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CHARACTERISTICS AND DEVELOPMENT OF NAVAL FUEL OILS

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Introduction

It is the purpose of this paper to review certain fuel characteristics to which technical aspects of fuel utilization lend a very special significance.

Sulphur is certainly one of the most undesirable elements to be found in a combustible, whether the fuel be for use in boilers or Diesel engines. If, unhappily, its presence has to be tolerated to some extent in order to avoid undue restriction of supplies in these difficult days, it is nevertheless essential to ensure that the sulphur content should not exceed a certain maximum percentage.

With regard to sodium, the adverse effects of introducing this alkali into the furnaces of boilers are well known. Indeed, it seems probable that the presence of sodium is also responsible for certain difficulties in the use of heavy fuels for Diesel engines. It is, therefore, of prime importance that measures should be taken to prevent, or to minimize, its presence. In the first place, only a small proportion of sea water should be allowed in fuels, and secondly, a maximum ash content should be fixed.

At the present time, however, the question which raises the most serious difficulties is that of pumping fuels at low temperatures. The fact is that there is as yet no standardized method on the basis of which the future development of the pour-point of a mixed-base fuel—that is, of an asphalt-paraffin base fuel—can be predicted. But investigations are now being undertaken to develop a method of thermal pre-treatment by means of which it is hoped to be able to determine a constant maximum pour-point.

The author also wishes to stress the importance for the marine engineer of such questions as:—

(i) The breaking of emulsions
(ii) The content in explosive vapours
(iii) The asphalt content, etc.

It is also desired to touch upon some special problems regarding the use of boiler fuels in certain gas turbines and in low speed Diesel main engines.

In looking back over the years preceding the Second World War, it can easily be seen how certain characteristics of fuel oils have changed in the meantime. These changes may be said to be the outcome of attempts to effect a balance or compromise between the increasingly exacting requirements of modern boilers and a quality of fuel which, by reason of present day refining practice, is steadily deteriorating. Two tendencies, which are at least divergent, if not actually conflicting, are clearly evident. On the one hand, it must be considered that each new boiler design results in a further improvement in performance, as will be seen from the figures given in Table 1. At the same time, these improvements are accompanied by an increase in gas temperature and gas velocity in the various parts of the boiler; and in addition the refractory lining has likewise become subject to higher furnace temperatures. Under these increasingly severe working conditions, the use of certain fuels has led at times to the destruction of the brickwork owing to excessive furnace temperatures, and to the slagging-up of the boiler convection surfaces.

Since the causes of these difficulties have not always been clearly discerned, attempts to deal with the problem have resulted in the insertion of rigid limits in specifications with regard to the content of sulphur, asphalt, ash, etc., which were held to be responsible for such troubles.

On the other hand, there is the fact that the Middle East with its asphalt-paraffin base fuels of high sulphur content,

TABLE I

Principal characteristics			Vessels				
			BASQUE at sea 1931	*FANTASQUE* at sea 1935	*MELPOMENE* at sea 1936	*MOGADOR* at sea 1938	*FIER* building 1939
Total heating surface in square metres			930	1,390	725	1,028	530
Horse power			11,000	18,500	11,000	23,000	14,000
Consumption in kg. per hr.	Max. continuous rating	Per sq. m. of total surface	5,860	590	435	79	1,068
		Per cu. m. of room	145	176	194	230	296
	Max. intermittent rating	Per sq. m. of total surface	6,810	65	478	973	1,181
		Per cu. m. of furnace	170	194	212	282	328

has largely superseded North and Central America as a source of supply of fuel oils to the countries of Europe. In the case of France, for example, it is estimated that in 1951 she will receive 85 per cent of her fuel oil imports from the Middle East, as compared with 45 per cent in 1938. This situation has perforce resulted in a tendency to increase the maximum sulphur content, which is of course an opposing tendency to that previously mentioned, to limit impurities. The trend towards the employment of fuels with higher sulphur content than hitherto used is all the more marked on account of the increased importance of light and medium distillates, particularly gasoline and gas oils, which is due to the ever increasing demands of industry and of all kinds of shipping. As a brief illustration of the rise in sulphur content, which is today as high as 3·5 per cent (F.F.O. Specification), it will be recollected that it was 3 per cent before 1939, and 2 per cent in 1934 and in fact it was as low as 0·5 per cent just after the First World War, if this is not to go too far back.

Furthermore, the paraffinic nature of the Middle Eastern fuels is also responsible for the difficulties which are being experienced in the pumping of oils at low temperatures. Also, modern refining techniques introduced in cracking practice are in their turn bringing into play new characteristics such as the degree of explosibility, or are revealing new aspects of—and also re-emphasizing—such old problems as stability' compatibility, de-emulsification, etc.

Thus the situation is that the requirements of modern boilers for fuels as free as possible from impurities are difficult to satisfy in view of the fact that the interests of economic production lie in a reverse direction. The summary just given furnishes the general background to the problem of drawing up limiting specifications for fuel oils to meet present-day conditions; and the aim of this paper is to review those characteristics which are at present being actively investigated. The point of view of the paper will be that of the user—that is, of the marine engineer responsible for the operation and maintenance of the propulsion plant of a vessel.

Sulphur

It will be appreciated readily that the progressive raising of the sulphur content in new specifications has given rise to much criticism and to a good deal of anxiety.

In the first place the troubles envisaged are of two kinds:—

1. Corrosion of the boiler drums, of the boiler tubes, and also of the platework.
2. The harmful effects of the sulphur fumes on the health of the operating personnel. Experience has proved that in a limited number of applications this latter problem is ultimately the more important.

Sulphur in fuel has often been defined as existing in two forms—namely, inert sulphur and active sulphur. The sulphur occurs in many series of compounds the chemistry of which is quite a complicated study. Attempts are sometimes made to assess the extent to which active sulphur compounds are present in the fuel before use, by examining the discoloration of a copper plate immersed in the fuel. However, from a combustion point of view it is the total amount of sulphur which is important. Regardless of the form in which it is present, combustion of sulphur produces sulphur dioxide (SO_2) and a certain amount of the more chemically active sulphur trioxide (SO_3). Various factors, such as the catalytic action of oxide surfaces, are liable to assist the conversion of SO_2 to SO_3.

There is therefore no real reason to attempt to distinguish the different forms of sulphur in a fuel, when the relevant problem is to discover by experiment the maximum sulphur content permissible for any given purpose.

To determine this point, the French Navy has carried out a number of tests, the most recent of which took place in the spring of 1948. As the author took part in these tests, the conclusions then reached will be stated briefly.

For the purposes of this last test, one of the boilers of a cruiser was fired with a Heavy Fuel Oil No. 1, of Middle Eastern origin. This fuel had the following basic characteristics:—

Specific gravity	0·955
Mineral acidity	0
Viscosity	105 centistokes at 50 deg. C.
Sulphur	3·5 per cent
Asphalt	6·04 per cent
Sulphated ash	0·020 per cent
Alkaline sulphated ash content ..	0·010 per cent

The boiler under trial was of the type brought into service in 1939, design pressure of 27 kg. per sq. cm. for superheated steam operation. It had previously been cleaned and fitted with test specimens of mild steel and copper which were placed in the tube bundles.

The test lasted for 125 hours, during which 282 tons of fuel were consumed. The other boilers in the ship were fired with the normal grade of fuel hitherto used which had a sulphur content not exceeding one per cent. The conclusions drawn from the results of this trial refer in the first place to the material, and may be summarized as follows:—

Lighting up: No trouble.

Brickwork: The brickwork of the boiler under test showed no particular evidence of deterioration. It was in the same condition as that of the other boilers.

Deposit on Boiler Tubes: The external dirt and deposit of soot on the nests of boiler tubes were not appreciably greater than those found with the use of the usual grade of fuel.

Nature of Soot Deposits: Four samples (Nos. 1, 2, 3, 4) were taken from the boiler under trial, and two (Nos. 5 and 6) from a boiler burning the usual grade of fuel. The analysis of these samples, which is given in Table 2, emphasizes a phenomenon which gave rise to some surprise at first. The soot from the boiler under test was quite comparable to that from the boiler burning ordinary fuel, and it was especially noted that the sulphate content was the same.

TABLE 2

Constituents	1	2	3	4	5	6
Water, per cent	7·6	8·2	10·2	7·8	8·6	7·8
Smoke black (tarry carbon matter)	24·6	38·2	34·8	47·4	35·9	37·3
Silicate, per cent	1·4	4·3	4·1	2·5	0·3	0·6
Iron as $Fe_2 O_3$, per cent	25·2	30·6	18·7	10·8	24·4	29·0
Aluminium as $Al_2 O_3$, per cent	0·3	Traces	Traces	Traces	Traces	Traces
Calcium CaO, per cent	0·3	0·8	0	0	0	0
Sulphates as SO_3, per cent	25·7	14·7	27·7	19·9	26·1	20·4
Vanadium as Va, per cent	1·9	0·6	1·5	1·2	1·8	1·8
Chlorides	0	0	0	0	0	0
Phosphates	0	0	0	0	0	0
Carbonates	0	0	0	0	0	0

It must be concluded from these results that the sulphate content of the ashes does not depend upon the sulphur content of the fuel—in fact, there will always be an excess of sulphur—but upon the elements, particularly sodium, which enter into combination with the sulphur in the furnace. The sodium may be present in the fuel itself, but is more likely to be introduced accidentally owing to the contamination of the fuel oil with sea water. It should be noted that the iron content is much the same in all samples. No special wastage can be attributed to the effects of the greater sulphur content of the new fuel employed.

Visible Corrosion: No fresh or abnormal corrosion was observed either in the tube banks or in the gas passages of the boiler.

Examination of the Test Specimens: Upon being examined and weighed, the test specimens were found to have become browned, although they still retained their polish; also, they showed no sign of pitting or corrosion. So far, therefore, as the material is concerned, the evidence is not unfavourable to the employment of fuels with a sulphur content of up to 3·5 per cent.

In dealing, however, with the physiological effects of the use of fuel with this degree of sulphur content, certain disadvantages present themselves. The chief effects noted in this connexion may be stated briefly as follows.

On the Bridge: With a following wind, it was found that the smell of sulphur was very marked. Both respiratory organs and eyes were apt to become irritated. With other wind directions, however, these effects were less marked.

On Deck: The sulphur fumes were noticed only when lighting up, and at slow speed with no wind, and at moderate speeds with a following wind. There was only slight irritation of the respiratory tract, and no ill effects were observed from this.

Engine and Boiler Rooms: The sulphur fumes were perceptible as on deck, and likewise with no apparent ill effects.

One particular point, however, must be noted. On board the cruiser under test, the galleys were burning boiler fuel. Here it was found impossible to use the fuel of higher sulphur content, because of the considerable discomfort suffered by the personnel when the sulphur fumes pervaded the overheated atmosphere of these small compartments.

To sum up, the results obtained during the course of this test confirmed previous opinions—that is, that with respect to the material, a sulphur content of up to 3·5 per cent could be tolerated without serious inconvenience. Beyond this limit, however, as the French Navy had been able to verify on several occasions, rapid deterioration of the platework takes place.

It is a fact that some of the boilers in refineries have used sulphuric tars without excessive attacks on the platework. But these boilers were under continuous operation, and the discharge of flue gas took place at a temperature higher than the dew point of sulphuric acid (175 deg. C.). The working conditions for marine boilers are very different. The intermittent shutting down of the furnaces assists condensation of active agents such as SO_4, H_2, and SO_3 in solution.

Consideration of these factors, together with those relating to the physiological effects of sulphurous and sulphuric gases, can only confirm the conclusion that a sulphur content of 3·5 per cent must remain a maximum for the present.

Ashes and Sea Water

For a long time the specifications for furnace fuel oils have omitted any mention of ash content. Some deterioration of the brickwork, such as washing away of the refractory, must be attributed to the action of sodium, the chemical reaction proceeding according to:—

$$Al_2O_3 + H_2O + Na_2SO_4 = Al_2O_3, Na_2O + H_2SO_4$$

The alumina, which forms at these relatively low temperatures of about 900 deg. C. has fluid properties resembling those of glass; and the reaction proceeds continually as new surface becomes exposed. The magnitude of the phenomenon will be clearly evident if it is considered that the alumina forms about one-third of the substance of the fire clay, and that about two-thirds of the ash from the fuel is made up of sulphate of soda. It will thus be seen that under these conditions, an ash content of 1 part per 1,000 corresponds to a wastage of 1,500 kilograms of brickwork per ton of fuel consumed.

The chief cause of sodium in the fuel is the accidental introduction of sea water into the fuel tanks. The role played by sea water was suspected before the last war, and it is now well established that the greater part of the sodium introduced into the furnace of a boiler results from the fact that an emulsion of salt water and fuel has been burnt. The paper read on this subject by Gray and Killner* describes these consequences very clearly.

Nevertheless, it would be unwise to neglect an additional source of sodium—that is, the sodium content of the fuel itself. It should be remembered that crude petroleum is never entirely free from water, and that the salts contained in the water remain in the oil after distillation. Moreover, during the refining process, the refiners sometimes add not only lime (which is less harmful, although it forms sulphate of lime which can be removed only by mechanical cleaning) but also sodium to prevent corrosion due to sulphur and naphthenic acid. There may, therefore, be solid crystallized salts in the residue which constitutes the fuel; and this in addition to the salts from the sea water. Consequently, it would appear necessary to impose a limit on ash content of Navy fuel, and a maximum of 0·1 per cent (1 part per 1,000) would seem reasonable.

To illustrate this point, it will be observed that an ash content of 0·1 per cent, of which it is assumed that two-thirds of its weight is formed by sulphate of sodium, corresponds per ton of fuel consumed, to the introduction into the furnace of a mass of alkaline metal approximately equal to that contained in 20 litres of sea water, which is a considerable quantity.

If the action of the sodium were limited to its attack on the fireclay, it could probably be neutralized by the use of a better and more resistant material. But unfortunately, as Gray and Kilner have shown in their aforementioned paper, sodium is also the cause of the formation of deposit on the boiler tubes.

As an instance of the rapid scaling-up of the boiler tubes as a result of using contaminated fuel, difficulties experienced in a large French warship can be cited, although the particular circumstances of this case would make it difficult to determine whether the contamination was due to the presence of sea water or to the introduction of sodium in the process of refining. However it was, the steaming capacity of the boiler became steadily reduced, and very soon the personnel were obliged to carry out most difficult cleaning operations. Fig. 1, Plate 1, shows the appearance of the deposit upon the tubes.

As can be seen, the narrowness of the gas passage between the tubes would render such boilers very susceptible to choking by ash deposit.

The troubles experienced in this particular case occurred in 1945-1946, and reference to them is made because a very simple and effective solution has since been found. It is, in fact, sufficient to install an arrangement for spraying the tubes. The deposit, which is primarily composed (as has already been stated and shown by numerous analyses) of soluble sulphates, is by this means easily removed.

The necessity remains, nevertheless, to avoid the introduction of sodium into the boiler. The engineers in charge of the ship's propulsion plant should be able to control the sea

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* 1948. Trans.I.Mar.E., Vol. 60, p. 43. "Sea Water Contamination of Boiler Fuel Oil and Its Effects".

water content of the fuel. This emphasizes the need for the provision of measuring instruments designed for shipboard use, such as those which use the entrainment of water by petrol vapour of the British Admiralty pattern.

It should not be relied upon to recognize the presence of a dangerous quantity of water in the fuel by the visual appearance of the flame. For example, another large warship was found to have consumed an emulsion of 10 per cent sea water without the boiler-room staff realizing the fact for some time.

The French Navy allows a maximum water content of 2 per cent, and this must be checked whenever a change over is made from one fuel to another.

In connexion with this question of limiting the water content in fuels, there should be some mention of the efforts which have been made to rid fuel oil of all emulsified water which it might accidentally contain. The various risks of fuel contamination by sea water may be summed up as follows:—

(*a*) Sea water ballast which always leaves traces of sea water at the bottom of the tank or in some parts of the piping.
(*b*) Leaks in the seams of the tanks.
(*c*) The introduction of damp air as the fuel is consumed.
(*d*) Sea entering the ventilating shafts in rough weather, etc.

The agitation which takes place during rolling and pitching may result in the formation of an emulsion, which, if the troubles previously mentioned are to be avoided, must be broken up or removed before the fuel is used. The author must confess that, for the present, it would appear that this is the only practical course to pursue. Therefore, if an emulsion takes place accidentally, some means must be found to break it.

The physical characteristics of fuel which assist separation are:—

(*a*) A low specific gravity.
(*b*) A low viscosity.
(*c*) A natural tendency to de-emulsification.

These are factors which cannot be taken into consideration when drawing up a specification.

With regard to specific gravity, too low a limit must not be set for this, as otherwise it would not be possible to purchase certain heavy fuels such as those from Trinidad. As to the viscosity, this is determined by other considerations, such as the rate of flow when oiling ship. Thanks to tank heating arrangements, viscosity can be controlled to some extent by the engine-room staff.

With respect to a test for de-emulsification, any attempt in this direction would seem to have little chance of success in the case of many fuels, particularly those derived from cracking. It is, therefore, necessary to provide some means of breaking up the emulsions.

Considerable help toward the solution of this problem has been provided by the work of Lawrence and Killner* which records interesting results obtained by the use of "Teepol". The surface-active properties of this product explain its action. It reduces the surface tension of the aqueous solution and consequently of the interfacial tension between the Teepol-treated fuel and water. Here then is a simple means of separating the water. Moreover, there are a number of other surface-active agents which act in the same way and which can be made easily available.

As a matter of interest, mention can be made of the laboratory experiments carried out with forty-one different commercial products, which have given surface tensions varying from 46·8 dynes per cm. to 22·7 dynes per cm. Their effectiveness can be appreciated if it is remembered that the tension of pure distilled water is 73 dynes per cm. and that of a solution of Marseilles soap is 21·4 dynes per cm. It is believed that the use of these products ashore, assisted by a temperature sufficiently high to help the globules of water to settle by decreasing the fuel viscosity, should give results.

Experiments carried out at the Naval fuel stores to find a method suitable for the breaking up of emulsions on an industrial scale by the application of a commercial surface-active product (Sinnopon) have, after considerable efforts, been crowned with success.

It should, however, be noted that the drop in interfacial tension between the two phases fuel and water reduces the energy necessary to the formation of an emulsion, and that a fairly gentle agitation will produce dispersion—that is, a result opposite to that aimed at. This fact would seem to prohibit the use of this method on board a ship at sea.

Another source of anxiety, which is connected with the previous one, arises from the observation that the interfacial tension between a fuel and a solution seems to be little affected by the amount of surface-active agent contained in the latter. It would seem that a stable interfacial tension is attained from the moment when a very thin layer, perhaps even only a single molecule in thickness, is adsorbed at the interface. This layer would, of course, be produced from very low concentrations.

Thus it might happen that in a tank which had previously contained an emulsion which had been treated with an emulsifying agent, there might remain enough of the active product which, after dilution with a new fuel charge, would still be effective to assist the formation of an emulsion in the event of admission of water or sufficient motion of the ship. The problem of the breaking up of an emulsion on board ship is therefore not yet entirely solved. In fact, it is even probable that there is no single general solution. The various emulsions differ from one another according to the nature of the disperse phase which may be fuel or may be water (as is generally the case with emulsions on board ship), and their stabilization is due to a variety of causes. They are more or less assimilable in colloidal suspensions, and it is certain that the various means in use to produce flocculation of such suspensions will all have to be brought into play according to the case and the result aimed at.

Behaviour of Fuels at Low Temperature

For some years past, and since fuels from the Middle East have come into more general use, difficulties have been experienced in the employment of fuels at low temperatures. Shore installations have been brought to a standstill owing to the impossibility of pumping the fuel. The same troubles have been experienced on board merchant ships in cold waters. This was not so much due to an exceptionally low ambient temperature, but to the fact that the paraffin base fuels of the Middle East are most unfavourably affected by cold.

One can for discussion purposes classify petroleum fuels into:—

(*a*) those of naphthenic or asphaltic base,
(*b*) those of mixed asphaltic-paraffin base.

Such a division is not, however, very accurate.

The variation in viscosity of the former with the temperature follows Walther's law fairly closely, which is to say, a straight line relationship obtains in a diagram in which the logarithm of the temperature is plotted against the log-log of a linear function of the viscosity.

The divergencies which have been observed in viscosity determination according to whether the measurement is carried out with increasing or decreasing temperature are too small to be of any decisive importance. The viscosity naturally increases with the cold, but the fuel remains fairly fluid until it reaches a certain low temperature because it does not contain any solid constituents. But after passing a certain temperature, known as the " pour point," it loses its fluid properties. The important factor is that for an

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*Jl.Inst.Petroleum, 1948, Vol. 34, p. 821. "Emulsions of Sea Water in Admiralty Fuel Oil with special reference to their Demulsification".

asphaltic fuel, this pour point is practically independent of the manner at which it is determined. It is almost constant. At higher temperatures, the fuel is fluid, and its viscosity is given sufficiently accurately by the viscosity-temperature curve.

This is not the case with Middle Eastern fuels, for which it is difficult to define a viscosity below 50 deg. C. For some fuels there is even an actual " drop point " above 50 deg. C. It is only at a temperature above 50 deg. C. that, as the wax is dissolved, the fuel behaves in the manner indicated by Walther's law.

At temperatures below 50 deg. C. the paraffin crystallizes and the structure, influenced by the very variable state of the crystallization arising from the circumstances existing at the time, is no longer constant. The fuel is no longer viscous and Walther's law therefore does not apply. To illustrate the great variation in viscosity below 50 deg. C. for this type of fuel, an instance may be given of a sample which had a viscosity below 50 centistokes at 50 deg. C. and for this reason might have been classed among the light fuels, whereas in fact it was solid at 45 deg. C.

That is why, in order to determine a fixed datum point, the specification of F.F.O. (furnace fuel oil) lays down the limiting viscosity at 50 deg. C.

The crystallization of paraffin is responsible for yet another phenomenon which has serious consequences. With the inconstancy of the pour point, there are certain fuels for which the variation of the congealing point between the port of embarkation in the Persian Gulf and the port of discharge in Europe varies as much as 20 to 25 deg. C. Little need be said to emphasize the danger which a ship would run in using such a fuel which, having been embarked on the understanding of a satisfactory pour point, would be found to have become solidified in the tanks a few weeks later.

It is said that the congealing point depends upon the previous thermal or mechanical history of the fuel. Now this influence of the history of the fuel can be better explained by noting that the variability of the pour point seems to be affected by simultaneous presence of paraffinic and asphaltic matter. These latter act somewhat in the manner of a " pour point depressant " used for lowering the congealing point of certain lubricating oils. While cooling, the asphaltic matter which comes out of solution, is deposited on the nascent paraffin crystals in course of formation, thus isolating them from the " nutritive " matrix, arresting their development, and so causing a formation of small crystals which forms a rigid structure only at fairly low temperature, or for a more lengthy period of contact. Without asphalt, a rigid structure of large crystals would have formed quickly at a higher temperature. The action of the asphalt is, therefore, to lower the pour point. Unfortunately, this action is but temporary, and, as it were, the paraffin crystals free themselves in the course of time from their asphalt envelope to build up a system of large crystals which they would have formed at once if no asphalt had been present.

This interpretation of facts assists the understanding of the principle of certain methods which are carried out in the laboratory in order to determine a pour point which would avoid for the user any " surprise," and which could be called the " true pour point." The aim of such a method would be to determine the temperature above which the fuel would always remain fluid, and below which it would certainly solidify sooner or later even if its thermal or mechanical history allowed it to remain temporarily fluid.

Certain authors (" Cold Test for Fuels," by Moerbeek and A. C. Van Beest) have shown that it is sufficient to apply the A.S.T.M. method to fuel freed from asphalt, either by the action of sulphuric acid or by selective extraction by a solvent. The same result might be obtained by a technique employing purely physical means. The method of heating up to 100 deg. C. has been recommended, whereby the asphalt and paraffin would be entirely dissolved. All influence of prior history would thus be removed. This would be followed by a cooling to 0 deg. C. in order to crystallize the wax and precipitate the asphalt. The product would then be reheated to about 35 deg. C. to 45 deg. C., which would once more dissolve the wax, whereas the precipitated asphalt would remain undissolved and, therefore, would have not more influence than any other sediment. In this condition it would be possible to determine the " true " congealing point of the fuel. The matter is being studied in the Naval Laboratory in order to obtain by various tests confirmation of the exactitude of these views.

It is unnecessary to emphasize the importance of the development of a practical method to determine the maximum gelling point temperature. If such a method were to be perfected, it would be possible to establish a limit to the true pour point for the Naval fuel, so that both technical requirements and financial considerations could be satisfied.

Once the uncertainty with respect to the real value of the pour point has been cleared up, the primary consideration will be to establish the temperature at which the fuel can be carried in the tanks. For reasons of health and safety it is estimated that this temperature should not be above 30 deg. C. Fuels which have a " true pour point " considerably below this could therefore be used. The principles governing the use of fuels can be stated as follows:—

Heating is carried out in two stages.

The tanks are fitted with coils which ensure a uniform heating effect which liquifies the fuel so as to enable it to enter the suction intake of the pump.

The heating coils are placed as low as possible so as to reduce the volume of unpumpable fuel as completely as local arrangements permit in order to avoid what has been called the " Igloo effect " (or rat-hole), i.e., the formation of a cavity left by the melted fuel which has been drawn away by the pump.

The general heating system must be capable of raising the temperature of all the fuel to 30 deg. C. even under the most severe temperature conditions, which in Europe has been fixed as 1 deg. C. for sea water and 8 deg. C. for the atmosphere.

The heating of waxy fuels once they have congealed is difficult, since the convection of heat throughout the solid mass cannot take place, and progressive melting by thermal conduction is a very slow process. The heating of the tank to 30 deg. C. will thus be slow, and it may take as long as 6 hours for the boiler room tanks and 24 hours for the reserve tanks. In this connexion it must be kept in mind that the temperature of the heating surface must not be too high, in order to prevent excessive " coking " of the fuel where it is in contact with the heating coils, which, if allowed to occur, would call for unduly frequent cleaning.

Final heating is carried out by a heating coil surrounding the suction pipe. Its purpose is to raise the fuel which has become fluid to a temperature which will ensure a maximum viscosity consistent with boiler operation at full power. This viscosity is about 600 centistokes.

The use of paraffinic fuels also requires the heating of the suction pipe between pump and fuel tank.

Arrangements must also be made for lighting up the boilers from cold. Steam for heating the fuel may be obtained from a neighbouring ship or from a lighter; or heating may be carried out electrically with electric current provided by the auxiliary generator plant of the vessel, or from some outside source. But arrangements of this kind are costly and heavy, and they also reduce efficiency and complicate operation.

Failing sufficient viscosity-breaking equipment, this is the price, however, that must be paid if one is not to limit oneself to those fuels from the Middle East which, after a long storage at about 0 deg. C. still possess a viscosity lower than 600 centistokes. Such fuels contain a large proportion of gas oil which should not be fired under boilers, but should be reserved for use in Diesel engines; otherwise both industry and shipping are likely to suffer from shortages of Diesel fuel.

Stability and Compatibility of Fuels

Reference has been made to the "coking" of fuels in contact with heating coils. This matter is linked up with the more general question of the stability of fuels and their mutual compatibility.

As understood by the user, a stable fuel is one where flocculation does not occur nor are asphaltic deposits produced in storage or under service conditions. Compatibility of a fuel is its capability to form stable mixtures with other fuels.

Experience has proved that not all fuels are stable, nor are all compatible with each other. Ships have in fact found themselves in difficulties after using mixed fuels from different sources. Piping and heating coils have been found blocked, and this has necessitated the shutting down of boilers and the carrying out of difficult cleaning operations. These troubles have occurred when the products of cracking—and particularly of thermal cracking—have been used.

The explanation of these facts lies in the very nature of fuels. Fuels are composed of residues, of very complex mixtures of hydrocarbons belonging to all the series, some of them of very high molecular weight. To these must be added, although only in small quantities, asphaltic products containing oxygen, sulphur, and sometimes nitrogen. The different series of hydrocarbons, with their various members, exist in very variable proportions according to the origin of the crude oil and to the treatment it has received. In certain cases the mixture proves stable thanks to a mutual solution of the constituents. Similar compounds of a series are soluble in the neighbouring compounds of a series. Like dissolves like.

All series of hydrocarbons, however, have not the same solvent power, especially where it is a matter of solubility between different hydrocarbon series. In this connexion, certain definite qualities emerge. Aromatic hydrocarbons are excellent solvents, whereas saturated hydrocarbon compounds are much less so. Ordinary petrol precipitates asphalts, benzine dissolves them. The mixture which goes to make up a fuel may still appear stable, because of a dispersion of colloidal nature, containing large insoluble molecules, micro-crystals of paraffin, etc.

The equilibrium of the colloidal system is assisted by the presence of certain peptizing compounds such as anthracenic oils distilled from coal, tars, and aromatics obtained from solvent refining operations. Viscosity is also a factor affecting equilibrium. The basis of the reasons which have been given to explain instability derives from very important experimental findings.

Fuels from cracking as they come from the still, are stable. Left to themselves, they leave no deposit when heated to temperatures of 80 to 100 deg. C. The same applies to fractionated fuels, but mixing them frequently results in flocculation. This leads to the conclusion that in cracking operations, as in straight distillates, the different constituents are present in such proportions that an equilibrium is attained from the mutual solubility of the various constituents, a gradual peptization taking place of the heavier compounds by the neighbouring lighter ones, from the higher members to the lowest of a hydrocarbon series. Similarly, solution and peptization of the heavy constituents by solvents and dispersants, to which reference has already been made, may occur, with aromatics, for example, as well as with naphthenes. Stability results from a certain harmony in the relative proportions of the constituents.

The mixture of two stable fuels by altering the mutual concentrations, alters the equilibrium of the solutions and of the suspensions, and leads to a breakdown, so that the fuel flocculates. This point of view is entirely confirmed by the work of Butlin.* It provides a means of evaluating one of the characteristic elements of stability. It refers, it is true, to the compatibility between fuels and gas oils, but the principles upon which it is founded are, in the author's opinion, also valid for mixtures of fuels.

With any given fuel it can be determined experimentally with which diluent—white spirit—(without aromatics) with the addition of *n* per cent of xylene—it can be mixed, in the volumetric proportions of 1 to 5 without flocculation.

The smallest value for *n* constitutes the "xylene equivalent" of fuel. This may be regarded as a measure of the tendency of fuel to flocculate. The expression $100 - n$ would, on the contrary, be a measure of its stability. It would therefore seem possible to find the relationship which must exist between the "xylene equivalents" of two fuels in order that they should be compatible, or else the maximum "xylene equivalent," in order that the fuel should be stable for Naval purposes.

An investigation into this matter is now taking place in the French Fuel Testing Station.

But if the users have not as yet attained a standardized laboratory method of control for stability, they have for a long time been taking precautionary measures. Thus it is that the French Naval Specification of 1st March, 1937, laid down:—

> "That F.F.O. (furnace fuel oil) must show no tendency to form sediment between temperatures of 0 deg. C. to 40 deg. C."
>
> "F.F.O. should not show any tendency to form excessive sediment in the heaters when being raised to a temperature corresponding to 30 centistokes."

It should be noted that here 30 centistokes is the viscosity of the fuel taken at the burners.

Control was effected by means of a centrifuge with a mixture of equal parts of fuel and of a fluid paraffin oil (with zero iodine value). The mixture was first raised to 100 deg. C. and the amount of sediment gave a conventional classification of the fuel. In case there was some technical difficulty, a supplementary stability test was also allowed for. The fuel was heated for 24 hours at 140 deg. C. and then placed in a centrifuge together with an equal volume of benzine at an approximate temperature of 50 deg. C. The amount of sediment was also measured in this case.

Since the last war, the French Navy has ceased to use these methods in favour of the N.B.T.L. test given in the specification of the American Navy. This test is universally known, and reproduces fairly well the temperature conditions to which the fuel is subjected in practice on board ship. The test actually consists of the formation of a closed circuit for 20 hours of a certain quantity of fuel around a heater tube in such a way that the temperature of the fuel is maintained at 93 deg. C. At the end of the test the deposits on the tube are examined. In order to arrive at a better appreciation of them, about 20 cm. of the tube is washed with benzine, after which half this section is cleaned by hand with a clean soft rag. The tube is then subdivided into three lengths:—

(i) Neither washed nor wiped.
(ii) Washed but not wiped.
(iii) Washed and wiped.

To quote the specification: "A stable fuel is characterized by the presence of a simple film of fuel on the first length, and a discolouration or negligible amount of film on the second length."

It is obvious that the third length would show a bright metal surface, with no discolouration.

It is not enough, however, to ensure the stability of the fuel. It is also necessary to prevent a heavy flocculation after oiling ship at any port where the ship may call. It is furthermore necessary to control the compatibility of the

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* Jl.Inst.Petroleum, 1950, Vol. 36, p. 43. "Stability of Fuel/Gas Oil Blends".

Fig. 1.—Typical deposits in the tube nest of a boiler of a battleship after operation with contaminated fuel.

Fig. 2.—Photograph showing the amount of deposits which have accumulated at the inlet of a gas turbine. Chemical analysis of the deposits is as follows:

Soluble constituents 65.7 per cent.

Insoluble constituents 43·3 per cent.

Soluble constituents	
Sodium sulphate, per cent	43·1
Calcium sulphate, per cent	6·1
Nickel sulphate, pfr cent	4·1
Iron sulphate, per cent	12·1
Magnesium sulphate	traces
Manganese sulphate, per cent	0·1
Chlorides	traces

Insoluble constituents	
Silica, per cent	2·6
Carbon, per cent	4·6
Iron oxide, per cent	9·2
Vanadium oxide, per cent	14·7
Lead oxide, per cent	0·7
Undetermined, per cent	1·2

FIG. 3.—STATIONARY BLADING AT GAS INLET SIDE

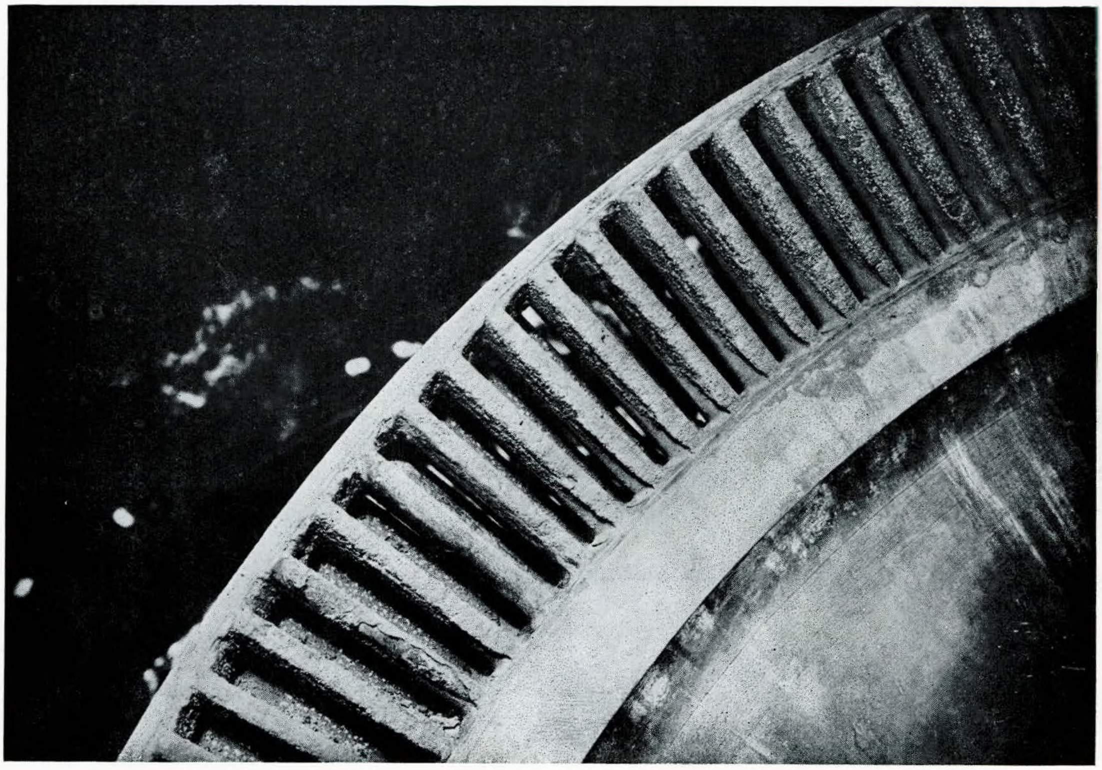

FIG. 4.—ROTOR BLADING
THE DEPOSITS ARE LARGER IN QUANTITY AND HARDER TOWARDS THE PERIPHERY OWING TO CENTRIFUGAL ACTION

fuel which has been taken in with the fuel which is already in the tanks. Yet i is obviously impossible to test each fuel with every other fuel which may be encountered. Two reference fuels, therefore ,have been selected, which are considered to be at opposite limits of the possible range. These are:—

One is of a paraffin base obtained by distillation. This is the Middle East type of fuel.

The other is a mixture of fuels derived from cracking, such as the fuels produced on the West Coast of the U.S.A.

It may be assumed that the fuel under consideration will be compatible with any other Navy fuel provided that it is separately stable at the N.B.T.L. test when mixed in equal parts with each of the reference fuels.

The N.B.T.L. test, while empirical, has much to commend it, but it cannot be determined on board ship. If it were possible to produce a test as simple as the xylene equivalent and relate this to practical questions of stability and compatibility, the Navy's problems would be greatly eased.

Explosive Vapour Content.

Before the last war, the French Specification did not concern itself with the content of gaseous hydrocarbons dissolved in the fuel, but the present specification fixes an upper limit, as in the American Navy Special. Evidently, as is still the case, a minimum flash point was laid down; but the object of this is to limit the amount of light products, both liquid and gaseous. It is only with some difficulty that the presence of these products in dangerous proportions can be discerned when making tests with the Luchaire or Pensky-Martens apparatus.

Some modern cracking processes are inclined to leave in the fuel oil a certain amount of lighter hydrocarbons, an excessive quantity of which could be dangerous. During storage, specially in tanks on board ship, these dissolved gases are slowly liberated and the confined atmosphere above the fuel may become explosive. Their presence may also be dangerous when the burners are being lit. The presence of such dissolved light hydrocarbons can be checked by shaking at 52 deg. C. in a half-filled container. The air in the container becomes filled with volatile constituents, and the content of explosive vapours is measured by the use of a properly graduated explosimeter. The explosibility indicated should be less than half the lower limit of explosibility of natural gas.

Asphalt

There is a tendency in modern specifications to ignore the asphaltic content of fuel. But even if the influence of asphaltic compounds is neither so marked nor so deleterious as that of sodium or sulphur, its technical aspect should not be overlooked.

For its complete combustion, asphalt requires a fairly high temperature and as fine a pulverization as possible. As soon as the asphalt content gets above 10 per cent, heating and pulverization are insufficient to ensure proper combustion; and small dry pellets are formed in the furnace. Their formation is due to the fact that droplets of a fuel containing asphalt burn only on the surface, leaving a core of unburnt combustible.

Heavy Fuels and Gas Turbines

The French Navy has not so far had any experience with gas turbines used for propulsion. It possesses, however, some " Sural " boilers for which the combustion air is provided by turbo-compressors which are driven by gas turbines supplied with the furnaces gases from the boilers.

Here again the presence of sodium has caused a certain amount of trouble. The gases, on entering the blades, are still very hot (above 500 deg. C.), and sometimes alkaline sulphate in the form of paste, drawn in by the current of gas, is deposited on the blades, thus bringing about accumulations of deposits.

When making an inspection of these boiler turbo-blowers, the following observations were made concerning the origin of the deposits (see Fig. 1—4, Plates 1—2):—

(1) The dirt is particularly heavy at the inlet (see Fig. 2, Plate 1). The deposit formed is compact and flakes off easily.

(2) The stationary blades (see Fig. 3, Plate 2) are very rough even on the side where the gas leaves. On the back of the blades the deposit was 3 to 4 mm. thick, probably owing to the reduced speed of the gas.

(3) The deposit on the moving blades (Fig. 4, Plate 2) is less heavy. It is found principally near the blade tips, due to centrifugal action, and on the back of the blades at the inlet side.

The deposit is of the same kind as that found in boilers, but more compact, harder, and more adhesive, particularly where it has accumulated by centrifugal force on the outside root of the blade where it is removed only with some difficulty when dry. But removal of the deposit when wet can be effected easily. This is done by soaking it for several hours in softened water, after which it can be washed off with a hose.

Chemical analysis has shown that the magnitude of the deposits is not due to accidental incomplete combustion leaving a small amount of unburnt carbon; neither is it related to the ash content; but it increases rapidly with the sea water content of the fuel. The deposit which takes place fairly slowly at first after cleaning, increases more rapidly when it has reached a certain thickness, and also when the boiler and superheater tubes on the inlet side of the gas current become soiled.

This can be explained quite easily by the fact that the deposit remains in the form of solid particles, agglomerated but not viscous, so long as their temperature remains below 550 deg. C. In this condition the impurities brought in by the gas cannot be retained; but as soon as the boiler and superheater tubes reach a certain degree of dirtiness, heat absorption diminishes and hotter gas therefore enters the turbine. When a temperature of 550 deg. C. is reached, the pasty consistency of the alkaline sulphate helps to bring about agglomeration of all the solid waste carried along with the flue gases.

The growth in thickness of the deposit in time may be represented by Fig. 5.

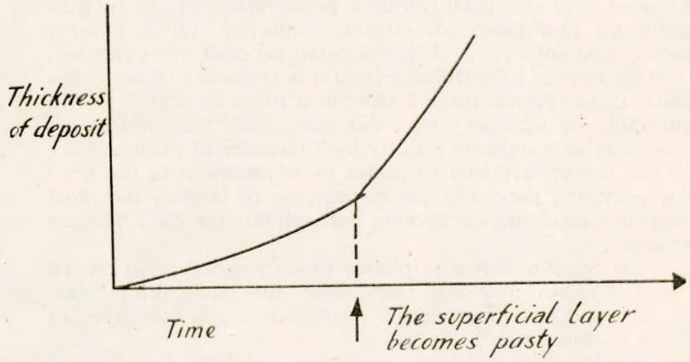

FIG 5.

Mention has been made of the destructive action of vanadium which is formed in various residual fuels in appreciable amounts up to about 0·05 per cent, more especially in heavy fuels from Venezuela and Iraq. This is a dangerous element, and is a veritable poison for steels which have a high molybdenum content, and which have to withstand high temperatures.

As the author has no personal experience in this connexion, he cannot give first hand information on these matters. But it is well-known that in refineries vanadium has attacked the tubular supports of "still-pipes" made of molybdenum steel to a point where they have disappeared completely. When gas turbines enter regular service, this point will have to be considered in the specification.

Boiler Fuels in Diesel Engines

For several years, a number of successful attempts have been made to use heavy boiler fuels for marine Diesel engines. So far such attempts have been confined to large main engines running at relatively low speeds, such as 120 r.p.m.

Some time before the last war, Burmeister and Wain engines fitted in French Naval tankers were run on relatively heavy fuel up to 50 centistokes at 50 deg. C. It was simply specified that such fuel should have the following purity characteristics:—

Sulphur content	less than 2 per cent
Asphalt content	less than 1·5 per cent
Ash content	less than 0·5 per cent

One of the French Shipping Companies (the Compagnie Auxiliaire de Navigation) in similar engines used a fuel of approximately 300 centistokes at 50 deg. C. A report on this subject is given by Monsieur J. Perrachon in the Bulletin of the Association Technique Maritime et Aeronautique, No. 48 of 1949, page 347.

The experiments of the *Auricula** also prove that the use of heavy fuels (1,500 sec. at 100 deg. F.) is both possible and economical in Diesel propelling engines. In fact, the author considers that fuels of most varied viscosity and even of varied chemical nature can be used without any difficulty in slow speed internal combustion engines.

During the 1939-45 war, submarine engines of the Sulzer type, for instance, were able to run on ground nut oil, provided that certain precautions were taken regarding the organic acidity of this oil. This fuel had of course characteristics which differed very materially from the ordinary normal gas oil, i.e.:

(*a*) Viscosity at 20 deg. C. was 85 to 90 centistokes instead of 3 to 9.
(*b*) Flash point of 258 deg. C. instead of 75 deg. C.
(*c*) Spontaneous ignition temperature of 400 deg. C. instead of 260-280 deg. C.
(*d*) Heating value of 9,560 calories instead of 10,700 calories.

Engines have also been run on a great variety of oils such as palm oil and rapeseed, cotton, sunflower, olive, linseed, maize, and soya oils. This list could no doubt be extended.

With respect to petroleum fuels it is necessary to lay down fairly close specifications if trouble is to be avoided. It will probably be necessary to avoid using such fuels unless the characteristics indicate a fairly high measure of purity.

The reports referred to above draw attention to the need for purifying the fuel. As in the case of boilers, the most injurious elements are sodium and sulphur for the following reasons:—

(*a*) Sodium forms sulphates which are deposited on the valves and are responsible for back firing when the hot gases find a passage through this layer of salt.
(*b*) Sulphur produces corrosive sulphur dioxide and trioxide.

The centrifuging of the fuel aboard ship allows the sodium to be got rid of to some extent by extracting the salt water and so eliminating certain solids in suspension. For certain fuels even such means are insufficient, and there is no doubt that recourse will have to be made to washing the fuel with fresh water to remove the chloride and the naphthenate of sodium, as has already been stated. Unfortunately, it is not possible to do this on board ship, nor is it very easy ashore, as there is danger of producing emulsions.

A determination of the ash content will give some idea of the efficacy of the measures taken. It should be possible to get it below 0·05 per cent, which would be quite acceptable.

As regards sulphur, the only possible course at present is to fix a maximum content.

Whenever the temperature at any part of the engine which may be contacted by the combustion gases falls below the dew point—that is, somewhere in the region of 175 deg. C.—sulphuric acid condensation with a solution of sulphur dioxide may take place. The temperature in a crank case is obviously much lower.

Diesel motors ashore, however, operate at high temperatures, yet the operating personnel are well acquainted with the amount of wear, dirt, and difficulty of maintenance resulting from the use of gas oil contaminated with sulphur. Even a sulphur content of below 1 per cent can have a most injurious effect. It has, in fact, been found necessary to produce special heavy duty lubricating oils, such as Supplement No. 1 and Supplement No. 2, in order to avoid corrosion and other troubles. The high prices of such lubricants are sufficient testimony of the importance placed by the operators on a fuel free from sulphur.

Even if some of the evil consequences of sulphur were to be minimized by the resistance of the material, this element remains nevertheless most injurious to marine engines, and the author considers it essential that a limitation of the sulphur content to 2 per cent should be imposed.

From a technical point of view, the high viscosity of fuel oil does not constitute a serious difficulty, as it is only necessary to heat it to a sufficient fluidity for injection. Fortunately there remains a certain margin, and the pulverization is still correct up to about 25 centistokes. If relatively thick vegetable oils such as have been mentioned above, are used, their viscosity still allows satisfactory injection. As compared with gas oil, however, it has been found necessary to increase the load on the needle springs in the mechanical system from 20 to 50 kg. per sq. cm. For engines with an air-blast injection system, the air pressure has to be increased, from 5 to 10 kg. per sq. cm. It may be noted that a viscosity of 25 centistokes can be obtained at 90 deg. C. with the Grade II type of fuel of the U.S. Navy (300 centistokes at 50 deg. C.), which is not excessive.

Another feature of vegetable oils is their ignition delay. It has been found necessary to advance the injection from 1 to 2 degrees. Such considerations are also valid for heavy petroleum fuels. Incidentally, these fuels possess certain advantages over light fuels, inasmuch as their use results in smoother running and the engine knocks less. The author has noticed this on many occasions with Burmeister and Wain engines.

In conclusion, the author considers that the use of heavy fuels in Diesel engines is dependent on their purity. The principal characteristics of this essential purity are a low ash and a low sulphur content. Adequate arrangements for heating the oil to a suitable viscosity for injection are also necessary. No special technical problem is raised by these requirements.

As regards the question of whether it is financially advantageous to use these products, this can only be decided by drawing up a balance sheet. On the credit side would appear the low price of these fuels, while on the debit side there would be the cost of setting up purifying and heating installations and their amortization. But neither of these factors can be considered as fixed.

With respect to the question of availability of fuels, it is certain that the demand for gas oil and for light fuels will be increasingly difficult to satisfy; so that it would, therefore, be desirable to persuade the makers of Diesel engines to make their equipment more flexible in regard to fuel requirements.

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* Lamb, J. 1950. Trans.I.Mar.E., Vol. 62, p. 217. "Further Developments in the Burning of Boiler Fuels in Marine Diesel Engines".

DISCUSSION

Com'r (E) L. E. S. H. Le Bailly, R.N. (Member, I.Mar.E.) said that for the last two years he had had the privilege of working with M. Blanchier trying to ensure that the fuels and lubricants of the Western Union allies were interchangeable and, where possible, even to a standard specification, and he could therefore bear witness to M. Blanchier's knowledge on the subject—which indeed was already evident from the paper.

Thanks to the wisdom and foresight of Lord Fisher, Prince Louis of Battenberg and Mr. Winston Churchill, the British Navy had been one of the pioneers in the use of liquid fuel. In those days and for quite a number of years afterwards, the navies had had little to worry about, for they had been the only large-sized pebbles on the petroleum beach; but since then the whole world situation had changed, and any navy which did not give very serious consideration to fuel problems today would be guilty of something worse than shortsightedness.

Some of the Royal Navy's problems were the same as those of the Merchant Navy, e.g. combustion problems. Others, such as handling fuel, both at sea from ship to ship and on board ship when fuel was used as an instrument to correct heel due to enemy damage, were possibly purely Naval problems.

What was really required was the gift of prophecy, because it was necessary to plan ships today for the fuels which would be in supply in two, three or four years' time. This was not made any the easier by the vigour and the speed with which the petroleum industry moved. He thought that of all great industries, from the little he knew of it, the petroleum industry seemed to be the most relentless in the way in which it discarded out-of-date techniques and old processes. New processes and new refinery techniques came in quickly and their effect on fuels must be foreseen if the boilers and the ships which were on the drawing board today were to suit those fuels.

The British Admiralty had been encouraged by their long and very happy association with the Anglo-Iranian Oil Company, and they had turned to the British petroleum industry as a whole with their problems. The petroleum industry, as one would have expected, had met the Admiralty whole-heartedly. The conjoint body which had been set up, the Admiralty Oil Quality Committee, consisted of representatives of the industry, independent petroleum technologists of note, and Ministry of Fuel and Power and Admiralty representatives. Although this team had not yet quite developed the gift of prophecy, the Admiralty felt that there was no better advice available to it anywhere in the world today than that which the Committee was giving. Whether some such body would be applicable to the Merchant Navy it was not for him to say, but the Admiralty had found it very valuable indeed.

M. Blanchier enumerated a great many of the difficulties with which users were faced; in his comments he would pick out three or four of them, and then leave the field open for the representatives of the petroleum industry.

He disagreed with the author on the importance which the paper attached to the effect of sulphur on personnel. His experience, both in peace and of war damage, suggested that if the ventilating systems of the ships were so badly designed, or if the enemy damage was so great, that funnel gases got into the machinery spaces, then 1 per cent or 2 per cent of sulphur one way or the other did not make much difference, the result was horrible anyway. As regards the effect of sulphur on the funnels, he was quite in agreement with the author.

The next point on which he wished to comment was the effect of the compatibility requirement, which the author mentioned, on the availability of fuel. If they were to tie down the fuels in supply to the navies to those between the two reference fuels which the author mentioned, it would mean that there would be a considerable margin on either side of those reference fuels of incompatible fuels which, in an emergency, might be needed.

With regard to the question of stability of fuel, in the N.B.T.L. heater test which the author mentioned the tests of fuel were at a temperature of 200 deg. F. They had heard yesterday that future combustion designs envisaged a viscosity which, as far as he could calculate, would require a temperature of 220-230 deg. F. to achieve it. This would mean that this test would not simulate real conditions, and therefore might, it seemed, have to be revised.

He was sure that all users would look forward to the petroleum industry's answer to the author's statement at the beginning of the paper that the quality of fuel, by reason of present-day refining practice, was steadily deteriorating!

Mr. H. F. Jones, commenting on the statement on page 203 of the paper about the restrictive limits for water, said that he believed all fuel suppliers in the industry quite agreed that there should be restrictions on the water content of the fuel; but the overall aim should be—*no* sea water in the fuel. However, that purpose was not achieved, nor were restrictive limits really effective, so long as ballasting with sea water or displacement of the fuel oil by sea water were practised.

On page 204, under the section headed "Sulphur," the author referred to corrosion of the boiler drums, of the boiler tubes and also of the platework. He thought that the term "platework" was rather broad, although this might be a fault of translation. The author did not specifically mention troubles in the low temperature zones, such as pre-heaters and economizers, and some information on this aspect would be welcomed.

Again on page 204, in referring to the specific gravity, mineral acidity, etc., the author referred to "the normal grade of fuel hitherto used which had a sulphur content not exceeding 1 per cent." His own guess would have been that this was an abnormal fuel.

The author, in presenting the paper, had corrected a printer's error on page 205, where the reference to a waste of 1,500 kilograms of brickwork per ton of fuel consumed should have read 1·5 kilograms; but in dealing with this aspect the author had assumed that all the sodium present, estimated at about two-thirds of the ash, reacted on the alumina. This seemed highly improbable, particularly as a portion of the sodium was deposited on the water tubes.

He was not quite clear about the meaning of the statement on page 205—"But these boilers were under continuous operation, and the discharge of flue gas took place at a temperature higher than the dew point of sulphuric acid (175 deg. C.)." Did this temperature refer to the dew point of flue gases when using fuel with a 3½ per cent sulphur content? If not, would the author clarify the statement.

On page 206 there was the statement: "Experiments carried out at the Naval fuel stores to find a method suitable for the breaking up of emulsions on an industrial scale by the application of a commercial surface-active product (Sinnopon) have, after considerable efforts, been crowned with success." He would like to know whether their use had facilitated separation of water by centrifuging or whether it had had the reverse effect and made separation by centrifuging more difficult.

In Figs. 1 and 2, the total for insoluble constituents should be 33 per cent and not 43·3 per cent.

On page 207 the author said: "The general heating system must be capable of raising the temperature of all the fuel to 30 deg. C. even under the most severe temperature conditions, which in Europe has been fixed as 1 deg. C. for sea water and 8 deg. C. for the atmosphere." He felt that possibly there was something wrong with the translation of that passage, because one would expect the temperature of the atmosphere to be below that of the sea water, so maybe the atmospheric temperature should read *minus* 8 deg. C.

On the last page, dealing with boiler fuels for Diesel engines, the author referred to the temperature in the crankcase, again giving the figure of 175 deg. C. as the dew point for sulphuric acid. (This had already been queried.) The crankcase of a Diesel engine was a different proposition from what had been referred to earlier in the paper, since it benefited from a film of lubricating oil giving some protection against sulphur attack on the crankcase and crankcase mechanism.

Finally, gas oil was mentioned as being "contaminated" with sulphur. Possibly this was loose translation, since gas oil had a small amount of sulphur in it which was inherent from the crude and remained in the gas oil after distillation. He thought that the word "contaminated" might tend to give the erroneous impression that the sulphur content was some form of external pollution.

Mr. H. T. Lorne said that, in reading the paper, he had obtained the impression that too much emphasis was being placed upon supposedly bad points of Middle East fuel oils; in fact they were known to be very satisfactory.

With regard to sulphur, for instance, Middle East fuel oils were known to contain combined sulphur, but it was very gratifying to note in the paper that 3½ per cent at least was tolerable. He suggested that a good deal more than 3½ per cent was tolerable, and that this 3½ per cent stated by the French Navy was purely an interim measure. He suggested that within a year or so from now, if the French Navy persisted in its tests, it would say that 4½ per cent was perfectly satisfactory.

Later in the paper there was a suggestion that no more than 2 per cent of sulphur should be allowed in Diesel engines. He found this very hard to accept, and he recommended the author to refer to Mr. Lamb's paper (see reference on page 210), which had been presented to the Institute of Marine Engineers last year, in which he would find that far greater sulphur content fuels had been used with complete satisfaction.

With regard to deposits, with the increasing loads on boilers this was admittedly a problem which might arise in different forms from those which it had taken in the past. He thought that sea water contamination must be restricted to the very minimum. The suppliers were well aware that ash in a fuel was to be avoided and in fact took all precautions possible to make sure that contamination did not take place. But the taking of those precautions was useless if the fuel was to be burned with sea water, and he thought that there should be a drive to restrict sea water contamination to the very minimum.

With regard to cold test properties, the paper placed a great deal of emphasis upon measuring the highest pour point that could be obtained on a fuel. He believed that the emphasis was being wrongly placed, since careful study showed that by proper heat treatment one could improve the pumpability characteristics of fuels tremendously, and the fact was that the pour point might not be any sort of index of the pumpability or performance of the fuel oil. In most cases with the waxy asphaltic type of fuel oils that one got from the Middle East crudes, the pumpability limit could very often be some 20 deg. F. below the apparent pour point.

He earnestly recommended that, instead of spending a lot of time fixing the highest pour point that could be got out of a fuel, more effort should be devoted to finding out how to handle it under normal conditions.

Incidentally, the author quoted in the paper a fuel which, with all his experience of Middle East fuels, he had never yet come across. On page 205 the author mentioned a fuel which was congealed at 45 deg. C. That was a tremendously high temperature, and for the order of viscosity that the author talked about, he could not believe that it was a normal Middle East type of fuel oil but must have been a crude oil sludge or non-asphaltic wax type fuel.

The author stressed the bad effects of modern processes. That was far too sweeping a statement. In the past some cracking processes had undoubtedly caused fuel deterioration, but that was by no means always true. General experience went to show that it was only certain types of cracking processes which caused deterioration of fuel oils. There were strong reasons for believing that other types actually improved them in some respects. He would therefore ask the author to bear these observations in mind. It might well be found that great improvements would take place in the future due to the introduction of modern light cracking processes.

On page 209 there was a statement which was very detrimental to Middle East fuel oils. The author referred to the vanadium content in the ash of fuel oils and spoke of the destructive action of vanadium which was found in residual fuels in appreciable amounts up to about 0·05 per cent, more especially in heavy fuels from Venezuela and Iraq. He did not pretend to know anything about Venezuelan fuels, but Iraq fuel oil would have a vanadium content of no more than about 40 parts per million—in other words, 0·004 per cent. He therefore felt that the 0·05 per cent must be a misprint.

Mr. C. W. G. Martin felt that there had been a good deal of misconception on the question of the so-called "deterioration of quality" of fuel oil. This subject had arisen in a previous paper by Gray and Killner (see reference on page 205) in which paper they had discussed very much the same thing.

The title of the present paper was, after all, "The Characteristics and Development of Naval Fuel Oils." For very good reasons the Admiralty was accepting fuel oils of higher viscosity but, in spite of Commander Blanchier's reference, this did not mean that commercial fuel oils had deteriorated; in fact, in many cases the major petroleum companies were quoting specifications nowadays which were superior to those which they had quoted for bunker fuels before the war.

Many of the audience were concerned with the design, building, operation and maintenance of merchant ships and their supply of fuels and lubricants at ports throughout the world. Operators of merchant ships had always had to contend with pumping problems which were now causing concern to the respective navies. Because it was so much easier to equip merchant ships with heated bunker storage, and also because even the highest powered vessels in the Merchant Navy still came nowhere near Naval practice so far as pounds of fuel burned per cubic foot of combustion chamber was concerned, higher viscosity residual fuels could be used effectively in merchant vessels.

Even here, although not to be compared with the high rating of Naval boilers, there had been a considerable increase in the rate of heat release expected and there had been indications that some pressure-jet atomizers which had given admirable service in past years were falling short when applied to these higher rated boilers. This would appear to present a problem for the burner manufacturers.

Although expressing his general admiration for the paper, he had been rather disturbed at the references to sulphur as an "impurity," which it certainly was not. He understood an "impurity" to be some foreign matter which was introduced accidentally, or deliberately for some ulterior motive. Sulphur was no new thing, and thirty years ago Mexican fuel oil with a sulphur content of 3·5 per cent and over was quite common. The increase of production of Middle East crudes and the extent to which they were being processed in Europe had increased the proportion of relatively high sulphur fuels and had reawakened interest in the subject. One could take sulphur out of oil, but it was not economically possible as things were at present to remove it from residual fuels. The solution of the sulphur problem, whether under boilers or in Diesel engines, must be sought by other means.

He would like to give a few figures obtained from some work which had been done at Thornton Research Centre. On a special rig, at 800 deg. C., burning fuels with 0·8 per cent sulphur and 4 per cent sulphur, it had been found that there was no appreciable attack on a number of specimens of metal which had been introduced. Those experiments had also shown that increasing the sulphur from 1 to 4 per cent raised the dew point only 30 deg. C., from 120 to 150 deg. C., at 12 per cent CO_2. This corresponded to an increase in SO_3 content of exhaust gases from 0·003 per cent volume to 0·005 per cent volume. Those experiments had been in conditions in which catalytic conversion in flue ducting had been negligible. With an unlikely complete catalytic conversion, 1 per cent and 4 per cent sulphur fuels would give flue gases of dew point 180 deg. C. to 185 deg. C., the dew point in this region being little affected by SO_3 concentration.

There was thus no evidence to suggest that conditions might worsen comparatively suddenly with a sulphur content of 3½ per cent, and he said this by way of following up a previous speaker's remark that there seemed to be no particular magic in 3½ per cent as a sulphur limit.

Another point that might be of interest was that the addition of vanadium to the fuel under test had not increased the acid dew point. This indicated that in these circumstances vanadium pentoxide was not catalysing SO_2 oxidation. This might seem a little surprising to some people, because vanadium pentoxide was a catalyst used in the manufacture of sulphuric acid.

He was also very concerned at the attempt to restrict the sulphur content of fuel oil for Diesel engines to 2 per cent. This, of course, was illogical, and there seemed no reason for saying that the same fuel oil should be allowed to have 3½ per cent sulphur content if put into a boiler and only 2 per cent if burned in a Diesel engine. There were now thirty-six motor ships in the Anglo-Saxon Petroleum Company's fleet which were running on fuel oil with a sulphur content of between 2 and 3 per cent, without any adverse effect on cylinder liner wear rates as compared with those in the same fleet running on marine Diesel fuel.

He thought the author was quite right in trying to put a limit of 0·1 per cent on the ash so far as Naval fuel oil was concerned, though he thought it was quite unnecessary to make such a restriction for the heavier commercial grades. But the author was, he suggested, somewhat rash in assuming about two-thirds of the ash to be sodium sulphate. As for the equation quoted at the beginning of this section of the paper, perhaps the author would be good enough to indicate how he deduced it.

FIG. 6.

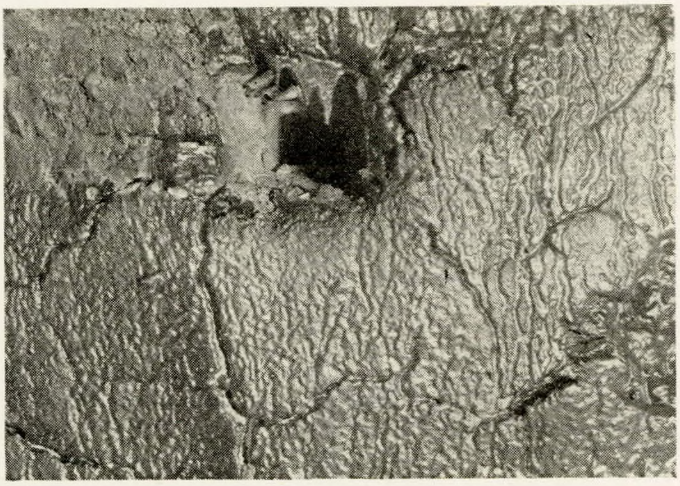

FIG. 7.

He doubted whether an ash content of 0·1 per cent was really equivalent to sea water contamination of 2 per cent. He had with him two photographs, the first of which (Fig. 6) showed the side wall of a water tube boiler furnace after steaming for several months on fuels of about 0·08 per cent ash, and the other (Fig. 7) showed the same area of refractory after steaming for a further 500 hours only on the same commercial fuel with 5 per cent of sea water in emulsion. He really could not feel that the amount of natural ash present in any fuel oil could have anything like the deleterious effects on refractories that sea water had.

There was also reference in the paper to the work of Lawrence and Killner on Teepol as a means of separating water from fuel. He thought it was necessary to be a little careful about these things. Teepol was effective in a certain critical concentration; if one exceeded it, one might do rather more harm than good. He gave the tip that there was no universally successful additive which would separate out water from fuel oil. Considerable experimental work had been done, not only in the laboratories, but on a large scale, in which additives had been tried, but so far there seemed to be very little hope in that direction.

The behaviour of fuels at low temperatures had been adequately covered by a previous speaker (Mr. Lorne). In his opinion, it was quite right to try to get away from the bogey of the pour point because, after all, it was the pumpability of the fuel at low temperatures at which one was really aiming, and not a paper figure determined on a couple of ounces of oil in a laboratory test jar. Nevertheless, it was appreciated that the question of pumping fuels at low temperatures was more serious in Naval practice than in the mercantile marine, and it would seem that the only solution was to provide adequate steam coiling in bunker tanks.

The question of stability was handled in a very comprehensive manner in the paper. He did not feel that he should waste any time discussing that matter now, since it had been presented fairly fully at the World Petroleum Congress a few weeks earlier.* He did, however, feel that the author might not have drawn quite the right deduction from the work of Butlin, which was not so much to deduce the stability of fuels from the xylene equivalent as to utilize this test as a means of deducing the probable compatibility of two different fuels.

The references in this connection to "benzine" should presumably be to "benzene" (C_6H_6).

* "The Stability and Compatibility of Fuel Oils," by C. W. G. Martin.

There was a somewhat alarming reference by the author to the modern refining techniques introduced in cracking methods being responsible for the degree of explosiveness. So far as the speaker could recollect, there were only two cases at most which might be quoted to support this claim. One of these occurred, he believed, in an American warship during the war, as a result of which the U.S. Navy introduced an additional specification test for explosive vapours. Modern refinery technique could easily cope with the small amount of any lighter hydrocarbons which might be left in thermal cracking residue.

Finally, he would like to comment on the author's reference to asphalt content. Commander Blanchier seemed rather worried to find that asphalt limits were not incorporated in fuel oil specifications. In the speaker's view, the omission was quite understandable, since the connection between the asphaltene (or hard asphalt) content as determined by laboratory solubility tests was most difficult to correlate with combustion characteristics. Failure to burn an asphaltic fuel was much more likely to indicate a deficiency in the burner than in the fuel oil. When it was remembered that asphaltic bitumen burned perfectly well if the right equipment and practice were employed, he thought the case for dispensing with an asphaltene limit in fuel oil specifications was well proved.

Mr. C. Gamlen said that the paper in part substantiated his findings over the past twenty years. Sulphur in fuel oil, or solid fuels for that matter, was certainly undesirable in either boiler or Diesel engine fuel, but certainly more so in numerous other types of installations such as steel and glass processing furnaces, etc.

In commercial use it was difficult to set up arbitrary limits as to sulphur and other contents. The Merchant Navy especially must take pretty well what fuels were available consistent with the economics of fuel oil production. Even the United States Navy, which had set up special navy fuels, had not eliminated problems of sulphur, combustion deposits and sludge.

With regard to emulsified oil and water, this subject had been a problem in ships for many years, and while no two emulsified patterns of fuel oil or crude oil emulsions were the same, the problem of de-emulsifying without the danger of re-emulsifying was being successfully handled to the complete satisfaction of the user. In the United States many hundreds of ships were being treated daily, with Diesel engines and steam boilers, at a very low cost.

According to the majority of fuel analysis certificates, sulphur was listed in its metallic form. This fact raised a question, for sulphur could hardly exist in its metallic state. Its presence in oils was generally in a combined form with some other metal, such as carbon di-sulphide, sulphates, etc.

Regarding dew point temperature, it had been shown in many papers and hundreds of lectures over the past twenty years that the dew point had quite a long range of temperature depending on the amount of water present. For example, moisture in the atmosphere would condense on a cold glass of water at quite low temperatures. During the period of starting a boiler from "cold," the amount of sweating and deposition of sulphurous and sulphuric acid was dependent upon existing circumstances.

The formation of sulphur compounds for the most part took place at quite normal temperatures—for instance, at boiler metal temperature. In the case of superheater tubes, an entirely different set of circumstances prevailed, so that the sulphates could actually become plastic. In this regard, and as the spaces between tubes closed, impediment was offered to the flow of gases out of the boiler to set up a new order of circumstances quite unrelated to the sulphur compounds. If the gases could not get out of the boiler, a reducing atmosphere, high in CO_2, was created to cause a chain of reactions.

Sulphur had always been present in fuel oils in lesser and greater amounts, even over 4 per cent. In fact his company had many records of samples taken from ships' tanks where the combined sulphur and sulphates averaged 8·8 per cent over a whole year. Yet those so-called undesirables had been, could be and were being successfully controlled by safe and simple chemical means. For instance, by correct treatment it was possible and practicable to remove water soluble sulphates by precipitation and centrifugal separation.

Regarding the so-called troubles due to the vanadium content of fuels, undoubtedly it was an excellent catalyst. Among the thousands of samples of deposits of combustion which his company had analysed over the past twenty years, vanadium had shown itself quite frequently in small amounts as from 0·2 per cent to 8 per cent, and this in the form of V_2O_2. However, it was of interest to note that when impediment was offered to the flow of gases from the furnace, accompanied with high CO_2 and high temperatures, they had found as much as 74 per cent on samples taken from superheater tubes, this in the form of V_2O_5.

Sulphates were usually water soluble. Not that he recommended that water be used; on the contrary, for reasons which were obvious. However, vanadium smeared like molten butter and formed layers over the sulphates which rendered the mass insoluble.

On the subject of deposits of combustion, extensive research indicated fairly definitely that deposits of combustion never built on clean metal surfaces, but usually on a sulphide or a sulphate base. Accordingly, it was entirely possible that the observed reaction taking place on the intercrystalline structure of surface metal might not be due to the independent action of vanadium but that of sulphur in the form of sulphides, a non-magnetic substance.

Regarding the breaking of fuel oil emulsions, this had been the subject of many thousands of experiments by his organization on many individual samples of oils from all parts of the world. Indeed, during the year 1950 and since they had conducted between fifty and one hundred tests per day. In this connection it was interesting to note that reagents which would not re-emulsify had been used in hundreds of ships and industrial plants, with complete success, over the past eighteen years.

In conclusion, he thanked the author for a splendid paper. He considered it to be an excellent contribution to work which had been started twenty-two years ago. He ended by stressing that it was entirely possible that the water content of fuel served a purpose of dissolving soluble sulphates, provided, of course, that the precipitated water was separated chemically before entering the boiler furnace or the Diesel engine.

CORRESPONDENCE

Mr. L. Baker, D.S.C. (Member of Council, I.Mar.E.) wrote that the author and the speakers in the discussion had tackled the problem of fuel from the viewpoint of the chemist. This was, however, only part of the story and was by no means necessarily the most important contribution to the subject. Fuel was essentially a natural product from which a number of relatively pure components had been removed, leaving behind the residual fuel and the impurities. The problem for the engineer was how to use the residual fuel with the least possible further attention from the chemist, for restrictions of any sort implied either a reduced availability or higher cost, or both. Neither of these could be justified for civilian and Service purposes unless there were some overwhelming advantages to be gained.

Sulphur was a favourite bogey of engineers who were anxious about the plant and it was not long since there was an outcry against raising the permissible sulphur to 1·5 per cent; 2·5 per cent was now common and higher percentages were occasionally met, yet in general no difficulty appeared to be attached to them in either boilers or Diesel engines that was not already there with lower sulphur contents. Of these, the most significant seemed to be the age-embrittlement of high nickel creep and heat resisting steels—a defect that was known when the sulphur content was limited to 1 per cent. He had satisfactory experience of 2·5 per cent fuels in boilers, with a final gas temperature of only 250 deg. F. out of the air heater at full power; care, of course, was taken to use the soot blowers regularly, to hand clean at quarterly intervals and to use the bypasses at lower outputs. Similarly the deleterious effects of sulphurous fumes on personnel were observed at only 0·5 per cent sulphur in the fuel if the ventilation conditions were not adequate by normal modern standards.

The use of Teepol for the removal of water was only recommended when it was known that water was present; with this limitation, and in the few cases when stable emulsions had been found, his experience had been entirely satisfactory. There was need, however, for an additive that was cheap and that would effectively prevent emulsions forming; there were many cases on record of 10 per cent of water in the fuel having caused no difficulty in combustion. The damage done by the water was found afterwards.

Although the pour point test was not representative of service conditions, some such test was necessary in order to determine the lowest temperature to which the fuel could be exposed with a complete guarantee of pumpability. In the early boiler oil conversions of ships, some difficulty was found in transferring fuel due to the valves in the pumps becoming sluggish at temperatures below the pour point.

Finally, the use of boiler oil in auxiliary engines had proceeded much further than the author suggested. The writer had some fourteen ships running their auxiliaries on boiler oil. They were Allens S 37C type running at 375 r.p.m. He had also seen a single cylinder unit of about 6-in. bore running at 900 r.p.m. on 3,500 sec. fuel oil without difficulty.

Summarizing this, he felt that the outlook of the chemists was too gloomy; surely the right way to proceed was to endeavour to handle the worst that could be met and thus be certain that no one would be placed in the invidious position of having to take a step into the unknown without the aid of the experts. There was a tendency for Government departments to be unrealistic about these matters; merely laying down a restrictive specification would not prevent fuels outside the specification being produced and would not prevent those fuels being supplied to ships when more acceptable grades were not available. There were some service requirements for which restrictive specifications were essential but there were many more for which such specifications could actually be so misleading as to be dangerous.

AUTHOR'S REPLY

The author, in reply, stated that the physiological effects of sulphurous fumes above and below deck to which he had referred were ascertained several times by the Test Commissions, which endeavoured to be as objective as possible. Perhaps there existed a threshold value of physiological reaction, and the variation in the sulphur content of the fuel by 1 or 2 per cent referred to by Commander Le Bailly would be sufficient to change the atmosphere from the one side to the other of the threshold.

The author recognized that the stability and compatibility requirements inevitably limited the supply position, but the object of any specification was to impose restrictions. He did not think, however, that the limitation introduced would be likely to create difficulties of supply.

Mr. Jones was right in assuming that the term "plate work" was used in a very wide sense, and that the corrosion troubles were in relation to the temperature of the components in question. Naval experience showed that corrosion was active in the zones of lowest temperature and of greatest humidity when the fires were banked. It was for this reason that the tube joints at the lower drums were most frequently attacked.

The second question raised by Mr. Jones referred to the expression, "normal grade of fuel." The fuel fired under the other boilers of the vessel during the test mentioned had been normal in the sense that it conformed with the Naval specification in force at the time (specifying a sulphur content of less than 1·5 per cent for 50 centistokes at 50 deg. C. fuel) while the fuel tested had been especially ordered.

Mr. Jones was right in presuming the possible wastage of brickwork to be 1·5 kg. per ton of fuel, and not 1·5 tons. The error arose from a mistake in transcription. The figure cited, illustrating the magnitude of the effect produced by the sodium introduced by the sea water, was given as the theoretical maximum. The author agreed with Mr. Jones that not all the sodium in the combustion chamber would react with the brickwork.

The temperature cited, of 175 deg. C., represented the dew point of the sulphur fumes. This question was treated in more detail below in the author's reply to the questions raised by Mr. Martin.

The breaking up of the emulsions referred to on page 206 was effected without agitation after admixing the agent, and not by centrifuging.

Mr. Jones was correct in pointing out that in Fig. 2 the total for insoluble constituents should read 34·3 per cent and not 43·3 per cent, and also that on page 207 the temperature of the sea water should read "—8 deg. C." and not "8 deg. C." (these being both typographical errors). Also the expression "contaminated with sulphur" did not reproduce the original meaning, and should be replaced by "with high sulphur content."

In a general way Mr. Lorne's comments on the relative importance of the sulphur content of boiler fuel, as well as of engine fuel, on the aspects of contamination by sea water, vanadium content, etc., were answered in the text itself.

The author, however, would like to make special reference to the problem of the cold properties of fuels. He himself wondered whether there could really be established a specification, ensuring a minimum of safety at sea, for a fuel to be used in a warship by assuming that pumpability often still existed at 20 deg. F. below the "pour point."

The fuel mentioned by the author on page 207 with reference to pumpability was introduced in order to underline the risk which the Navy would incur by failing to specify with sufficient precision the congealing characteristics required. The author did not say that this fuel was a "normal" Middle East fuel, but it was nevertheless produced by a refinery supplied with Middle East fuel.

Replying to Mr. Martin, the author said that it would appear to be beyond doubt that the oil refineries were now deriving profits from additional products in demand by industry, which ranged from petroleum ethers and other solvents to vaselines for perfumery, which they had not formerly produced. In these circumstances, it appeared not less certain that as the more numerous and valuable products were extracted from the crude, the residue would be left enriched with undesirable constituents. Sulphur, for example, was one of these. It was in this sense that the deterioration in quality referred to must be understood.

The author agreed with Mr. Martin that at 800 deg. C. there was no attack on metals, at least on ferrous metals, by oxidation products of sulphur contained in the combustion gases, irrespective of the sulphur content of the fuel (ranging from 0·8 to 4 per cent, as indicated by Mr. Martin). At this temperature the SO_3, which was the most aggressive compound, was probably highly dissociated. Moreover, this temperature was well above the "dew point."

With regard to this latter question, the author had formulated his ideas as follows:

As shown by a number of investigations, especially those by Johnstone in the U.S.A. and by Gumz in Germany, mentioned by Mr. Baritel[1], as well as those of the latter, the dew point was a function of numerous variables. While certain of the factors to be considered, such as sulphur, hydrogen and water contents of the combustible, and optimum excess air supply, could be accurately determined for a given fuel, other factors, such as the degree of completeness of the transformation of SO_2 into SO_3, and the humidity of the combustion air, were either *a priori* unknown, or they varied with the prevailing atmospheric conditions. It would seem therefore to be illusory, in view of its instability and its wide variations, to speak of a dew point of sulphur fumes or to ascribe to it a definite value.

However, it was the task of the engineer in charge of a heat power plant to safeguard the endurance of its material and to maintain it in good condition. What was therefore of importance was knowledge of the temperature, which might be termed the "safe" temperature, above which the fear of corrosion was largely, if not completely, remote. For the engineer it would be sufficient to know the highest possible dew point with the fuel used under the most unfavourable circumstances. Thus, according to the graphs given by Gumz in the case of Naval fuels in relation to specification F.F.O., with a sulphur limit of 3 per cent, the dew point would approximate to 175 deg. C.

Mr. Martin considered it illogical, as far as permissible sulphur content was concerned, to draw a distinction between boiler fuel and engine fuel. The author did not believe the quality requirements of a fuel to be independent of its use, whether for boilers or Diesel engines. The consequences of corrosion were not equally grave in the case of a boiler plant and that of a precision built mechanism as represented by an engine.

Mr. Martin had expressed his surprise at the parallel drawn by the author between the ash content and the contamination with sea water. The hypothesis concerning the composition of the ash, attributing two-thirds of its weight to sodium sulphate, was based on various analytical data on ash composition of fuels and the equivalence of 660 grams of SO_4Na_2 to 20 litres of sea water; as regards the amount of sodium, this could be easily established on the basis of reckoning with 26 grams of Cl Na per litre of sea water. The author had noted with satisfaction that Mr. Martin shared his (the author's) circumspection regarding the employment of surface active agents for breaking emulsions on board ship. As he had already stated in his reply to Mr. Lorne, the author thought that, contrary to Mr. Martin's statement, but in accordance with the opinion expressed by Mr. Baker, the question of the pour point was directly bound up with that of the pumpability, at least on board ship.

Mr. Martin was correct in pointing out that in connection with the stability test it was benzene (C_6H_6) that was referred to, and not benzine.

The author was glad to note that Mr. Gamlen shared his opinion regarding the deleterious effects of sulphur, wherever it might be present. He was also interested in his statement regarding the possibility of breaking emulsions by the use of agents without attendant risk of re-emulsifying. Mr. Gamlen had stated that the dew point was highly variable, and the author had expressed his opinion of this in his reply to Mr Martin. He would, however, in agreement with Mr. Gamlen's statement, add that the large variation in the dewpoint must be considered to be one of the causes why boilers in Naval vessels, which were more frequently banked than the boilers of merchant vessels and also subject to varying loads for military reasons, were more liable to corrosion than land boilers or boilers of merchant ships which were operated at more stable loads.

Chemical means for combating sulphur attack, in the opinion of the author, were not yet suitable for general application in the Navy. It had been found necessary, therefore, to make a compromise between high powers and high efficiencies on the one hand, and ruggedness on the other. The necessity to prepare and to treat the fuel within the range of present possibilities, was running counter to the latter requirement.

Mr. Baker had recognized the need for determining the minimum temperature at which pumpability was still assured. In fact, however, the pour point determination, although, of course, it introduced a conventional cooling speed and did not submit the fuel to the same shearing stresses as were produced by the pumps on board, nevertheless constituted for the time being the best means of estimating the lowest permissible temperature, particularly if the pour point were established as indicated by the author. With regard to Mr. Baker's general comments on the usefulness and the disadvantages of the fuel specifications, the author would point out that he did not consider that the quality requirements of the Navy could be held to be in the category of unduly rigid and therefore dangerous restrictions. When it was considered that, from every point of view, a Navy was a national asset of inestimable value, one must concede that no precautions taken in connection with its operation, so long as they were not uneconomic and were technically reliable and efficient from the military point of view, could be regarded as exaggerated.

This paper was read and discussed on Thursday, 28th June 1951 at the Central Hall, Westminster, London, S.W.1, at a meeting of the International Conference of Naval Architects and Marine Engineers, which was organized by the Institution of Naval Architects, Institute of Marine Engineers, Institution of Engineers and Shipbuilders in Scotland, and North-East Coast Institution of Engineers and Shipbuilders.

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[1] Baritel. Corrosion of boilers by oxygen compounds of sulphur (in French). Chauffage, ventilation, conditionnement. No. 4, 1945: No. 1, 1946.