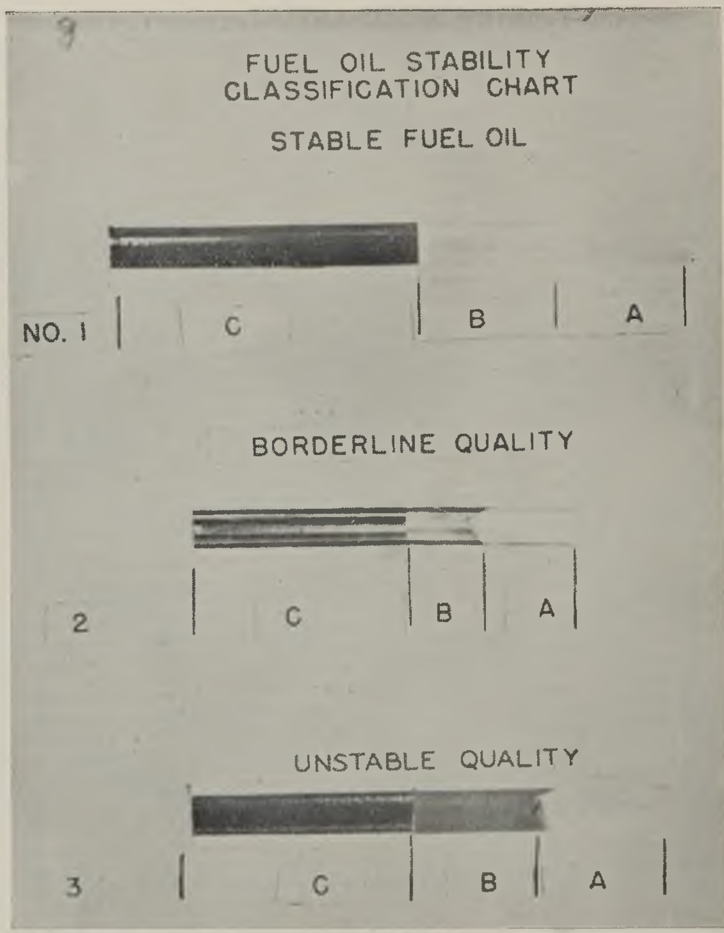

FUEL OIL STABILITY
CLASSIFICATION CHART
STABLE FUEL OIL
NO. 1
C
B
A
BORDERLINE QUALITY
2
C
B
A
UNSTABLE QUALITY
3
C
B
A

Fig. 8.

The apparatus used is shown diagrammatically in Fig. 6 and a sectional view of the heater element is given in Fig. 7.

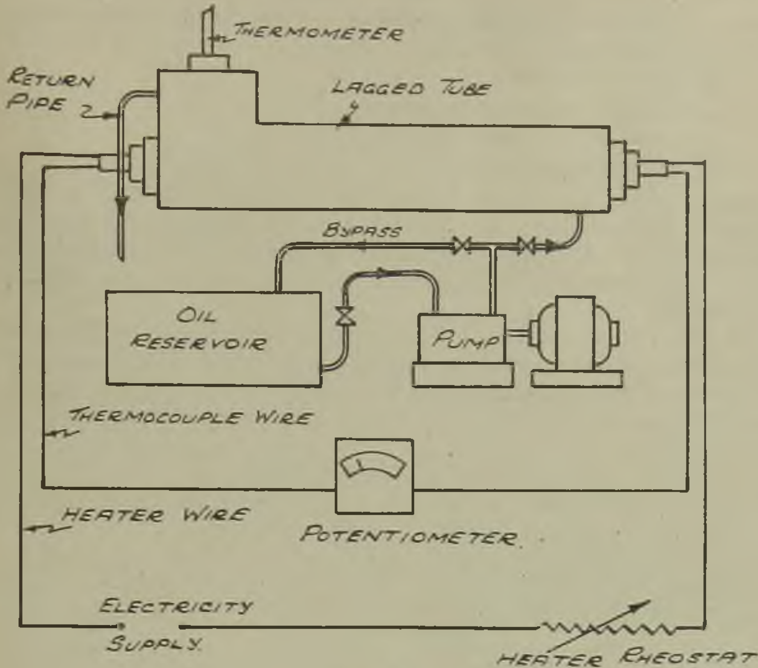


FIG. 6.

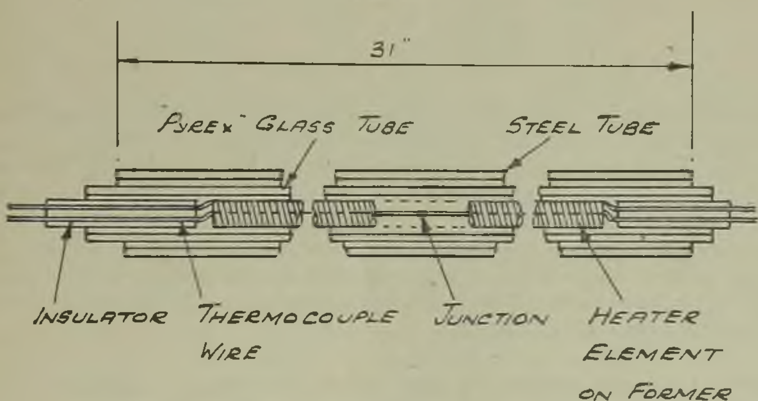


FIG. 7.

Briefly the test consists of subjecting the oil to a heating test which lasts 20 hours, during which time the oil is heated to a temperature of 200° F. The oil is pumped over the outside of a steel tube, inside which is an electric heater element maintaining a temperature of 600° F. The results of the test is assessed on the basis of the appearance of the tube at the conclusion of the 20 hours.

An 8-in. section of the steel tube is washed by flushing with a stream of benzol. After the benzol has drained off, one-half of the washed section is hand-wiped with a clean soft cloth. Thus, three sections of the tube are available for examination :

(*a*) a wiped, washed section;
(*b*) an unwiped, washed section; and
(*c*) an unwashed section.

Dependent on the appearance of these sections, the oil is rated as "Stable," "Borderline" or "Unstable." The method of rating is indicated in Fig. 8. Originally the U.S. specification differentiated 5 types of oils, but apparently wider experience with the test has resulted in simplification.

When the Panel commenced this work it was anticipated that there might be some difficulties in obtaining reproducibility of results between laboratories, on account of the qualitative manner in which the assessment was made. In practice, however, this doubt was not realised, as shown in the following table :

N.B.T.L. Heater Test.

Oil.	Laboratory.		
	1	2	3
1	Stable	Stable	—
2	Borderline	Borderline	—
3	Unstable	Unstable	—
4	—	Stable	Stable
5	—	Borderline	Borderline
6	Stable	Stable	Stable
7	Stable	Stable	Stable
8	Borderline	—	Stable

Thus, for the eight oils examined there was only one case of disagreement and this only as to whether the oil was "borderline" or "stable."

From this point of view, therefore, the test may be regarded as satisfactory although the Panel has no evidence as to how the results check with U.S. Navy practice. Similarly, the Panel has no evidence to indicate that its general adoption as a test for all types of marine fuel is necessary. Up to the present the work has been confined to oils which conform to the U.S. Navy Specification 7-0-1 f. viscosity clause, *i.e.*, oils having a viscosity below 225 secs. S.U. at 122° F.

From this brief account of what has so far been accomplished by the Panel, it will be seen that there still remains much to be achieved before satisfactory test methods are produced which will indicate the stability characteristics of fuel oils in relation to particular conditions of use. It is also obvious that there is still relatively little knowledge concerning the mechanism whereby those changes occur in a fuel oil which cause it to be designated as "unstable."

THE PROBLEM OF DEVISING TESTS FOR SOIL STABILIZATION.

By L. G. Gabriel, B.Sc. (Fellow).

Chairman of Soil Stabilization Panel of Standardization Sub-Committee No. 7—Asphaltic Bitumen.

It would probably be correct to call the Institute of Petroleum's decision to appoint a Soil Stabilization Panel an exploratory one. The first meetings of the Panel early in 1943 soon indicated that the problems on which attention was to be focused were somewhat different from those normally encountered by such bodies.

The difficulty lay in the somewhat restricted range of practical experience available. Extensive laboratory studies had been made both at the Road Research Laboratory at Harmondsworth and in several of the commercial laboratories represented on the Panel, and to a certain extent the conclusions of these investigations had been checked in the field, but the influence of a wide variety of practical conditions remained unexplored. Acknowledgment must be made of the great value of the American specifications drafted by the A.S.T.M. and the American Association of State Highway Officials, but it was felt that many of these tests needed close scrutiny before being included as they stood in any British standards which might be set up.

It should be emphasized at this point that the Panel was unanimous in its desire not unnecessarily to multiply the number of tests which would apply to any particular property or aspect of the problem. Thus, the procedure adopted was to collect as many as possible of the sets of tests already published in different countries, and then to determine the origin of any differences which might exist, and to endeavour to arrive at a logical method of operation which might stand a good chance of ultimately being acceptable to all parties. In some cases the ultimate choice of test conditions might coincide with one of the already published methods; in other cases an effort was made to deal with complications or factors which had apparently not been taken into account by existing methods.

As an illustration of this the question of the level of compaction at which performance tests of various types should be undertaken should be cited. There is an American compaction procedure which has received a measure of recognition as a standard procedure, and which is generally known as the Procter Method. In this method the soil mix is filled into a mould having a diameter of 4 in., and is then tamped with a rammer having a diameter of 2 in., twenty-five blows of the rammer being given, each one with a free fall of 12 in. An effort is made to distribute the blows evenly over the surface of the specimen. The problem is whether the degree of compaction reached in this method of working bears any relation to the actual values achieved in the course of field operations. Obviously, such criteria of excellence of the finished work as water-resistance, bearing capacity, and so on, will depend entirely on the degree of consolidation of the material, and it is a matter of great importance that data should be available showing some constant relation between the results of the test and the performance of actual material on the site. This is where the difficulty lies.

American experience would seem to show that the Procter standard of compaction is a fair and reasonable one to aim at with ordinarily available plant as used for such work. The work of the Road Research Laboratory in England tends towards the same conclusion. Nevertheless, it is known that a rather higher degree of compaction, if obtainable in practice with reasonable care and attention, would be conducive to a higher standard of performance, and in some cases would allow of the use of more economical aggregates. More recently higher standards of compaction have appeared rather tentatively in the U.S.A. and there is a feeling on the part of some members of the Panel that we should not hurry to accept the Procter level of compaction in England until the trend of actual field-work is seen more clearly.

There is a further problem associated with this question of the standard level of compaction. As an obvious alternative to the impact method of consolidation there is the use of a steadily applied pressure. This is used in Test A.4 of the schedule recently issued by the Panel. At the pressure level selected for this test, *i.e.*, 3500 lb./sq. in., there is no question that a rather higher density is produced than by the Procter method. It is recognized that this is a rather unsatisfactory position, but it should be possible to resolve it simply enough once a greater volume of practical experience is available. The endeavour should obviously be to select the highest level of compaction which can be achieved regularly in practice, with reasonable care in working, and to determine as precisely as possible equivalent conditions for producing this degree of compaction by impact or by steady pressure.

Other problems which need a similar increase in the amount of available practical experience for their solution are the devising of a standard test for resistance to the effects of frost, and the finding of a reasonably accurate chemical method of analysis to determine the binder content of mixes stabilized with bituminous materials.

The problem of the effects of frost is a particularly difficult one. The Road Research Laboratory has been at great pains to collect available data regarding soil temperatures during recent cold spells, and efforts have been made to decide on the order of temperature gradients which may be expected in severe winter conditions in England. Based on these data the Panel has endeavoured to form conclusions on the probability of frost-heave in stabilized work. Generally speaking the bulk of experience is that genuine frost-heave is of rare occurrence, but that disintegration of surface layers due to the effects of frost is much more frequent. An effort is now being made to produce various temperature gradients in laboratory specimens, and to study their effects on stabilized mixes. The work in itself is difficult, and adequate correlation with behaviour in the field is essential, the latter being particularly difficult in view of the normally temperate climate in England.

The problems associated with the accurate determination of binder contents are of quite another order. It need not be emphasized that the work of the Panel is confined to soil stabilized with bituminous materials, and it is only this type of binder for which it is being attempted to legislate. The methods commonly practised with other bituminous-coated road aggregates are those which obviously come first into consideration. It is found, however, that the high specific surfaces of normal stabilized aggregates, coupled with the usually rather high activity of these surfaces, results in the strong retention by absorption of considerable amounts of the binder, which in consequence are difficult to recover in the normal way by solvent extraction. Here experimentation with different combinations of solvents, allied possibly to procedures aimed at flocculating the finer aggregate, are being studied, and it is regarded as probable that the most serious of these difficulties will be overcome in the fairly near future.

In what has been said an attempt has been made to show some of the problems which had to be faced prior to the recent issue of the Panel's first report. Subsequent to the appearance of this report the difficulties have become even more significant. The reason for this is not far to seek : the first report represents the answers to questions on which the agreed data admitted of prompt finality. It was realized that the really difficult problems remained for subsequent treatment, and consequently the second report may still be some little while in appearing. Nevertheless, the work goes on, and in this connection it would perhaps be as well to remark in conclusion that the B.S.I. Soil Stabilization Committee RD/9 is now in the field, although, owing to the complexity of the preparatory work, its agenda is still in process of being formulated. The author has been honoured by being elected Chairman of that Committee, and was especially pleased to accept the office, as it afforded the prospect of very complete co-operation with the Institute's Panel. It is hoped that the pioneer work of the latter body will lighten the labours of the larger Committee, and that the Institute may thereby strengthen its rôle as one of the major technological organizations of the country.

THE USE OF LIQUID-IN-GLASS THERMOMETERS

By J. G. Durham.*

Inspection before Use.

It should be an invariable rule that before any thermometer is used it should be inspected visually with the aid of a small pocket lens and examination made—

(i) of the safety-chamber at the top of the stem, to ascertain whether any detached mercury has collected therein, either as a film or in small globules; and

(ii) of the bulb and contraction chamber, to ensure that there are no specks of gas in the mercury and no detached mercury in the contraction chamber or along the bore.

Adjustment.

Thermometers frequently arrive from the manufacturer with defects such as those already mentioned, and these can usually be readily adjusted.

For example, the "I.P. 22W A.M. Oxidation" thermometer often has detached mercury held up at the top of the contraction chamber and for a short distance along the bore. Shaking will seldom put this right, and it is almost always necessary to cool the bulb until the detached mercury comes down into the contraction chamber in the form of a thin film. If the side of the stem is then tapped gently, the detached mercury will form into a globule clinging to the wall of the contraction chamber. The thermometer should then be kept free from vibration and the bulb warmed with a methylated-spirit flame until the mercury is joined to the main column.

Where gas is found entrapped in the mercury at the shoulder of the bulb, it will usually be cleared by cooling the bulb by immersion in solid CO_2 or some suitable medium until the mercury is cooled below the speck. In extreme cases it may be necessary to cool the mercury to below its freezing point and then to force the speck above the mercury by giving the thermometer a downward swing.

Detached mercury may be located in the safety-chamber at the top of the stem, and can generally be driven down the bore by applying a methylated-spirit flame across the top of the thermometer. Should it become necessary to warm the bulb in order to rejoin the mercury, the thermometer should not be used for some hours until it has recovered from the temporary depression of zero.

Thermometers in Use.

Assuming that the thermometers are in good order, the mercury-in-glass types present little difficulty in use. Those of the spirit-in-glass type

* Communication from The National Physical Laboratory.

should be cooled very slowly, and with pentane as the filling it may take at least an hour to cool these satisfactorily to the boiling point of oxygen (−182·97° C.). To ensure that no spirit is left along the walls of the bore, all spirit thermometers should be cooled as slowly as possible, a good practice with standard instruments being to cool at the rate of 1/3° C. per minute.

Storage of Thermometers.

Care in the storage of thermometers is as important as care in use. Those which have a temperature range below 0° C. (say −40° C. to 10° C.) should, as far as possible, be stored vertically, bulb downwards, in a cool place. Spirit thermometers must be stored away from the direct rays of the sun.

Thermometers which have been heated should be allowed to cool to air temperature (20° C.) before being put away. They should not be exposed to sudden heating or cooling, particularly in the region of the contraction and safety-chambers.

Re-marking the Divisions.

If it is found during use that the paint has come out of the divisions of the thermometer scale, a temporary filling can be effected by rubbing an ordinary lead pencil over the divisions. This will suffice until the instrument can be withdrawn from the apparatus, cleaned, and the scale divisions re-blacked.

Stability of Zero.

Under this heading the suggestions are limited to the standard thermometers " I.P. 29W " to " I.P. 32W " used in the determination of Viscosity (Kinematic) in Absolute Units (I.P.—71/45 (Tentative)).

To obtain the high degree of accuracy required it is essential that frequent checks should be made on the ice-points of these thermometers. For this purpose it is necessary that the purity of the ice should be above question. In addition to checking the ice points, it may be desirable also to check one temperature on the main scale—say 70°, 100° or 210° F. In making this check it is important that the stirring of the comparison bath used should be adequate to give the accuracy demanded.

These thermometers are so openly divided that in use they should be treated similarly to calorimeter and Beckmann thermometers. Prior to the taking of readings they should be subjected to sufficient vibration or tapping to overcome any " situation " of the mercury column.

Partial Immersion Thermometers.

On those occasions when the defined immersion line is not the true immersion, which may, in some cases, be rather indefinite, common sense should be used in correctly interpreting the immersion.

In the case of some standardized thermometers the emergent stem temperatures have been specified, but the difference found in actual practice should be taken into consideration when applying the thermometer correction.

THE INSTITUTE OF PETROLEUM.

A Meeting of the Institute of Petroleum was held at Manson House, 26 Portland Place, London, W. 1, on Wednesday, March 14th, 1945, Professor F. H. Garner, President, being in the Chair.

The President said that the present meeting was a special standardization meeting, the papers to be read covering some of the main subjects which the Standardization Committee were at present discussing.

The following paper was then read by the author :

"Some Aspects of Standardization in Oil Measurement," by H. Hyams (Fellow). (See pp. 339–342.)

DISCUSSION.

Mr. J. S. Jackson said he had been astonished to find that there was no real law laid down for a tank with a bottom which moved. Should not some definite conclusion be arrived at as to whether they should have a water bottom or not ?

Mr. Hyams replied that they were not compulsory here, though they might be so in other countries. It was not unusual, particularly in this country, for gasoline tanks to have water bottoms, to avoid trouble in gauging, and it had been common practice during the war to have large water bottoms, to minimize evaporation losses. So far as he was aware, there were no existing laws insisting on water bottoms, and whilst in certain circumstances such water bottoms were useful, there were other good reasons for resisting compulsory water bottoms.

The President asked how far the bottom of the tank moved.

Mr. P. Kerr (replying to the last question) said that the idea that the bottom of a tank was moving was put forward more often than was necessary. When errors in measurement occurred the suggestion was made that the bottom was moving. That they did sometimes move was certain, but he thought the suggestion was put forward more often than the circumstances warranted. The foundations of a tank had to be particularly bad or the original stability must have failed in some way before the bottom could move to any great extent. He could remember a tank in Shanghai where the bottom moved up and down, but proof that the bottom was moving was seldom obtained. The objection to putting water in was that unless the tank was for use for water displacement storage it wasted space for oil and increased the cost of storage. Likewise the presence of water increased the rate of rusting.

Mr. A. R. Javes then read his paper :

"Sulphur Estimation by Lamp Method Using I.P. Test 107/45 (T)," by A. R. Javes, B.Sc., F.R.I.C. (See pp. 343–346.)

DISCUSSION.

The President said that it was a happy thought of Standardization Sub-Committee No. 3 to present a paper when apparatus such as had been used for so many years was replaced by a new piece of apparatus. The degree of accuracy which could be obtained with the present piece of apparatus would perhaps come as a surprise to some members.

Dr. E. B. Evans did not think he could add very much to the excellent picture given by the author of the background of this new method and the necessity for its introduction. Sub-Committee No. 3, like the other Sub-Committees, hesitated to introduce yet further methods of testing or to alter existing ones unless convinced that it was really essential. It had been done in this case only because they were convinced that the old I.P. and A.S.T.M. methods were not adequate for low sulphur contents. The A.S.T.M. also had recently found it necessary to discard their old method, and had now introduced one which, like the new I.P. method, involves burning the sample in purified air. The A.S.T.M., however, use both a different lamp and a different working-up procedure from those which have been described by Mr. Javes.

Mr. J. S. Jackson remarked that the Apparatus Committee felt that the chimney was a complex piece of work and very fragile. Ground-glass joints between the chimney and water jacket might perhaps be tried if it would not interfere with the accuracy of the test.

Mr. Javes replied that they had not found the apparatus fragile, and after the first day the operator soon found that he could handle it; there had been very few breakages with it, although they had a large number of sets in operation. If they used a ground-glass joint at the top he thought it would cause trouble. That part of the apparatus became very hot, and the joints would bind up, or they might break.

Mr. J. S. Jackson pointed out that he had been thinking primarily of the person who manufactured and delivered the apparatus.

Mr. Javes said that a form of chimney which had been used for a long time was one in which the water-jacket was held in place over the outlet tube of the chimney by means of rubber stoppers. Recently, however, the firm manufacturing the apparatus had supplied some chimneys with the water-jacket sealed directly to the outlet tube, and these had proved to be very satisfactory.

The following paper was then read by the author:

"Stability of Fuel Oil," by W. E. J. Broom, Ph.D., B.Sc. (Fellow). (See pp. 347–352.)

DISCUSSION.

The President said that the paper illustrated the large amount of work which had to be done in developing a new method of testing. The primary concern had been the reproducibility of the test, and the question of correlation in actual practice formed only a small part of the work so far.

Mr. A. R. Stark remarked that he had nothing to add to the paper, beyond saying that the work so far had been confined to producing reproducible laboratory tests. If they were working on the right lines the tests would correlate with practice, but if any test failed to correlate with practice it could not be satisfactory. He felt that it was necessary, therefore, to avoid putting anything forward for adoption before there had been an opportunity to study correlation with practice. With regard to the Hot Filtration test it would probably be some considerable time before it could be said that it meant anything.

Mr. C. S. Windebank asked whether the Panel had considered the possibility of using the U.S. Navy Heater test as a means of measuring storage stability.

Dr. Broom replied that the test had been considered from this view point. A suggestion had been made that the U.S. Navy used the Heater test to indicate storage stability, but inquiries had ascertained that such in fact was incorrect.

Mr. J. S. Jackson hoped that people would be patient with the Xylene Equivalent test, because he believed that it had possibilities so long as it was not expected to answer every question. It did touch the fundamental stability, and it did not take too long to carry out.

Regarding the U.S. Navy Heater test, he would give one word of warning. That particular test had given excellent results, but to his mind that practical performance test was an admission of fault. It meant that one did not know what one wanted to do when one did not know what was causing trouble. That was an admission of fault, and if their American friends could be persuaded to forget that apparatus altogether and begin again, a satisfactory test might be obtained.

Mr. P. Kerr thought that the paper had done other Panels much good, since it showed that all had their own difficulties to overcome. He took it that the articles were sometimes electrified and that differences in rates of settlement might therefore be anticipated.

Dr. Broom said he thought some types of potential sediment were electrically charged, but no work had yet been carried out on those lines. It did seem that the density and viscosity of the oil had quite a lot to do with the rate at which the particles settled. It had, of course, been very difficult to work on problems of this kind, and his own feeling was that they had not yet got their teeth properly into the problem.

Lt.-Col. H. F. Jones said that the surprise to him was not the occasional discrepancy, but the considerable agreement in the results obtained by the Panel.

Assuming a test was wanted, one should introduce a reasonably sound method, and then people would take interest and see to it that a good test was forthcoming. The U.S. Navy heater test in accelerating work on this subject had done much to justify itself. He thought the author's feelings that it might take years to co-ordinate the heater test apparatus results with actual results in practice was perhaps a little pessimistic. Surely no one expected exact correlation. If the method employed would rate most fuel oils in the same order of failure or success as encountered in actual storage, then the method was worth further consideration with a view to its being adopted as a tentative standard method.

Dr. Broom said that they were not trying to get the test published as a standard method. When the Panel was formed they had been told by the main standardizing body what they were to investigate, and that was what they had done.

Mr. A. R. Stark asked whether the use of copper piping could have any effect on the reproducibility of results.

Dr. Broom replied that he did not think so. A certain experiment which they had carried out had shown no effect, and if there had been a catalytic effect, the oil used would probably have given a different result.

Mr. J. S. Jackson then read the following paper :

" The Problem of Devising Tests for Soil Stabilization," by L. G. Gabriel, B.Sc. (Fellow). (See pp. 353–355.)

DISCUSSION.

The President said that this was a new venture on the part of the Standardization Committee, and it was evident that the Sub-Committee concerned were dealing with a very difficult problem.

Mr. Javes asked whether any effort had been made to make water absorption tests on the spot without taking the soil away.

Mr. J. S. Jackson said this would not be possible, as the treated soil was invariably highly water repellent. Actually no perceptible absorption of water would occur for some days. The only hopeful procedure was to withdraw a portion of the compacted treated soil with the minimum amount of disturbance, trim it roughly into cylindrical form, and expose it to water in the usual way.

Mr. A. R. Stark said that he was surprised to find no word in the paper about the difficulties of sampling the material before making a laboratory test. The material used for compaction testing was not just a spadeful of soil taken at random from the field, but was graded soil material.

Mr. J. S. Jackson replied that that was the first essential, and the subject had been dealt with in the Report. The Report pointed out that the area must be surveyed carefully to detect possible variations in the soil, and that each obvious type of soil must be generously sampled. The testing should also be done on a generous scale. The normal procedure was to sieve out the stone and work on the material retained on the BS7 sieve. It was, of course, the fine clay particles which absorbed most water. When he spoke of soil he meant ordinary agricultural soil. There was a certain amount of confusion in this connection because the word "soil" covered everything from boulders down to clay. When Americans spoke of soil they might be referring to material which we in Britain would call gravel or sand.

The following paper was then read by the author:

"The Use of Liquid-in-Glass Thermometers," by J. G. Durham. (See pp. 356–357.)

DISCUSSION.

Mr. J. S. Jackson asked whether some general indication could be given as regards the accuracy attainable with partial immersion thermometers like the Cleveland Flash-Point Thermometer, which were used at very small immersions and at relatively high temperatures. The Cleveland thermometer I.P. 28W had an immersion of only 25 mm. and the temperature range is 20–760° F., and stem corrections were not applied in practice.

The Author said it could be summarized that the smaller the immersion, the lower the order of accuracy attainable. For years thermometers similar to the Cleveland had been tested at the N.P.L., and the limits of accuracy of the test had been widened according to the depth of the immersion. With an immersion of under 2 in., an accuracy of better than $\pm$ 2° F. could hardly be expected for thermometers ranging up to 760° F.

The same difficulty existed with open-scale thermometers, such as the calorimetric type. When used at small immersions the results could seldom be relied on to within $\pm$ 0·002° C. This accuracy, however, was attained at total immersion, or with a considerable depth of immersion, or when the temperature of the exposed column differed only slightly from that of the bulb temperature.

Asked whether, if one desired fine readings, it would be better to use a solid-stem thermometer of the necessary length, or whether a Beckmann thermometer was preferable, the Author replied that during the past twenty years solid stem calorimeter thermometers had continued to gain popularity and the B.S.I. had drawn up specifications for thermometers of this type. There were also a number of solid-stem adjustable-range thermometers in use, including the "pipette" type. The latter was easier to set than the Beckmann pattern, but all were subject to errors such as were found in ordinary thermometers.

It was stated by one speaker that in oil measurement one of the difficulties with the ordinary solid-stem thermometer was that the black marking disappeared, but this might be overcome by using the enclosed-scale type of thermometer. What disadvantage, if any, was there in using that type of apparatus apart from the fact that it was fragile?

The Author replied that with a good thermometer there was no disadvantage, but condensation inside the sheath might be a source of trouble. The main thing with an enclosed scale was to have a datum-line engraved on the sheath, so that allowance could be made for any movement of the scale. Regarding the paint used in the divisions of solid stem thermometers, there was one kind of filling which could be regarded as permanent—namely, silicon ester mixed with Ilmenite black. The technique of mixing and preparing the paint and applying it was quite simple, and the makers would supply small quantities.

THE ENGINE TESTING OF H.D. OILS.

By Heavy Duty Engine Oil Panel of Standardization Sub-Committee 5—Engine Tests.

Laboratory and Engine Tests of Lubricating Oils.

It is generally agreed that the performance of engine lubricants can be assessed only by actual engine tests. The physical and chemical properties of a lubricating oil are valuable for identification purposes, but, excepting viscosity, these properties give little direct information as to its performance in an internal-combustion engine. It has therefore become customary to submit lubricants to engine tests, and many papers have been published on this subject during the last twenty years.

The operator of internal-combustion engines is obviously most interested in the behaviour of lubricants under service conditions, and ultimately commercial oils must be judged by their everyday performance. It is, however, not always possible or convenient to test lubricants in actual service, and it is naturally desirable to obtain as much information as possible regarding the performance of an oil before it is put into service. Consequently a great deal of oil testing has been done with test-bed engines which cover the range of types from essentially production units to single-cylinder engines specially designed or modified for test purposes.

Type of Test Engine and Test Conditions.

A difference of opinion exists as to the most desirable type of test unit. Some authorities favour the use of production engines and others prefer to employ specially adapted or single-cylinder units. It is probably fair to say that the use of the simplest possible unit on the test bed gives the best control of experimental conditions, and hence yields the most consistent results with the smallest expenditure of time and money. On the other hand, it may be difficult or impossible with a single-cylinder unit to simulate successfully all the working conditions encountered in service, and some important factor affecting the performance of the lubricant may be omitted or overlooked. Against the use of multi-cylinder production engines for lubricant testing may be mentioned the difficulty of maintaining constant and controlled running conditions and the expenditure of time and material involved. Under present circumstances it is not possible to make a clear-cut decision between the use of the simplest test engine and the complete production unit for oil testing. As far as the oil producer is concerned, the complete evaluation of his products generally involves all types of engines, from a single-cylinder unit, running under conditions adjusted to take care of the prevailing important factors, to representative production engines working to a standardized test programme on the bench, and followed eventually by observations of performance under actual or simulated service conditions.

Although it is plainly desirable that laboratory engine testing should be carried out in conditions such as to yield results which will be at least comparable with those obtained during service running, the laboratory test must inevitably be a more or less accelerated one, and this may make precise correlation unobtainable; it should be the aim, however, to place oils in a correct order of merit, or, as a minimum requirement, effectively to sort out good from indifferent grades.

It might seem at first sight to be desirable or even necessary to submit an oil to test in every type of engine that it might be called upon to lubricate, or at least to verify its performance against that of proved lubricants in those engines known to operate under exacting conditions. Fortunately, however, engine testing and operating experience of the last few years has pointed to one or two important conclusions which permit a considerable simplification of the testing scheme. In the first place there are certain fairly well-defined factors associated with the lubricant in which difficulties may occur under severe duty service. Among these may be mentioned ring sticking and piston lacquering, bearing corrosion, and combustion-chamber deposits. A series of lubricating oils placed in order of merit as regards, for example, resistance to ring sticking in one type of engine will, in general, retain the same order when run in an angine of another similar design under conditions in which ring sticking will occur.

Although this conclusion may need modification in detail, it opens up the possibility of developing standard and universal methods for rating the performance of lubricants for internal-combustion engines. For this purpose test units may be taken from production engines, each type of engine being selected to examine one or more factors of lubricating-oil performance. The choice of engines will depend primarily on the trends of their normal behaviour; for example, to rate ring sticking, an engine must be selected which, at least under overloaded and extreme conditions of duty, can be made readily to stick rings. At the same time, other points such as convenience in handling must be considered when the unit is selected.

The course of action outlined above has already been taken in the United States in connection with the rating of heavy duty crankcase lubricants for high-speed diesel engines.

Development of Oil Tests in U.S.A.

The first engine test unit to be widely used in the U.S.A. was the single-cylinder Caterpillar diesel of $5\frac{3}{4}$ in. bore and 8 in. stroke, which was specially designed for the laboratory evaluation of lubricating oils in respect of ring sticking, liner wear and piston deposits. It first came into use about 1937 because the Caterpillar Tractor Co. would not give their approval to branded motor oils unless they had passed the engine test. The piston and cylinder assembly is essentially as used in the production engine, but the general construction of the unit is very rugged so as to minimize the risk of involuntary mechanical failures which might interfere with the test routine. Moreover, the unit is so designed that it can be dismantled in twenty minutes for inspection of the cylinder liner, piston and rings. As a test engine it has proved very satisfactory and 65 units are currently being operated in the States.[1] For the assessment of the high-temperature stability and bearing corrosion properties of H.D. oils, the Caterpillar Co.

also have a further test procedure utilizing their four-cylinder $4\frac{1}{4}$ in. × $5\frac{1}{2}$ in. diesel engine.

General Motors Corporation have also adopted the policy of approving H.D. oils on the basis of tests carried out in engines of their own design and manufacture. One such test is made in their Series 71 two-stroke diesel which has oil-cooled pistons and imposes severe demands on the oil in regard to oxidation resistance and the prevention of carbon deposits under the piston crowns. It will be noted that all the tests so far mentioned have been associated with diesel lubrication problems. General Motors have also given some encouragement to the use of H.D. oils for the lubrication of gasoline engines when they are operated under severe conditions. In this connection they introduced a thirty-six-hour accelerated test, using the six-cylinder Chevrolet engine for resistance to oxidation, bearing corrosion and piston lacquering.

All these American tests were originated by the engine manufacturers, although they were readily accepted by the oil companies as the only means of developing acceptable H.D. oils. Owing to its short duration, the Chevrolet test has been widely used and seventy-four engines are at present being operated in the States.[1] This particular test was the subject of the first attempt by the A.S.T.M. to standardize an engine test procedure.[2] The proposed test method has since been modified in detail and is still under review with the object of improving reproducibility.[3]

In 1941, the U.S. Army Motorized Ground Forces standardized the use of H.D. oils, and, under the Allied pooling arrangements, this policy was extended in 1942 to include British military equipment. Since that time Army–Navy H.D. oils have been subject to the following qualification tests laid down by the Co-ordinating Research Council in New York.[4]

- L-1, 480-hour endurance tests in one-cylinder Caterpillar diesel for ring sticking, liner wear and piston deposits.
- L-2, accelerated run in and high load test of about three hours, using above engine with special modifications to check the ability of the lubricant to prevent scuffing under these conditions.
- L-3, 120-hour high-temperature oil-stability and bearing corrosion test on Caterpillar four-cylinder 37 b.h.p. Caterpillar diesel unit.
- L-4, 36-hour accelerated test in Chevrolet six-cylinder petrol engine for resistance to oxidation, bearing corrosion and piston lacquering.
- L-5, 500-hour full load test in General Motors Series 71 multi cylinder two-stroke diesel engine.

H.D. Oils Panel of Institute of Petroleum.

The Standardization Committee of the Institute of Petroleum decided early in 1944 to consider the adoption of engine tests for lubricants, and the H.D. Engine Oil Panel was set up in April, 1944, under the ægis of Sub-Committee No. 5, which deals with the engine and mechanical testing of oil products.

In the first place membership of the Panel was confined to representatives of laboratories equipped to carry out engine tests on lubricants, to departments of Ministries concerned with the supply and use of engine oils, including the Admiralty, the War Office, the Ministry of Aircraft Production and the Ministry of Supply, and to the London Passenger Transport Board, representing the commercial user of oils on a large scale with facilities for service testing under conditions of close observation.

The Panel decided that it was desirable to obtain some direct experience of the U.S. test engines and methods using oils of normal and heavy duty types, and also to explore the possibility of developing a suitable test or tests based on a mechanically convenient British engine, even though this unit had to be run under conditions more severe than those obtained in service.

Three laboratories are at present co-operating in the Panel's programme. Each laboratory has obtained the Caterpillar single-cylinder engine required for the L-1 and L-2 tests; Chevrolet engines have been received, or are in transit, for the L-4 test; and two GM-71 engines are available and can be adapted for the L-5 test. There is no immediate prospect of obtaining the four-cylinder Caterpillar engine required for the L-3 test.

The choice of British single-cylinder diesel engines of a convenient type for test use was very limited, and was finally made in favour of the Crossley B.V. four-stroke Ricardo Mark II type unit. In this connection it should be remarked that there is no evidence to show that this engine suffers in normal use from ring sticking, and the preliminary runs made show that exceptionally severe running conditions will be required to enable oil ratings to be obtained in reasonably short runs.

It is also intended to extend the work to include a two-stroke design of diesel engine of the Kadenacy type.

The behaviour of lubricants can be appreciably modified by the type of fuel used, whether in a diesel or a gasoline engine, and, to eliminate variations due to this cause, a sufficient stock of both a high-speed diesel fuel and a suitable gasoline have been allocated for the first part of the programme.

Two lubricating oils have been selected, one a standard type of Admiralty I.C. engine oil of S.A.E. 30 grade without additives, and the other a U.S. H.D. type which has been approved for both Army and Navy use, and which is known to be a single product, and not a mixture of two or more approved blends from different sources. Preliminary tests are concerned with determining the differences between these two oils by the several test methods, and with the development of test technique in the British engines which show whether significant differences exist under severe conditions of duty.

Work has been proceeding at the Anglo-Iranian Oil Co.'s laboratory at Sunbury for some months on the L-1 test on the Caterpillar engine.

The first tests were to L-1 procedure, except that the engine was shut down each night and not run during week-ends, but the engine has now been fitted with a fully automatic control system and is operated continuously under specified conditions, without need for attendance, except for the purpose of taking an occasional fuel-consumption or other necessary reading. A new liner, piston and rings are fitted for each 480-hour run, and the extremely good finish and also the accurate dimensional checks of the parts are commendable.

Development of the Crossley engine test has been started at the

Shell Lubricating Oil Laboratory at Thornton, but, so far, satisfactory engine conditions have not yet been established, and a suitable method for rating piston cleanliness is still in a state of evolution. Various minor modifications have been made to adapt the engine for oil testing, including fitting the hollow crankpin with an aluminium alloy plug to prevent sludge deposition; increasing the area for water flow between jacket and cylinder-head; replacing the cooling radiator with an evaporative type of cooler; eliminating the oil cooler; making provision for a controlled heating of the inlet air; fitting an oil heater and adding suitable thermometers, etc. So far the tests have been made using the working parts originally supplied with the engines and intermittent runs of ninety-six hours' total duration have not usually resulted in sticking piston rings, although the H.D. oil shows less piston skirt lacquer and heavier top land deposits than the normal oil.

It is too early to draw any conclusions from this work, and no attempt has so far been made to use lead bronze for the connecting-rod bearing for the purpose of determining corrosion effects.

Special Requirements of Test Engines.

Consideration of other oil test engines, and of examples of lack of reproducibility of results, has led to a survey of requirements for this class of work, and it is doubtful whether any engine can be used in its commercial form without modification.

Among the special requirements may be mentioned accurate and very close machining limits for cylinder liners, pistons and ring grooves and piston rings, and also for the connecting-rod and main bearing bushes and journals. A surface finish should be given in the specification of each part, together with a sufficient description of the actual machining operation and tool to be used. This is particularly important for the liner, piston and rings. It is recognized that differences of relatively large amount may not be open to criticism in service, but since the object of an oil test is to give a result which is as reproducible as possible in other similar test engines, normal production variations are too great to be tolerated. The surface finish of an aluminium piston, for example, can be appreciably affected by the feed of the diamond tool used for the finishing operation, a feed increase (cuts per inch) of 50 per cent. resulting in a reduction of depth of finishing cut by about the same amount. Thus, a fine feed reduces the carrying capacity of the piston skirt for oil at the same time as increasing the number of high circumferential ridges on the surface. In practice, the combined effect of these variations may be negligible; on the other hand, some of the well-known differences between engines of the same make and type in relation to oil consumption may be associated with them. Piston ring finish is also important, good ring bedding in the grooves being essential if reproducible consumptions and sticking times are to be secured. The cylinder bore needs to be consistent, and this involves the use of a new liner for each test, and also a very good finish to get the maximum reproducibility. High liner finish is not, however, consistent with easy running-in, and it is probably necessary to use a fine-turned top pressure ring to get an early stable condition of ring operation, or to roughen an initially high finish liner surface in a methodical and reproducible manner.

In addition to the specification of surface finish upon the more important of the engine parts, it is realized that material composition and microstructure should be both controlled and specified, this especially in the case of cylinder liners and piston rings. Break-in and wear-rate characteristics are greatly influenced by these two properties, of which microstructure may be considered as being the most vital criterion, as it represents the final link between material specification and wear performance in the case of such cast-iron parts.

Oil control is also important, and this involves repeated attention to the truth of the crankpin and the connecting-rod bearing; the best results are likely to be obtained by the adoption of hardened crankpins made to very close limits, with lapping between tests to maintain consistency. The use of hardened crankpins may also be necessary to allow lead bronze bearing metals to be used for bearing corrosion tests.

Close attention is necessary in respect of the physical characteristics of piston rings. Upon these depend the ability of the rings to control blow-by and top-of-bore lubrication conditions. In addition to close control of the normal dimensional checks on these parts, the question of pressure exerted against the cylinder walls—both as an average figure and also with regard to its qualitative distribution around the periphery—will need specification.

For reasons such as the above the Crossley engines are being modified to include cylindrical turned pistons of specified surface finish, including standardization of the feed rate for the final diamond turning operation; the crankpins are being ground, and hardened pins will be used as soon as manufacturing conditions permit; the water spaces between the cylinder jacket and head are being opened out and an extra flow pipe fitted to give adequate flow when evaporative cooling is used, should this be needed to obtain sufficient severity of test; the oil pump normally fitted is being replaced by a gear pump driven independently, and the oil feed to the rocker gear and timing system is being controlled; the cooling system is being modified, so that either pump-circulated or evaporative cooling can be used; the crankcase breather valve is being deleted and an oil baffle fitted, so that piston blow-by can be measured without loss of oil; an oil heater is to be fitted under the crankcase to give oil temperature control without the use of a local hot-spot, such as is liable to occur when an immersion-type heater is used.

These and other details and the actual test procedure require the closest attention if a satisfactory oil test procedure is to be developed, and when everything possible has been done the interpretation of the results still depends very much on the experience of the operator in this class of work.

Road Tests.

Large users, such as the London Passenger Transport Board, have in the past relied upon service tests to determine the suitability of new or modified grades, or to approve alternative sources of supplies of their standard grades. In August, 1944, the L.P.T.B. commenced a comprehensive test with H.D. 30 oil, engines in a total of about 140 vehicles at two garages being involved. The salient results of this test would doubtless have become available to the Panel in due course, but it was felt that it would be of much greater value if comparable service data could be obtained in respect of the two reference oils, which, as already mentioned, have been selected for use in the development of the laboratory engine tests. It has been possible to obtain the co-operation of the L.P.T.B. in this project, and service tests were commenced in January of this year; it will, of course, be some time before they are completed.

Two groups of twelve newly overhauled direct-injection type, high-speed oil engines of A.E.C. manufacture are involved. To minimize risk of inadvertently using the wrong grade of oil for topping-up, the engines are segregated at two garages, selected as being comparable in respect of character of routes operated. One group of engines is being lubricated with the S.A.E. 30 oil and the other with the H.D. 30 oil. The Board's standard grade of C.I. engine lubricating oil was employed during bench testing of the engines immediately following overhaul, but in accordance with the normal practice the engines were drained before despatch, and, upon being fitted into buses at the respective garages, were first filled with either the plain or H.D. oil; oil-filler caps and the nearside of engine casings were distinctively marked. Engine bases are being drained and refilled after each 12,000 miles in service. Samples representing the circulatory oil are being taken immediately prior to each oil change and also at intermediate 6000-mile periods. The engines will be subjected to detailed examination at the completion of their service life.

In conclusion it should be emphasized that the technique of engine testing of lubricants is still in a tentative form. Only recently has the importance of precision in detail been recognized for laboratory tests to be repeatable; not only must the test units themselves be very closely duplicated, but the cleaning procedure, maintenance, break-in run conditions, etc., standardized with the greatest care.

Numerical methods of rating the oils have been suggested and deserve further attention, but, at present, the rating must depend to some extent on a carefully balanced judgment of many factors, some in favour and some adverse to a given sample.

From the point of view of the user the value of an H.D. oil depends on whether the product gives a definite over-all improvement in engine economy in terms of total maintenance costs over the full life of the unit.

The ultimate aim of the Panel is to provide data from laboratory engine tests to enable a forecast to be made of probable oil behaviour in any engine in respect of each important factor affected by the lubricant.

References.

[1] N. C. Penfold, S.A.E. Preprint of "Some Comments on Engine Testing of Heavy Duty Oils," Nov., 1944.
[2] "A.S.T.M. Standards on Petroleum Products and Lubricants, 1942," Appendix IV, 28.
[3] B. E. Sibley, "L-4 Oxidation Engine Test," S.A.E. Preprint, Jan., 1945.
[4] R. M. Weller, *Petroleum Engineer*, 1944, **15** (8), 204.

THE INSTITUTE OF PETROLEUM.

A MEETING of the Institute of Petroleum was held at Manson House, 26 Portland Place, London, W. 1, on Wednesday, June 13, 1945, the Chair being taken by the President, PROFESSOR F. H. GARNER.

The following paper was then read by Mr. C. H. Barton: "Engine Testing of Heavy-Duty Oils." (See pp. 362–368.)

DISCUSSION.

THE PRESIDENT said that, as Mr. Barton had emphasized, this was an interim report. The Panel had been particularly fortunate in having the co-operation of the London Passenger Transport Board, as the Board had almost unique facilities for carrying out tests of the kind which were most important in this type of work—namely, full-scale practical tests. Mr. Barton had mentioned the question of the interpretation of the results actually obtained in the engine. It was quite understandable that at the present stage the Committee could not make any definite statement in that respect, but some reference might be made to the methods used in America in the series of caterpillar engine tests. In connection with these engine tests, one was always struck by the point that it was either possible to standardize the engine to a great degree of precision, or the engine could be calibrated with reference oils. In the latter case there must be available a reference oil whose performance was based on road tests. In the former case the engine had to be so carefully finished as regards clearances, etc., in order to obtain reproducible results, that it was no longer the same as that supplied by the manufacturer to the user.

He would be glad if Mr. Barton could give the reason why the Panel had adopted the Kadenacy engine as part of its testing equipment.

They would all look forward to having a further paper when the work had made more progress.

MR. C. S. WINDEBANK said he would like to make a few comments on behalf of Sub-Committee No. 5 on the way in which this work had come about, because that had a distinct bearing on the manner in which it was being carried out. Heavy duty oil was essentially an American development, and the way in which it had been developed in America was well known to most of those present. It commenced with the production of a number of diesel engines which were highly satisfactory in operation, but which called for frequent top overhauls owing to rapid deterioration of the lubricant. Consequently, the oil companies developed a class of lubricants which were given the name "Heavy Duty Oils" which permitted operation of the engines for extended periods between overhauls.

In this country we were tackling the job from the opposite direction. We had available to us heavy duty oils, or, as they were sometimes called, "All-purpose lubricants," and these oils were continually modified and improved. On the other hand, most of the diesel engines available in the U.K. were known to operate quite satisfactorily on straight mineral oils, although these engines might be expected to operate still more satisfactorily on heavy duty lubricants. It was hoped that British engine-builders would soon take full advantage of heavy duty lubricants, and it was therefore considered timely to provide ourselves with methods of test for assessing their value in British equipment.

The fact that present British diesel engines were designed for operation on straight mineral oils presented the first difficulty which the heavy duty oils Panel had come up against, for they could not get hold of a British engine which was suitable for the test. Consequently, they had had to take an engine which did not really require a heavy duty lubricant, and increase its sensitivity by exaggerating the conditions of operation. This, he added, was open to criticism, but there was little else to be done. It was considered desirable to accumulate experience at this stage which would stand us in good stead a year or two later.

Perhaps an apology was necessary for having presented this paper in its present form, in that it contained so little in the nature of practical data. When the programme of papers for presentation at the present session was originally formulated, it was hoped that there would be engine data available by this time, but development was necessarily slow in these days owing to delays in delivery of equipment and in allocation of labour, and there was, in fact, only a negligible amount of engine data available. In consequence, the Panel responsible for the paper had some misgivings in presenting it, but it was considered that in spite of the aforementioned criticism it might usefully be read in its present form, if only because it was hoped that it would promote some interesting discussion.

The Panel was necessarily restricted as to the number of people working on it, and at the moment its composition consisted of the representatives of laboratories operating test engines and representatives of the services, the Institution of Automobile Engineers and the London Passenger Transport Board. But there were many others interested in the general problem, and the Panel was hopeful that some of these people would make constructive comments at a time when some benefit could be derived from them. In a few years time these comments might not be very useful, or at least not so useful as they would be to-day.

He himself had been accused of being unduly pessimistic on the question of engine tests, but he would like to emphasize that it was a very difficult subject, and this paper would be justified if it impressed on some of the more hopeful people who were awaiting the results of the activities of the Panel some of the difficulties which had to be overcome. As Mr. Barton had pointed out, the Americans had the benefit of some six or seven years experience in the engine-testing of heavy duty oils, but it was only to-day that they were coming across some of the snags. There had been some very good papers presented recently in America, one in particular being that by Messrs. Donaldson and Sands, which was read before the A.S.T.M. last autumn. In this the authors showed the extreme importance of hitherto uncontrolled engine factors, such as, for instance, the type of water used in the cooling jacket in the L.4 oxidation test, which had been shown to make very distinct differences in regard to getting comparative results between laboratories. Fuel also had been proved to play a very important part. He had recently received a communication from Esso Laboratories, Bayway, again concerning the L.4 oxidation test, which demonstrated the difficulty of getting comparative ratings even with the same installation, if the fuel were changed during the period of the tests. Work had indicated that changes in fuel (within the specification limits) could be responsible for manifold variations in bearing weight loss in this test.

In concluding he said that he would avoid ending on a pessimistic note by repeating his request for comments from people outside the Panel, for the Panel really wanted the advice of all those interested in this problem.

Mr. R. Stansfield, remarking that Mr. Windebank had ended up on a pessimistic note, said he would like to carry the matter a little farther.

Some years ago the main points to be examined after an engine test of a lubricating oil were combustion-chamber deposits, ring sticking and type of ring groove carbon, piston-skirt sludge and crank-case sludge.

Developments in the refining and blending of oils and changes in engine materials and running conditions had combined to alter or modify the requirements of such tests, and it was important to bear this in mind when determining a suitable technique for heavy duty lubricants.

Broadly, the earlier petrol and diesel engines and the lubricants then available tended to give relatively heavy carbon deposits of various consistencies, and ring sticking and piston-skirt sludging when the running conditions were extreme, with crankcase sludge which became troublesome with reduced operating temperatures at low loads.

As performance improved, with rise of m.e.p. and running speed, the heat to be carried away through the piston and ring belt and the temperature of the lubricant increased, and it became necessary in some cases to adopt new bearing materials to improve load-carrying capacity, and then to use oils which did not lead to corrosion of the more sensitive bearing alloys. Piston-ring sticking tended to become more serious, while combustion-chamber deposits were generally smaller in bulk and harder.

Certain of the larger medium-speed diesel engines reached a stage of development in service at which normal oils no longer sufficed to keep piston rings free for satisfactory periods, and the smaller high-output diesel engines, and petrol engines running for long distances at high speed, also suffered from bearing corrosion and piston lacquer troubles, with some piston-ring sticking.

Heavy duty oils were introduced to meet the exacting requirements of these engines, and there had been considerable improvements in the effectiveness of the oils during the few years they have been in use.

It was now the exception for a good heavy duty lubricant to give either piston-ring sticking, appreciable piston-skirt deposits, heavy combustion-chamber deposits, or any bearing corrosion under moderate conditions of use, and even when the duty reached what may be termed type-test running in high-speed diesel and petrol engines the new oils gave a large measure of freedom from such troubles.

These considerations involved alteration in attitude towards engine tests, and it was no longer essential, or even necessarily desirable, to find conditions of test which should invariably result in ring sticking or bearing corrosion.

If engine tests were developed for heavy duty oils against the old background, which was largely considered in terms of total angle of stuck piston rings, the running conditions needed to be so severe that they bore no relation at all to the most arduous service duty. Such severity could well defeat the object of the tests, and break down oils which would never give trouble at reasonable heavy duty loads and speeds.

It was true that laboratory requirements tended towards the adoption of short period runs for convenience and cheapness, and this, in turn, involved the use of more extreme test conditions if sufficiently obvious effects were to be obtained in the time available, but caution must be exercised not so to shorten the test that it became a meaningless coking and cooking of the lubricant in an entirely non-practical way.

In his view, a modern test for engine lubricants should be of little shorter duration than would suffice to give definite ring sticking in a modern high-duty engine run under the most severe service conditions on one of the medium quality normal lubricants.

Heavy duty oils and any others should then be graded by comparison of ring sticking, if any; lacquer deposits; sludge; combustion chamber deposits; bearing corrosion, if any; cylinder and ring wear; deposits in the ports of two-stroke engines; and oil consumptions taken at regular intervals throughout the tests.

More than one type of test and test engine was probably necessary to cover the entire range of high duty engines, and testing could be facilitated by the adoption of standard reference oils of which one might be the minimum requirement for normal engine grades, and one the minimum for heavy duty grades.

Dr. E. R. Redgrove speaking as one who for the past forty years had been led to believe that every ill from which an engine or a vehicle suffered was due entirely to the lubricating oil, thought that the question of engine tests which was again coming to the fore after several years of obscurity due to the War must be thoroughly investigated until a definite conclusion was reached. The work which the Institute was now doing was a valuable contribution to the problem, a problem which was of greatest interest to both suppliers and users of lubricating oils, not only in this country, but throughout the world.

It might be that the engines produced in this country did not require oils in which additives had been included. But considering that all wars greatly accelerate inventive genius, it is to be expected that post-war models of internal-combustion engines—apart from the immediate post-war reproduction of pre-war models—would require something very different in lubricants from what had been known up to the present.

Every support should be given to the good work now being carried out by the special panel of the Institute, from which engine-builders, as well as suppliers and users of lubricants, would benefit.

He hoped that subsequent reports would show that additives could be produced which would overcome not only the inherent faults of some lubricating oils, but also faults or peculiarities which might exist in some fuels, and be a contributory cause of the troubles which it was desired to overcome.

Mr. E. Thornton suggested that oil testing should envisage testing in engines under service conditions, but added that with the perfect engine used to-day, this might involve a period of ten years. Should heavy duty lubricants be used with new engines or with engines which were not so perfect?

Mr. J. G. Withers expressed the view that the Panel had rightly stressed the great importance of a close check on dimensional tolerances in the engine used for testing. Everyone would agree that the clearance between the piston ring and the groove was likely to be a very important factor affecting the ring sticking. A 10 per cent. tolerance on 2-thousandths of an inch was two ten-thousandths, which allowed only one ten-thousandth on either the piston ring or its groove, and was far from commercial practice. Selective assembly was the only way. Another factor was waviness of the ring or groove. If the ring was wavy it was likely to bind partially in the groove and lead to premature sticking. Alignment of crankshaft and cylinder was also an important matter affecting ring action.

An argument against the use of very short test periods was that in many engines 100 hours or more running was required before a steady oil consumption was obtained. If, in these cases, the test period was shorter than 100 hours, the engine was never really run in. It was important that a stable oil consumption should be maintained for the bulk of the test period.

Lt.-Col. H. F. Jones, expressing his interest in the remarks of Dr. Redgrove, said that as one who had been primarily interested for about twenty years in fuels, he had found that users accepted the lubricating oil recommended by their suppliers or the engine maker, and thereafter the fuel was consistently blamed for any faults.

He agreed that standardized methods of engine tests for lubricating oils would be all to the good, but he did not think they were an easy job. The question of additives was continually cropping up in relation to heavy duty oils, and in evolving standardized methods for testing heavy duty lubricants it seemed possible that too many people were viewing it as a method of testing additives, which become the chief topic rather than the performance of the finished product. The user, and this should hold good for the military Services, should not be so interested in additives as in the result obtained from the finished lubricant, whether or not it contained additives. It should be on its performance that an oil is rated as a heavy duty oil, not on its additive content.

Mr. E. A. Evans said he wondered if they all really realized precisely what the work of the Panel was out to achieve, and how it was achieving it. One thing which had come out very forcibly indeed in connection with this paper was the extremely heroic work which was being done not only by the members of the Panels themselves, but also the companies with which they were connected. When men of the calibre of Mr. Windebank and Mr. Stansfield, whose experience and knowledge of the subject differentiated them from anyone else, spoke as they had done, it must make others feel terribly pessimistic as to what would have to be faced in regard to the testing of these heavy duty oils. They had been told that liners had to be taken out and new ones fitted, that for testing purposes the piston rings had to have a certain surface finish, that there must be very fine measurements and tolerances, and a whole host of things, and it all made those who had been accustomed to testing oils in the past shudder at the very thought of the engineering background which was necessary for this class of work. Where was all this going to lead? Did it mean that all the companies who were interested in lubricating oils or who were interested in heavy duty oils had to be equipped with these test engines and with the highly skilled engineers to do the work? He did not know, but in America the large companies had been doing a great deal of work, and he believed it was true that the Armour Institute was now adapting itself to carry out tests for those who wished to have them done. It was a pity that in this country we have nothing of a similar character; but perhaps we would. It was very difficult to know precisely in what direction we should look. This was the type of work which individual people could not do themselves. Whether the Institution of Automobile Engineers Research Organization was the right body or not was a matter for future discussion, but it must be very clear to everybody that this was very academic work, and because of that fact it would have to be carried out by somebody.

Continuing, he asked whether it was the intention to use these engines for appraisement of the additives themselves—obviously it must be to some extent—or was this work to be exclusively devoted, as Lt.-Col. Jones said, to the finished article? Were they going to try to persuade people to supply standard fuels which would not affect the lubricating oil? It was a matter of very serious import, because we might be faced with vast changes in fuels or we might be frustrated by the introduction of fuels which would not co-operate with the lubricant.

It seemed to him that most attention was being devoted to the two-stroke engine. Mr. Barton might say they were using a Crossley, which was a four-stroke engine. The Crossley might be considered to be a poor choice as a test engine purely on the grounds that it did not give trouble from deposits in normal service. It would be a great help to know whether heavy duty oils were particularly suitable for the two-stroke engine and less suitable or not so requisite for the four-stroke engine. Were we going to try to induce diesel-engine builders to use heavy duty oils at this stage, or were we going to wait just a little until we knew more about them? Lt.-Col. Jones might have said a little about their effect in the Services. His own view was that those people who wished to press the heavy duty oil a little untimely could stay their hand until the Panel had done a little more work and had been able to classify these things and make their proper recommendations.

Mr. C. D. Soltz said he did not see the necessity for using a badly worn engine to simulate actual operating conditions. Oil test ratings carried out under carefully controlled conditions should correlate if the conditions have been chosen correctly.

The problem as to whether the test should be short or long obviously involved engine reliability. Basically the aim should be to make the test as short as possible and thus reduce the possibility of engine variables influencing the result.

The question as to the general policy governing the development of H.D. oils really depended on the engine manufacturer. Was he intending to make use of such products by designing his engine to run for considerably longer periods or did he intend to increase the power output by redesigning and thus throwing a greater load on the oil in terms of heat dissipation? The test conditions required would obviously depend on the general policy decided by the engine designer.

He (Mr. Soltz) thought that there was no reason why some simple little engine could not be developed for oil testing in a comparatively short space of time. There was no difficulty in the actual design but, as in the United States during the development of the C.F.R. fuel test engine, considerable exploration of the problems for which the engine would be required would be necessary.

Dr. W. E. J. Broom thought it a little unfortunate that the title of the Panel charged with the task of producing an engine test for lubricating oils should have the term "heavy duty" tacked on to it. The problem, as he saw it, was, that the Panel had the job of producing an engine test for lubricating oils. The problem would have been just the same in 1925, in his view, with the exception that the oils they would then have had to deal with would not have been as good as they were to-day; neither would the engines. Even at that time they might have found difficulty in obtaining an engine which would give them what they wanted. The problem to-day was more difficult, because the oils were better, and so also were the engines. Consequently, as had been said, it was necessary to take an engine which, so far as was known, operated satisfactorily on good oils, and artificially make its conditions of operation more severe. Therefore he felt it was unfortunate that the emphasis had been laid on the heavy duty side and on additives, because the problem should be simply one of testing lubricating oils.

All the difficulties with regard to engine parts, etc., were obviously due to the fact that engines were not precise scientific instruments. Those who had had the misfortune to have had to try some of these experiments had, of course, soon found that out, and those who had undertaken this difficult task were to be thanked for their efforts to get a standard engine in order to get reproducible results under bench type conditions. This was one angle on the problem. There was quite a different angle; to obtain results which were translatable into service conditions. Some of them had had experience in the past where the short-time severe engine test could exaggerate the conditions and produce a distorted picture of events which did not necessarily occur under road conditions. As a chemist, he himself was a little perturbed at the large amount of money that would be necessary for these engine tests, because it seemed to him that an engine test was used simply to determine whether an oil was good or bad, and it implied that we need not worry very much about why it was good or bad. But we should not overlook the comparable chemical research that should go hand-in-hand with these engine tests in order to tell us more about the "whys" as well as the "hows."

Further, he considered these tests were really only a half-way house, because whatever the nature of the test on the engine in the laboratory, we should still be up against the practical test on the road. That was obviously well recognized by the Panel inasmuch as they had managed to get the co-operation of the London Passenger Transport Board in carrying out actual road tests.

Finally, he said he was pleased to see one or two engine-builders present, and would like to have their views on this general question of oil-testing. A point which came to his mind was that when the Panel had done its work and there was a standard test procedure available, how would the engine-builders as a whole view the procedure? Would they expect those who were interested in lubricating oils to carry out tests in each individual engine, or would they be prepared to say that an oil which gave a satisfactory rating in the I.P. test would be good enough for their engines?

Dr. D. Clayton said there is a Service interest in this development because, although ring sticking (the primary reason for the introduction of heavy duty oils) is not a trouble, improvement in cleanliness of certain classes of engines results. Moreover, in getting the most out of engines in the future, advantage must be taken of what improved materials the oil suppliers can provide. He would not like, however, to see in this country, as originally in America, this type of oil used merely to cover up bad design.

Warning had been given at the meeting of the great difficulties entailed in engine testing. Previously, however, he had sensed a delight on the part of some of the oil suppliers in undertaking engine tests, and a discouraging criticism of anyone putting forward a laboratory test—correlation was always required with engine tests, even though it is apparent that there is in fact no standard of engine behaviour.

He did not disagree with the need for engine tests at the present juncture, but felt that laboratory tests, coupled with a background of general engine experience, had served well in the past, and that encouragement should now also be given to the development of the special laboratory tests evidently necessary, in parallel with the engine testing. In the investigation of ring-sticking tendencies, bearing corrosion, etc., there should be an analysis of the phenomena so that the fundamental requisite conditions could be laid down for the laboratory tests. The indications given by Mr. Barton of the general constancy of rating for ring sticking in different engines surely implied that there was some common factor.

Mr. A. T. Wilford said he wished to support what had been said in favour of simplification. The position of the user, and especially the large user, in regard to these newer types of lubricating oils, was going to be very difficult indeed. Presumably some test had to be carried out with each particular make of oil. There was no suggestion that oils from different sources of supply would be identical; indeed, we could be quite certain they would not be, and the onus was placed on the user of testing all these oils before he could decide which he would use. He was also faced with having to re-test the oils from time to time during the period of a contract. That could be done effectively by service tests, but very careful precautions were required in order to get conclusive results. For example, when the London Passenger Transport Board changed from a conventional type of lubricating oil to one of the duo-sol type, it took three years of controlled service testing to prove the latter worthy of adoption. But would it really be feasible for any concern to do the continual engine or service testing which would be necessary to establish, first, whether a particular oil was suitable, and, secondly, guarantee that this oil remained constant during the run of the contract? That was where some more simple test, as already suggested, would be extremely valuable. Such a test, whether it were one embodying the use of a single cylinder engine or one based upon an arbitrary laboratory rig, must be neither so expensive nor so time-absorbing as are the engine tests at present contemplated. Investigations with the view of developing a test of this character would seem well worth while.

Lt.-Col. Jones referred to the suggestion that more should be said with regard to results experienced by the Services. He reminded those present that the changeover had to be effected while campaigns were being waged, and there were no facilities or technical personnel to carry out any reliable technical study in the field. The American Army trials had, however, shown advantages from the use of heavy duty oils. The opinion of British users indicated that there had been little noticeable advantage or disadvantage in comparison with the previous high-quality W.D. engine oils, and this appears to have been endorsed by the few isolated trials on petrol-engined Service vehicles in this country. He had seen no reports on diesel engines, but had heard their performance praised, which probably reflects credit on heavy duty oil, especially if backed by Admiralty experience. The susceptibility of some heavy duty oils to absorb water had caused some concern in handling and packaging, but this had been overcome without detriment to the user.

He pointed out that changes in the nature of an oil, during say a contract period, are not necessarily applicable only to heavy duty oils and, apart from the influence of additives, it might continue to be difficult to diagnose by simple test whether the new oil was the same as before.

Mr. F. Weatherill, remarking that reference had been made to the fact that the production of a heavy duty oil did not of necessity involve the use of additives, asked whether the use of an additive was looked upon as a temporary means of solving a problem which would ultimately be solved by the refinery. He also asked if there was any particular reason for choosing 12,000 miles as the period for the tests described in the paper.

Mr. W. Pohl said that whilst Mr. Wilford did not say so in his comment upon the need for a simple test from the user's point of view, he believed he had in mind a chemical laboratory test. In that connection he put in a plea on behalf of the chemist. It was often the experience of the chemist, when attempting to develop a labortory test to correlate with engine performance, that the engine performance varied with the number of engine tests and the chemist was never able to catch up with the engineers rating. Therefore, in embarking on this programme, he suggested that the first thing to do was to obtain a repeatable engine test.

Mr. K. Arter remarked that emphasis had rightly been placed on the difficulty of obtaining reproducible results in these engine tests, and there was rather an essential point of difference between the work done in America and that done here. The American engine tests were originated by the engine-builders, who were rather worried by certain mechanized troubles, and they sought the co-operation of the oil companies in overcoming them. In England, however, there did not appear to be very much interest in heavy duty oils because the majority of engine people seemed to be happy with their existing types of straight oils; consequently, the Institute was having rather a hard task in trying to adapt existing commercial engine types for the purpose of testing. Moreover, with all the pressure of war production it had not been possible here to obtain the wholehearted co-operation of engine builders. Under normal conditions, if this very onerous work was proceeded with and improved oils were obtainable, no doubt the engine-builders would, in course of time, find them very useful, and such oils would enable them to improve the efficiency of their engines. Therefore, in proceeding with this work it was very desirable that the Panel should have the co-operation of the engine-builders. Indeed, he believed that without that co-operation it would never be possible to establish a universal standard test.

One other point. The American C.R.C. tests were essentially qualification tests—*i.e.*, tests carried out on a particular brand of oil. Once this brand was approved, it was not customary to repeat the tests at frequent intervals; in fact, it would not be possible to do so. He had been given to understand that the General Motors 500 hours test, for example, cost $18,000, and he did not see any immediate prospect of establishing a simple engine test which could be applied at frequent intervals for routine testing. This would need to be a fairly long-term project.

Mr. P. W. L. Gossling, referring to previous speakers' views upon the desirability of not neglecting the chemical viewpoint and of developing laboratory tests, stated that until we had standardized engines and conditions of operation, there was nothing we could use as a datum line. He believed that satisfactory laboratory tests would be evolved, but it would not be possible to get very far until we had something with which we could compare them, and that, in his view, was the value to the chemist, as apart from the engineer, of the work of the Panel.

Mr. C. H. Barton, in reply, said there were certain matters which could be dealt with in the usual way, such as wear of cylinder liners, ring-groove deposits and even estimating the extent of piston-ring sticking. The difficulty of dealing with such questions as the amount of lacquer deposit on the piston, or sludge in the oil holes, etc., was so great that in America the final assessment of the C.R.C. tests was done by the Armour Institute. The important parts of the engine were inspected after the test, and the Report by the Institute decided whether the oil had passed the test or not.

This brought him to the very important point raised by Mr. Evans as to what was going to happen if the Institute of Petroleum put forward a standard engine test. His own view was that the solution probably was to have a central testing body. This organization which would possess the necessary engine equipment, would be in a position to test and report as to whether oils satisfied the heavy duty standard or not.

Another question brought forward by the President was why the Committee had selected the Kadenacy type of engine. It was felt that both a four-stroke and a two-stroke engine should be included in the programme, and it seemed to the Panel that the Kadenacy type was one likely to be widely used.

As Lt.-Col. Jones had said, the term "heavy duty" did not necessarily imply the use of additives. If a refinery could produce an oil which would comply with the heavy duty standard it would be accepted as a heavy duty oil even if it contained no special additive. The aim of the Panel was to develop test methods which distinguished between the heavy duty oils and those which did not reach that standard. Of course, if an oil producer or refiner acquired a test engine, he could evaluate and compare additives and to find the correct proportions to blend with his particular oils.

The point had been raised as to whether aero engines came into the picture. The Panel early decided that in order to make effective progress it would be necessary to concentrate on one subject at a time, and as heavy duty oils were primarily developed for high-speed diesel engines, it was better to concentrate on this subject, particularly as the original terms of reference of the Panel were to study tests for heavy duty oils. However, the fact had not been lost sight of that at some time the question of evolving engine tests for oils intended for other engines, including aero engines, would have to be considered. He understood that work on developing standard engine tests for aero engine oils was in progress and there was a representative of the M.A.P. on the Panel.

Mr. Thornton had raised the important point that many engines did not need heavy duty lubricants and, conversely, that such a lubricant might not always be satisfactory in an engine which did not require it. In the first place, he imagined that the average user of an engine would not employ a heavy duty oil unless he thought it was necessary; if heavy duty oils were used in engines which did not require them, they would obviously show no advantage over other suitable oils, but the question as to whether they could be inferior to the latter in performance would be a matter to be decided by the user in consultation with the oil supplier. Indications so far were that an engine's requirements as regards heavy duty oils did not depend on its age, but on its working conditions.

The point raised by Dr. Broom was one which had not been answered by any engine-builder, *viz.*, whether engine-builders would be prepared to accept the Institute of Petroleum tests when they were developed. That was a point on which the panel hoped to obtain the opinions and advice of the engine builders by co-option of their representatives on to the Panel.

He, Mr. Barton, could not answer Mr. Weatherill's question as to whether additives were a temporary phase. He believed it was the opinion that they had come to stay, at any rate, for certain applications.

The possibility of a small test engine was really an important question, and it was one which the Panel had constantly in mind. That was one of the reasons why the Crossley was selected. If it were a choice between a large unit, say 50-h.p. per cylinder, and 10-h.p. per cylinder, the choice would be the 10-h.p. on the ground of cost of running, simplicity, etc.

In America reference oils were used to standardize the test engines, and he felt it was essential that the Institute of Petroleum tests should include the use of reference oils so that operators could check their engines. At the moment, the oils which the Panel were using had not been definitely adopted as reference oils; one of them was a good quality, straight engine oil and the other was a heavy duty oil. The Panel was first attempting to work out conditions of running which would distinguish between the two oils.

On the question of the fuel used, the American specification had been followed for the present partly because American engines were being used. Eventually fuels would be specified and stocks made available, and thus one variable would be eliminated between engines.

Mr. Evans had asked whether heavy duty oils were particularly necessary for two-stroke engines as against four-stroke engines. That was a point upon which he personally had no views, but it was most likely that some types of two-stroke engine would be perfectly happy on non-additive or non-heavy duty oils, as are most four-stroke engines.

Mr. A. T. Wilford, in reply to a question as to why the oils being used in the service test were changed after each 12,000 miles rather than some other mileage, stated that this corresponded with the normal "docking" period for the vehicles, when among other things injectors were cleaned, fuel pumps were recalibrated and cylinder heads received attention if necessary. Under the present system of garage maintenance it would be possible (though at much inconvenience) to change the oil after each 6000 miles, but this would conflict with existing practice, which past experience had indicated to be satisfactory compromise. The engines using the experimental oil were thus being treated in the standardized manner in respect of frequency of oil changes.

A Speaker said he had had occasion to use the I.P. mineral oil and found it a very good quality. Was there any proof that that had actually failed to come up to the heavy duty rating?

Mr. Barton said that the S.A.E. 30 oil had not, as yet, been submitted to the American heavy duty oil tests. The oil was simply selected on the basis that it was not an additive-containing oil. If it turned out to have heavy duty properties it would be necessary to look around for another mineral oil not possessing these properties.

Asked whether any precautions had been taken to ensure that the fuels used in the various sets of engines were from the same sources and of comparable purity, Mr. Barton said the L.P.T.B. tests had been carried out on regular supplies of fuel from the Petroleum Board and it was assumed that these supplies were the same in character. The bench engines were using fuel from a stock set aside by the Petroleum Board.

Mr. Stansfield said that tests made so far indicated that the non-high-duty oil chosen was quite a good grade.

On the motion of the President, a hearty vote of thanks was accorded to the author of the paper.