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Sea Water Contamination of Boiler Fuel Oil and its Effects

By Engr. Rear Admiral C. J. GRAY, C.B.E., D.S.O., R.N.(ret.)* and WYCLIFFE KILLNER, R.N.S.S.†

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Chairman: W. SAMPSON (Chairman of Council)

Synopsis

The problems of deterioration of furnace refractories and the formation of bonded deposits have become so prominent to Naval and Marine Engineers that a better understanding of their causes is essential.

The change in the characteristics of the boiler fuel oil since the early days of the 1939-1945 war has resulted in changing the behaviour of sea water and fuel oil when kept in contact and where motion is inevitable.

The authors offer the results of their investigations associated with the slugging and rapid deterioration of furnace refractories and the formation of bonded deposits which have occurred in H.M. Ships, in an attempt to show the cause of these troubles and also to emphasise the importance which sea water plays in connection with these two problems.

The old saying "Oil and water do not mix" held until the early part of the 1939-1945 war, so far as the boiler fuel oil supplied to H.M. Ships was concerned, for when water came into contact with this oil, and the two were vigorously agitated one became dispersed in the other and remained in that condition, only, however, for so long as the agitation continued. When the motion ceased separation began immediately and was complete after a matter of minutes, leaving two layers of immiscible liquids, the upper layer consisting of oil free from water and the lower layer of water free from oil.

This was clearly demonstrated in 1939 when the authors conducted a series of tests on a number of makes of static oily water separators. The conditions laid down for the trials specified that the mixtures to be dealt with should consist of various percentages of fuel oil and water and that after being mixed mechanically they should be allowed to stand for 15 minutes before being passed through the separator.

The makers of the separators on their part guaranteed to deal with the mixtures at varying rates according to the percentage of oil and water, and after passing them through the separator, to give back dry oil and to discharge water free from oil.

The conditions laid down for these trials pointed to a lack of appreciation at that time of the behaviour of water and fuel oil when mechanically mixed, for in practice it was found that however drastic the mixing, and whatever proportions of oil and water were used, a complete separation of the two liquids occurred in the mixing tank by the end of the 15 minutes period of standing. Under such conditions, when pumping began, the separator was supplied first with clear water, secondly with a mixture of oil and water, when the water/oil interface approached the suction of the pump, and finally with dry oil.

During the intermediate period of pumping when oil and water were both being drawn from the tank, the gear wheel type of pump in use acted as an homogeniser so that the discharge consisted of an intimate mixture of oil and water resembling coffee, but samples taken from a point some ten feet further along the discharge pipe showed that separation was already in an advanced stage, and instead of the coffee-like mixture, the samples consisted of water in which

were suspended globules of oil about the size of small peas.

Figs. 1, 2 and 3 show the state of the oil and water at various stages.

It can be seen, therefore, that with the pre-war grade of fuel oil, used in these tests, the separator had very little to do. Its main func-

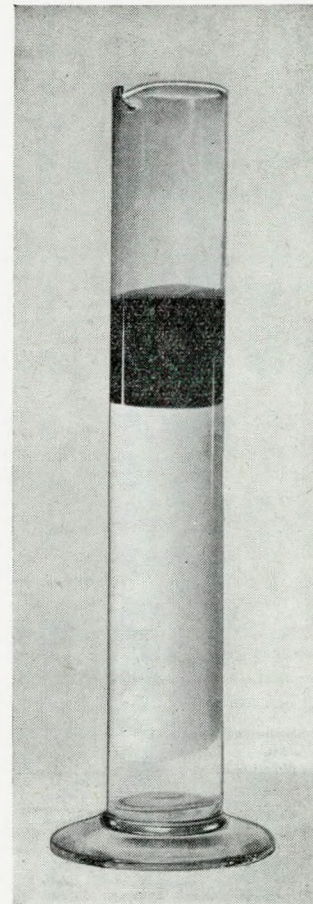


FIG. 1.—State of the oil and water in the tank after mixing and standing for 15 minutes, showing the clear line of demarcation between oil and water.

* Officer in Charge at The Admiralty Fuel Experimental Station 1941 to 1947.
† Principal Scientific Officer at The Admiralty Fuel Experimental Station.

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tion was, by a system of baffles, to cut down the turbulence and so give a longer time to allow the globules of oil shown in Fig. 3 to rise through the water with which the separator was originally filled, and to collect at the top of the separator.

With the fuel oil supplied to-day these trials would have been very different, the agitation and stirring given to the oil and water in the mixing tank would have caused a stable emulsion to be formed, in which the proportions of water and oil would have depended upon the extent of the mixing and the time for which it was kept up. These proportions would also have depended upon the original proportions of oil and water in the tank, for it is known that a water/oil emulsion reaches the saturation point when the oil and water are approximately in the proportions of 26 per cent. of oil to 74 per cent. of water. Any water in excess of this amount, however thorough the mixing, would remain as free water.

The static separator could have had no effect in separating the water dispersed in the oil as an emulsion, it would only have separated the free water from the emulsion.

In the summer of 1942 it was becoming more and more apparent that a change in the quality of the boiler fuel oil being supplied to the fleet in home waters was causing a good deal of difficulty in the boiler rooms in ships of all classes. This change was due to the deeper cracking processes adopted to produce aviation fuels with the consequent degradation of the residues used as a basis for the production of boiler fuel oil.

This suggestion is supported by the fact that in September, 1941, the Admiralty specification for boiler fuel oil was amended and the permissible viscosity at 70 deg. F. was raised to 1,500 secs. Redwood I, whereas prior to this date a typical Admiralty fuel showed a viscosity of 800 secs. at this temperature. Owing to more vicious cracking, and possibly aggravated by the particular crude oil in common supply, it is probable that the higher viscosity oils contain a lower percentage of the volatile fractions, and a higher content of

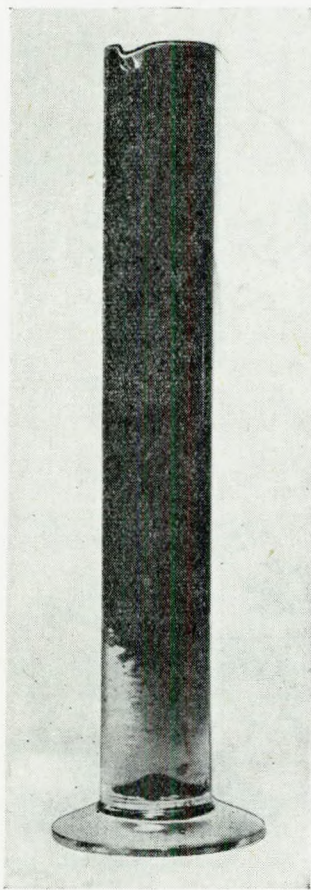


FIG. 2.—The coffee-like mixture as drawn from the pump discharge consisting of very fine particles of oil and water. Separation has already started.

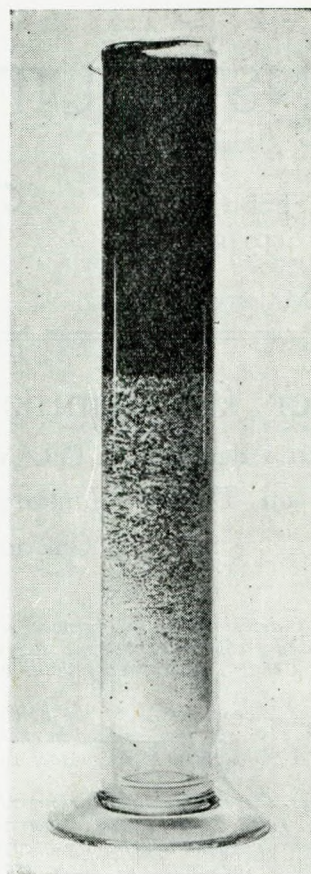


FIG. 3.—Sample as drawn from a point 10 feet from the pump. Separation is in an advanced stage and the fine particles have coalesced and formed larger globules.

compounds of high molecular weight, and a greater amount of unstable substances such as asphalt.

This grade of fuel oil when in contact with water will, when subjected to agitation such as would be produced by the motion of a ship, readily form an emulsion so stable that separation does not take place when the mixture is subjected to moderate heating, standing or centrifuging.

The means by which water may come into contact with the fuel oil in H.M. Ships are more numerous and more likely to occur in war time than in peace time; among them are:—

- (a) Wet oil supplied to the consuming ships, owing to deteriorating conditions of tankers, lack of opportunity for repairs, and rapid turn round with incomplete clearance of ballast water before reloading.
- (b) Leaking oil tanks in the consuming ships caused and aggravated by keeping the sea in all weathers, lack of opportunity for repairs, underwater explosions, near misses, etc.
- (c) Ballasting oil tanks with sea water to maintain the stability of the ship.
- (d) The displacement of oil fuel from wing tanks by sea water in order to maintain protection.

The formation of emulsions and their properties

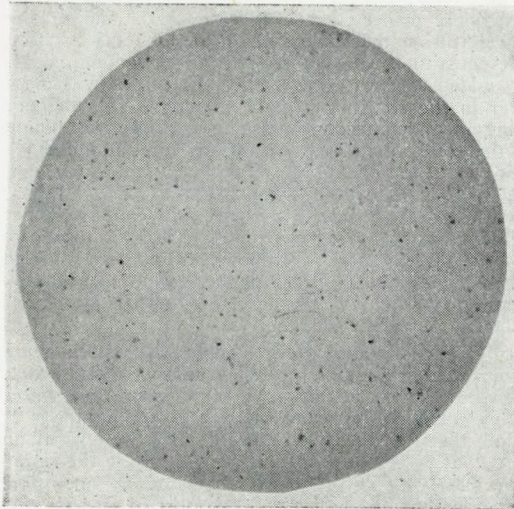
When two immiscible liquids are shaken up together sufficiently vigorously to subdivide them into a fine dispersion one of the liquids is distributed in the other and an emulsion is formed. Emulsification is, therefore, the subdivision and dispersion of one liquid in another. In an emulsion there are two phases, a dispersed phase and a continuous phase, the liquid forming the dispersed phase is in minute particles dispersed in a field of the liquid which forms the continuous phase. In emulsions of oil and water the oil may be in the dispersed phase and the water in the continuous phase or vice versa.

The emulsions with which we are concerned are water/oil emul-

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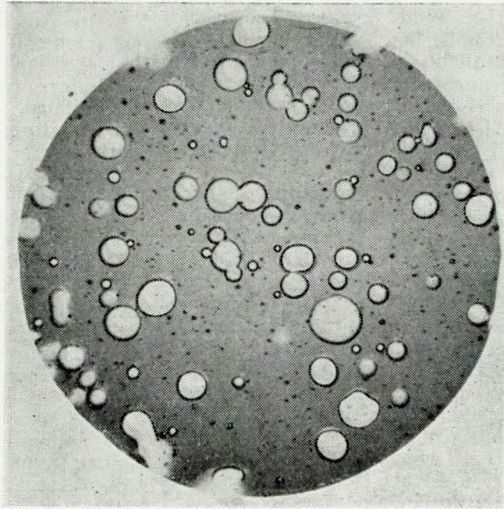
sions where the water constitutes the dispersed phase and the oil the continuous phase. Present day fuel oil supplied to H.M. Navy easily takes up 74 per cent. of water which is the maximum for the close packing of the water droplets.

The figures below show fuel oil containing various amounts of water :—



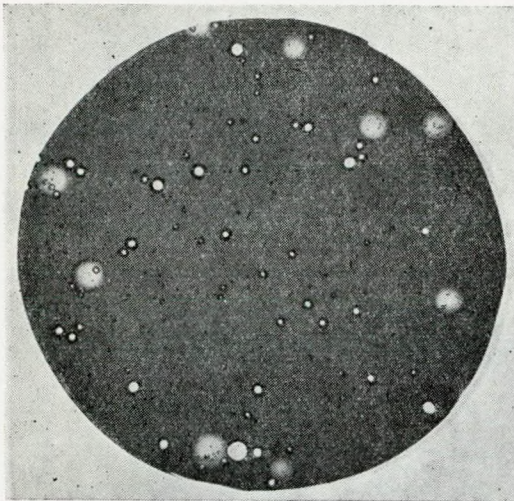
× 100.

FIG. 4.—Water free boiler fuel oil in which minute particles of carbonaceous matter can be seen.



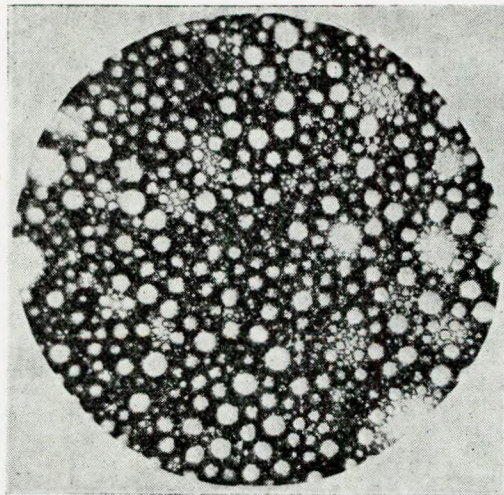
× 100.

FIG. 6.—Oil containing 10 per cent. of water.



× 100.

FIG. 5.—Oil containing 5 per cent. of water.



× 100.

FIG. 7.—A heavy emulsion containing approximately 60 per cent. of water, showing the close packing of the spheres.

Breaking of emulsions

Whether an emulsion will remain stable when agitation is stopped depends upon whether a stabiliser or emulsifying agent is present; where such an agent is not present the emulsion will break and separation will occur.

There are two stages which operate in breaking an emulsion; in the first stage the dispersed drops coalesce, and in the second stage the lighter liquid rises through the heavier one and the heavier liquid sinks. The original state is reached in which the liquids are in two separate layers having a clear cut interface. Of these two stages the first one is the more important, and where it does not operate, separation may be very slow or may not occur at all. The coalescing of the small drops occurs as a result of colliding; these collisions being due to Brownian Movement. When by coalescence the drops become sufficiently large for gravitational sedimentation to occur, separation is achieved.

The collision frequency depends upon the magnitude of the Brownian Movement, the distance between the drops, and the viscous

resistance to the Brownian Movement. It is, therefore, clear that in an emulsion where the drops are widely separated such as in Figs. 5 and 6, the collision frequency will be less than where the drops are closer together, whilst a viscous liquid will reduce the distance through which the drops will move and, therefore, the collision frequency will again be less.

For an emulsion to remain stable an emulsifying agent must be present to form a stabilising layer around the drops of the dispersed phase where it acts as an energy barrier. The frequency of the collisions is not altered but only those collisions which occur with sufficient energy to overcome the barrier are effective. The emulsifier acts as an energy barrier either by giving the drops an electric charge so that mutual repulsion prevents effective collisions, or by acting as a skin around the drops and so giving them rigidity.

Having shown the mechanism by which emulsions break and the factors which render them stable, it becomes very evident that the nature of the emulsifying agent or stabiliser had to be found. This was a troublesome problem and involved research over a very wide field. Fuel oils have an organic acidity and may contain finely divided solid matter; it is well known that soaps can act as stabilisers and this organic acidity will, under certain conditions, form a soap, also finely divided solid matter is used in certain cases to stabilise an emulsion. The organic acidity and any finely divided solid matter were removed from a fuel oil but it was found to emulsify as readily as the oil before treatment.

Dr. A. S. C. Lawrence of the Imperial College, who was collaborating with the authors on the emulsion problem, found that filtration of the oil through a sintered glass disc at room temperature allowed a small amount of oil to pass through before the filter choked up and that this filtered oil did not emulsify. Filtration of the same oil at 50 deg. C. did not result in the filter becoming choked and the filtered oil readily emulsified. It was evident that the stabilising agent in this case was the material held by the filter when filtration was carried out at room temperature and this material was found to be soft asphalt. It was subsequently discovered that if soft asphalt recovered from a fuel oil was added to Nujol, a stable emulsion could be made although the Nujol without the soft asphalt did not form a stable emulsion with sea water.

There are several possible ways of breaking emulsions and amongst them are :—

- (a) The addition of an agent to increase the solubility of the asphalt.
 - (b) Redistillation.
 - (c) Addition of a volatile solvent and distilling off the solvent together with the water.
 - (d) Addition of a surface active substance which will displace the asphalt.
- (a) A number of materials were tried but no hopeful results were obtained.
- (b) This method would not only be accompanied by heat losses but

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the operation is troublesome owing to frothing and bumping.

(c) This method is also accompanied by heat losses but in addition it is impracticable on a large scale owing to the difficulty of removing the last traces of the added solvent, the presence of which would result in the recovered oil having a low flash point.

(d) A number of surface active agents were tried with varying degrees of success and finally it was found that some of the commercial wetting agents gave remarkably good results. Teepol was selected as it not only gave good results, but being a liquid it was convenient to work with and was available in good supply. It was found that after adding a wetting agent to an emulsion, agitation caused the emulsion to become less viscous, it was also found that, on heating, complete separation could be achieved giving two distinct layers, the upper one being dry oil and the lower one water free from oil.

Having succeeded in breaking emulsions it was necessary to obtain some knowledge of the factors which govern the operation. It is well known that surface active agents reduce surface tension and this may assist the dispersed drops of water to coalesce. It is also well known that heat increases the Brownian Movement and reduces the viscosity of an oil; the energy of the collisions of the dispersed water would, therefore, be greater in a heated mixture. The filtration experiments referred to showed that the asphaltic matter was taken into solution when the oil was heated. It is obvious that these factors materially assist in the breaking of an emulsion; attention was, therefore, given to the concentration of the surface active agent required and the effect of heat.

The surface tension of sea water, to which had been added varying percentages of Teepol, was measured and the figures obtained showed that 0.08 per cent. was the critical concentration. It therefore appeared that something of the order of 0.1 per cent. of Teepol, calculated on the water present, added to an emulsion and stirred into it, would, on heating, cause the emulsion to break and separate, this proved to be the case.

Experiments were then made to find the best temperature at which to maintain the emulsion after adding the Teepol, and this was found to be between 120 and 150 deg. F. An emulsion without the addition of Teepol was found to remain stable for some weeks when maintained at these temperatures.

To summarise the position, an emulsion is formed by agitating fuel oil and water so as to break up the water into small particles and disperse it in the oil where soft asphalt envelopes the water particles, thus forming an energy barrier which gives stability and so prevents the coalescing of the water particles. The addition of a wetting agent lowers the surface tension of the water particles and, by preferential adsorption, replaces the asphalt at the water/or interface, thus removing the skin or energy barrier. Heating increases the Brownian Movement of the water particles and reduces the viscous resistance of the oil, the collisions occur with more energy and the water drops coalesce and become sufficiently large to fall through the field of oil thus giving separation. This sedimentation is assisted by the lowering of the viscous resistance of the oil by heating whilst heating the oil also causes the asphaltic matter to be taken into solution.

The work referred to above was carried out in the laboratory using something of the order of 400 ml. of emulsion contained in beakers; larger trials were made in glass tanks using 10 gallons of emulsion and these gave the same results as the small scale experiments. Trials in a tank containing 2 tons of an emulsion with a water content of 63 per cent. were made and it was found that complete separation was achieved in 24 hours.

The breaking of emulsions has been accomplished on a large scale in H.M. Ships and in tanks on shore at oil depots. In a battleship 80 tons of dry oil were successfully recovered from 115 tons of emulsion.

To ascertain whether oil separated from an emulsion had changed in character a saturated emulsion was made up and broken by Teepol and heating, the recovered oil and the original oil were tested and the results are given in Table I.

Properties of emulsions

It has already been stated that an emulsion is a two phase system where one liquid is finely dispersed in another. It is one of the characteristics of an emulsion that it can be diluted by the addition of the liquid which constitutes the outer or continuous phase. If, therefore, fuel oil is added to a water/fuel oil emulsion and the mass is agitated, the water in the emulsion will be distributed throughout the mixture, resulting in an emulsion containing a lower percentage of water, although the total amount of water present will not have altered. If 20 tons of emulsion containing 75 per cent. of water, and, therefore, consisting of 15 tons of water and 5 tons of oil, is mixed with 80 tons of dry fuel oil the resultant mixture will contain 15 per cent. of water, i.e. 15 tons of water and 85 tons of oil, the importance of this feature will be shown later. If, however, water is added to a saturated emulsion, the emulsion rides in the water, mixing may cause pockets of water to be held by the emulsion, and the interface will be very irregular as shown in Fig. 8.

This irregularity of the interface gives trouble when discharging water overboard from a tank containing a thick emulsion and water. It may be known that the tank contains say 80 tons of free water and 20 tons of a heavy emulsion, but even where the suction pipe is at the bottom of the tank the irregularity of the interface may result in what seems to be oil, but is really emulsion, appearing at the pump discharge either immediately or very early in the pumping operation. This fact led to trouble when discharging a quantity of unsaturated emulsion and free water from a ship's tank and is referred to on pages 5 and 6.

A water/fuel oil emulsion containing a high percentage of water is very tenacious; when a rod is pushed into it the emulsion clings to

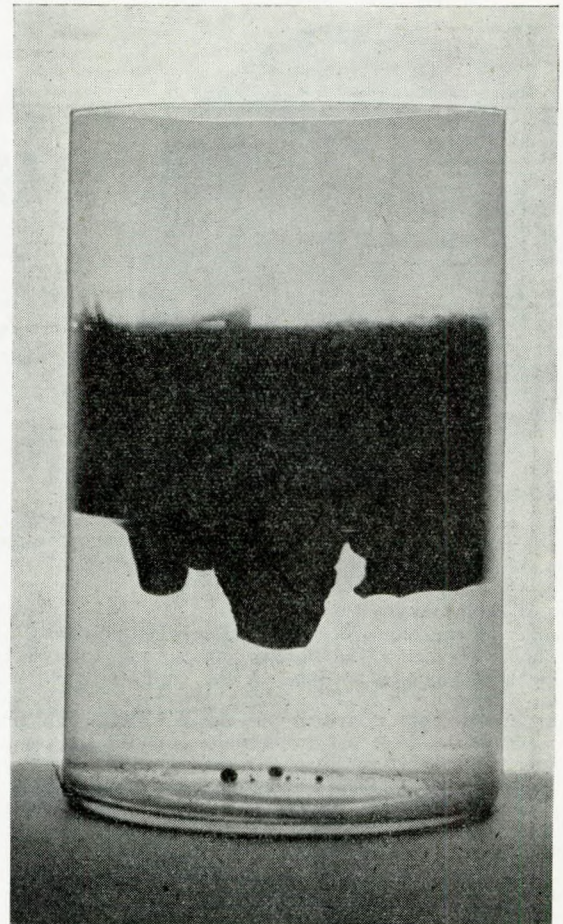


FIG. 8.—The irregular interface which forms between a heavy emulsion and free water.

TABLE I.

	Original oil	Recovered oil
Specific Gravity at 60 deg. F.	0.949	0.950
Flash Point, deg. F.	215	230
Viscosity Redwood I in seconds:		
at 70 deg. F.	1050	1092
at 100 deg. F.	347	346
Sulphur per cent.	1.32	1.25
Water	0.2	0.5
Ash	0.02	0.05
Hard Asphalt	4.04	4.0
Carbonaceous Matter	Nil	Nil
Wax	Nil	Nil

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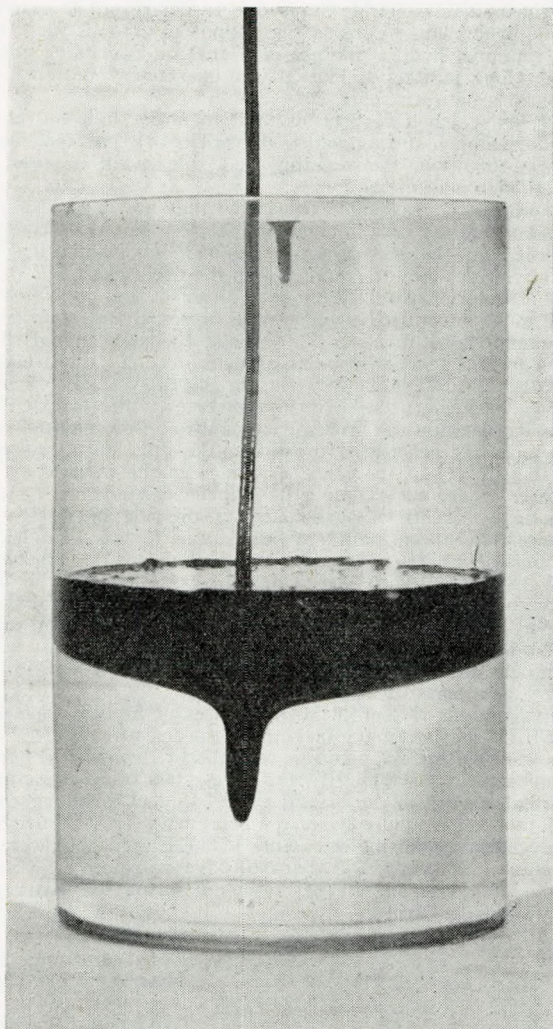


Fig. 9.—Showing the tenacity of a heavy emulsion.

the rod and the point of the rod does not penetrate the emulsion, as shown in Fig. 9.

Formation of emulsions in ships

The ease with which sea water/fuel oil emulsions form is not generally realised. Whenever sea water and fuel oil are in contact and there is motion an emulsion will form; these conditions obtain at sea to-day.

To ascertain the extent to which emulsification occurs when it is necessary to resort to ballasting, a series of trials were carried out in a cruiser. The tank selected for the investigation contained approximately 11 tons of fuel oil which was found to have a water content of 0.8 per cent. Sea water was admitted to the tank until the oil blanket had been raised to within 18in. of the crown of the tank which then contained approximately 11 tons of fuel oil and 170 tons of sea water.

During ballasting a moderate sea was running on the beam causing an appreciable roll of the order of 5 deg. each way, the contents of the tank were, therefore, agitated and the conditions were in fact conducive to the formation of an emulsion.

For the purpose of taking samples, a portion of the 2in. air vent pipe at the tank top was removed, and by means of glass tubes and a small sampling device it was possible to determine the position of the oil/water interface and to take samples at various depths of the oil layer.

During the subsequent ten days, the ship proceeded to sea daily, during which time further agitation of the tank contents took place due to the ship's motion.

Table II shows the water content found in the samples taken at the stated depths and times. Although these samples were taken with the ship at anchor there was, on occasions, too much motion on the

ship to be certain that the samples obtained were truly representative of the mixture at any particular depth.

TABLE II.

Number of days at sea	Time samples were taken	Depth samples were taken below surface of oil			
		6in.	1in.	4in.	8in.
		Per cent water			
1	0930	13			
2	0935	10			
3	0900		12	15	37
4	0915		14	18	43
5	0915		18	23	*
6	0900		19	24	45
8	0930		35	35	60
9	1645		40	50	50
10	0900		47	50	50

* This sample consisted of free water and emulsion.

The results shown in Table II indicate clearly that after the initial emulsification which takes place during ballasting, further water is taken up in progressive amounts dependent upon the time that the oil and water are in contact, and the amount of motion on the ship, a higher water content being evident as the interface is approached.

In this particular case the continued motion of the vessel had resulted in the mixture becoming homogeneous. It is reasonable to suppose that as the emulsion takes up more water and becomes more viscous it does so at a decreasing rate owing to it being more sluggish in movement. It is also reasonable to suppose that provided sufficient free water is present, time and motion will ultimately result in the formation of a saturated emulsion which will probably be unpumpable.

After the final samples of emulsion had been taken the discharge overboard of the ballast water was started. At first the discharge was seen to be free from oil apart from the usual slight iridescence on the surface of the sea. After pumping for a short time the discharge contained oil in such quantities as to prohibit further discharge overboard in harbour.

A sullage lighter was brought alongside and pumping was restarted using a portable rotary pump with the suction hose passed through the manhole and terminating in an "elephant's foot" at the bottom of the tank. The record of the discharging operation is given in Table III.

TABLE III.

Time	Depth of oil and water	Tons remaining in tank	Remarks
—	14' 4"	181	Before starting pump.
Not known	12' 1"	157	Oil showing in discharge overboard.
F. & B. pump stopped, rigged portable rotary pump through tank manhole, discharging to sullage lighter.			
1505	12' 1"	157	Discharging to lighter.
1605	8' 10"	116	
1705	5' 5"	71	
1805	4' 9"	59	
1905	3' 6"	39	
2005	3' 11"	37	
2105	2' 8"	—	
2205	2' 4"	—	
Added 1 ton of Diesel oil, pumping restarted and no difficulty found in pumping the tank dry.			

At the time it was not clear why oil appeared in the overboard discharge after pumping such a relatively small quantity of water as it was thought that there would have been clear water to within a very little distance of the emulsion/water interface and that something of the order of 120 tons could have been rapidly discharged without any fear of oil contamination in the harbour. The only suggestion which can be offered is that even in the case of an emulsion containing 50 per cent. water the interface is very irregular, and dollops of emulsion, having only a small positive buoyancy, break off and are drawn down into the suction stream.

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A sample of the emulsion remaining in the tank when the rotary pump failed, was found to consist of water (emulsified) 47 per cent., oil (emulsified) 53 per cent. The viscosity of the mixture at 70 deg. F. was found to be 4,760 secs. (Redwood I).

The appearance of the sample led one to suppose that it should have been pumpable and this is borne out by the figure for viscosity. The probable explanation is that the small fast running rotary pump dealing with a supply of free water and an emulsion, already containing a high percentage of water, acted as a homogeniser, brought the emulsion to saturation point and choked the discharge passages. The addition of Diesel oil thinned out the mixture in the tank, and the material in the discharge pipe, so that pumping could be continued.

The investigation showed that emulsions of fuel oil and water will form as a result of ballasting, the extent of emulsification being dependent upon the nature of the oil, the weather conditions, and the length of time that the water and oil are in contact with each other.

Effects of sea water contamination

The effects of sea water contamination of fuel oil may be numerous, the most important of which are:—

- (a) Loss of thermal efficiency.
- (b) Deterioration of furnace refractories.
- (c) The formation of bonded deposits in gas passages.
 - (a) The first of these is a very obvious effect, the effective range of a ship is reduced by the presence of water in the fuel oil, 10 per cent. of water present means 10 per cent. less fuel available. It also means a waste of oil in steaming due to some of the available heat units being used to bring the water in the oil to the temperature of the gases.
 - (b) The deterioration of furnace refractories occasioned by the presence of sea water is of great importance and has not yet received the consideration which it deserves.
 - (c) The formation of bonded deposits in the gas passages of the tube banks is also of great importance. Such deposits may not become evident until they have accumulated sufficiently to impede the passage of the furnace gases through the tube banks, and at least one case is known where a reduction of the power of the boiler had to be accepted owing to inability to burn the requisite amount of fuel with the fan power available.

Deterioration of furnace refractories

In recent years the occurrence of the failure of furnace refrac-

tories in the boilers of H.M. Ships due to deterioration by slagging has become prominent. Various suggestions to account for this have been put forward, such as the use of a fuel oil containing vanadium compounds, long periods of high power operational steaming, extension of periods between refits, etc.

The cases which have been brought to notice indicate that after months of steaming, during which the brickwork has remained in a satisfactory condition, the slagging and subsequent failure of the bricks is sudden and unexpected.

From this it is reasonable to assume that the failure is not due to the type of fuel oil now in common use in so far as its constituents are concerned, but that it is caused by the introduction into the furnace of some matter capable of reacting with the firebricks.

Sodium chloride would have such an effect and is a most likely substance to be introduced owing to the causes already outlined.

Examinations of furnaces where slagging has occurred show the brickwork to be in various stages of deterioration. Firebricks taken from a furnace for examination during the early stages of slagging have shown dark incrustation on the surface of the bricks. Underneath this incrustation the bricks are found to be discoloured by some matter which has penetrated the brick, the discolouration fades off towards the surface of the brick remote from the furnace.

In cases where the slagging has reached an advanced stage the thickness of the firebricks, particularly on the side and back walls of the furnace, have been found to be reduced to less than half their original thickness. In such cases the surface of the brickwork on the walls is coated with dark glass-like slag while the floor is covered with a similar substance, which in some cases is of the order of one inch thick. Wherever the slagging has reached an advanced stage, that formed on the brickwork of the furnace walls will have run down onto the floor and has been observed to flow with the motion of the ship, as a mass of molten material.

In investigating this problem three cases of firebrick deterioration reported from the fleet have been given special attention.

Case I. Cruiser "X".—In this case the brickwork had not shown any undue signs of slagging after some 5,000 hours steaming, but after normal repairs to the brickwork subsequent steaming caused it to deteriorate very rapidly by heavy slagging. This failure necessitated the renewal of all the brickwork. The Engineer Officer stated: "The condition of brickwork seems to have worsened very suddenly during the period when oil fuel received during the latter part of August was being burnt".

A sample of fuel oil received from this ship was found to contain 11.6 per cent. of sea water. No special mention was made of any difficulty being experienced in burning this water contaminated oil, from which it was inferred that the presence of the sea water in the fuel oil was unknown to the ship's officers.

Although there is no direct evidence, it is probable, that the oil was not contaminated to this extent when supplied to the ship, but came into contact with sea water in one or more of the ship's tanks where emulsification took place.

Case II. Cruiser "Y"
In this case the slagging of the brickwork and subsequent failure was also comparatively sudden. Specimens of the bricks were received, and an average brick was selected from which samples taken at the positions shown in Fig. 10 were chemically examined and the results are given in Table IV.

Case III. Cruiser "Z".

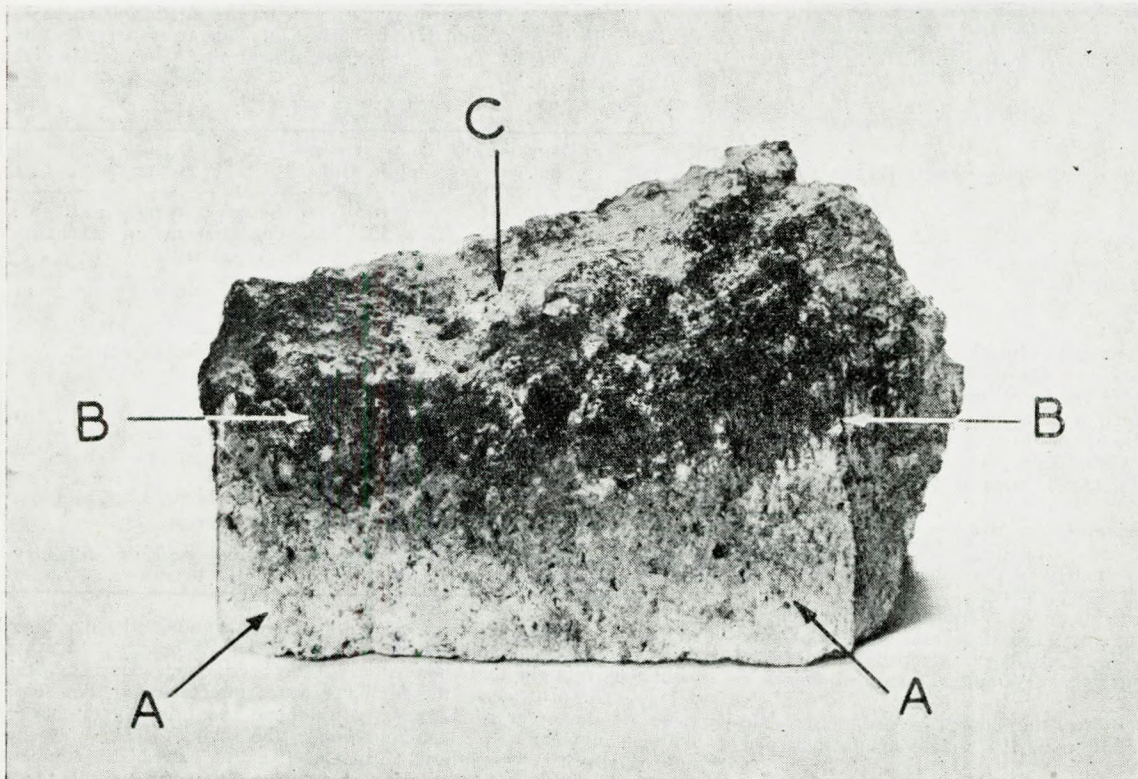


FIG. 10.—A. Unaffected brick. B. Partly affected brick. C. Slag or incrustation on the surface of the brick.



FIG. 11.—A sample of the glass-like slag from the furnace floor of Cruiser "Z".

In this case the brickwork in general showed heavy slagging and the floor of the furnace was evenly covered with a dark glass-like slag something over one inch in thickness, the smooth surface gave ample proof that the whole mass had been molten. Fig. 11 shows a sample of the slag and the results of the chemical examination are given in Table IV.

Description of samples of brick from Cruiser "Y" (Case II)

The bricks in general were coated on the surface exposed to the heat with a slate coloured slag or incrustation. Underneath this slag was a greyish honeycombed layer, while the intermediate portion of the bricks had a brownish discolouration which was most marked near the heated surface. The portion of the bricks remote from the furnace was normal in appearance.

By visual examination it would appear that a fluxing material had come into contact with the brick surface which, at high temperatures, reacted to form a fusible mixture of slag or incrustation. This slag or incrustation, when molten, appears to have penetrated into the firebricks causing the discolouration.

Consideration of the results of analysis

Sample "A" has the composition of a normal firebrick and has not been affected.

Sample "B" shows an increase in the amount of sodium compounds present.

Sample "C" shows that the amounts of silica and alumina have decreased and the amounts of compounds of iron, sodium and sulphur have increased considerably and a small amount of vanadium compounds is also present.

Samples "A" and "B" are practically unaffected by treatment with hydrochloric acid whilst sample "C" is decomposed by the treatment, which indicates that the surface of the firebrick nearest the furnace has undergone a complete change.

The presence of a relatively high percentage of sodium compounds suggests that sea water has been introduced into the furnace at some time. The sodium chloride would, at high temperatures, combine with the firebrick forming a mixture of fusible aluminates and silicates on the face of the firebricks. Sample "C" consists of such a mixture. This material, when

molten, would penetrate into the firebrick which would account for the presence of the sodium compounds found in sample "B" and the discolouration of the refractory material.

The amount of vanadium compounds is relatively small and would of course arise from the fuel oil burnt. The presence of only 0.3 per cent. of vanadium, calculated as vanadium pentoxide, suggests that the slagging has occurred over a relatively short period.

The amount of iron compounds in this sample is considerably greater than is normally found in slags of this type and it is difficult to see how such an amount can have got into the furnace other than by being introduced with the fuel oil as finely divided iron rust.

The report on the sample of fuel oil used by the ship showed the water content to be 0.9 per cent. but did not show whether there was any iron rust in the oil. The 0.9 per cent. of water present, even if it had consisted entirely of sea water, is not considered to be sufficient to have caused the amount of slagging which had taken place in such a short time. It would appear therefore that the slagging was caused by a fuel oil used previously and containing a much higher percentage of sea water and not by that in use when the sample was taken. If this assumption is correct the iron present could be accounted for by rusting of the tanks and pipes by the sea water in the water contaminated fuel.

Chemical reaction of slag formation

The acid character of fireclay bricks is not appreciable unless the bricks are at a high temperature, but it is then found that they combine with alkalis (soda, potash, etc.), or salts (chlorides, sulphates and carbonates) at a rate which depends upon their porosity. At high temperatures the silica and alumina of the firebrick turn out the acid radical from various salts, forming a new salt (alumino-silicate or silicate), and set the hydrochloric, sulphuric, or any other acid free, usually in the form of a gas. The alumina and silica of which the firebrick is composed, will, therefore, at high temperatures, readily decompose any sodium chloride introduced into the furnace as sea water, producing silicates and/or aluminates. The temperature of formation of these may be lower than the fusion temperature of the components. Various stages may, therefore, occur—the reaction stage, when combination of the firebrick and salt is taking place forming a semi-solid mass, to the stage when the mass is molten and flows. Fire-

TABLE IV.

	Cruiser "Y"			Cruiser "Z"
	Sample "A" Unaffected brick	Sample "B" Partly affected brick	Sample "C" Slag or incrustation	Dark glass-like slag
Loss on drying at 110 deg. C. per cent.	0.75	0.21	0.69	0.10
Further loss on ignition "	1.25	0.15	0.05	0.30
Results calculated on dried material				
(1) Soluble in water per cent.	1.30	1.47	11.65	0.50
(2) Insoluble in water but soluble in HCl "	1.50	2.53	62.90	42.40
(3) Insoluble in water and in HCl "	97.20	96.00	25.45	57.10
Analysis of matter soluble in water				
Silica calculated as SiO ₂ per cent.	1.30	1.47	< 0.01	0.06
Iron " " Fe ₂ O ₃ "			< 0.01	0.02
Aluminium " " Al ₂ O ₃ "			< 0.01	0.13
Sulphates " " SO ₃ "			6.25	0.08
Alkalies " " Na ₂ O "			5.40	0.21
Analysis of matter insoluble in water but soluble in HCl				
Silica calculated as SiO ₂ per cent.	1.50	2.53	2.60	1.07
Iron " " Fe ₂ O ₃ "			48.24	2.20
Aluminium " " Al ₂ O ₃ "			3.07	25.01
Titanium " " TiO ₂ "			0.35	1.00
Vanadium " " V ₂ O ₅ "			0.26	1.79
Calcium " " CaO "			1.20	1.00
Magnesium " " MgO "			1.20	0.20
Sodium " " Na ₂ O "			3.34	9.15
Potassium " " K ₂ O "			0.63	0.73
Sulphates " " SO ₃ "			1.50	0.05
Analysis of matter insoluble in water and in HCl				
Loss on ignition per cent.	1.15	0.15	0.05	0.30
Silica calculated as SiO ₂ "	50.71	47.38	15.20	47.13
Iron " " Fe ₂ O ₃ "	3.00	3.20	1.92	6.60
Aluminium " " Al ₂ O ₃ "	41.24	43.76	8.33	2.06
Titanium " " TiO ₂ "	1.20	1.10	0.25	0.12
Vanadium " " V ₂ O ₅ "	Nil	Nil	0.10	0.89

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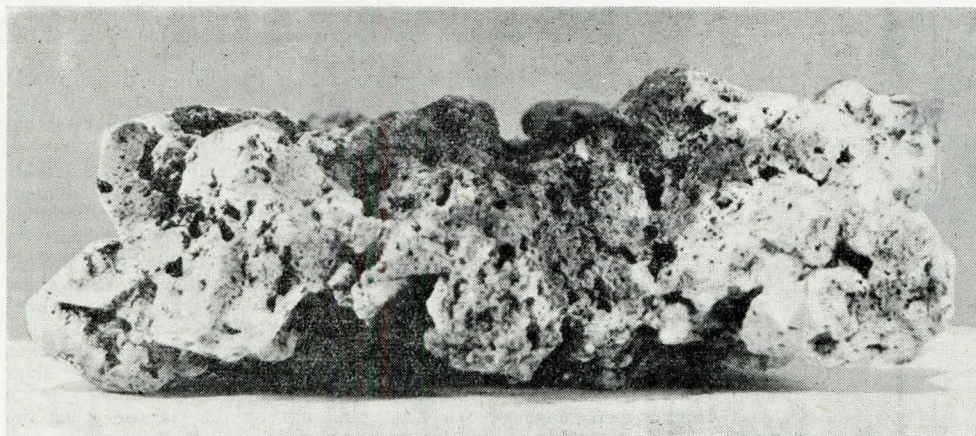


FIG. 12.—Specimen of bonded deposit.

bricks are of a coarse grained texture and, therefore, have a high degree of porosity, the molten slag penetrates the bricks, carrying with it any excess of salt which may be present, where further reaction takes place affecting the chemical composition of the substance of the brick, which results in changes of the coefficient of expansion and contraction of the various constituents, so that the different parts of the brick expand and shrink differently and soon begin to disintegrate. The molten slag also flows down the walls and may completely cover the brick floor of the furnace.

The presence of certain substances in the molten magma may promote crystallisation, the presence of a vanadium compound for instance, derived from the vanadium content of the fuel oil, promotes the separation of crystals when mixtures of alkali, silica and alumina are fused together. This may cause the slag to crack along the lines of the crystals.

The presence of iron compounds in a furnace may result in the formation of iron silicates which when molten readily penetrate refractory materials.

Description of laboratory tests

Laboratory tests were made to show the formation of slag under controlled conditions. Firebricks were prepared by chipping out a cavity approximately 1½ in. dia. and 1½ in. deep, so as to hold any added matter while being subjected to heat from a blowpipe, using coal gas and oxygen. Tests were made using:—

- (a) Salts from evaporated sea water.
- (b) Vanadyl sulphate.
- (c) Salts from evaporated sea water plus iron rust.
- (d) Salts from evaporated sea water plus vanadyl sulphate.

In the tests (a), (c) and (d) when the mass became molten, evidence of the chemical action with the firebrick was given by hot spots appearing in the melt as a result of the reaction taking place.

After heating for about 30 minutes the melt became very fluid and, on cooling, a dark hard glass-like slag remained. On breaking these test bricks it was found that penetration had taken place showing darkening of the firebrick, the darkening being more intense at the surface at which the heat was applied. In the cavity pitting was evident where the brick had suffered attack.

In the test (b) the vanadium oxide formed by the heating had melted and penetrated only slightly into the brick but there was no slag formed and the brick did not show evidence of attack.

The brick used in test (b) was then divided, sodium chloride was added to one half of the cavity, and further heat was applied to this portion. The firebrick was found to react with the sodium chloride resulting in the characteristic honeycombing of the brick and the formation of the usual glass-like slag. On breaking this portion of the brick deep penetration was found to have occurred.

Conclusions

That all the evidence to date indicates that the slagging of furnace brickwork in the boilers of H.M. Ships is primarily caused by sodium chloride reacting with the silica and alumina of the firebrick at high temperatures.

That the sodium chloride is introduced into the furnace in the form of sea water emulsified with the fuel oil.

That a higher grade quality of firebricks made from material found in this country, although likely to increase the resistance to normal wear and tear, is not likely to offer greater resistance to the action of sea water under high temperature conditions.

That cases of brick failures due to excessive slagging are likely to continue unless the entry of sea water into the furnace is eliminated.

The formation of bonded deposits in the gas passages

The formation of deposits in the gas passages through the tube banks and the superheaters of the boilers of H.M. Ships is a problem which came to light during the war period; cases were found where the deposit had collected to such an extent that the gas passages were very seriously choked. The deposits were found to be caked or bonded together by some binding material to form a solid mass and to render their removal by mechanical means, such as saws, extremely difficult if not impossible.

Although in general the trouble was not discovered in H.M. Ships until late in the war period it had previously been

experienced in the case of coal fired boilers. An interesting paper was read by J. R. Rylands and J. R. Jenkinson at a joint meeting of the Institutions of Mechanical and Electrical Engineers, held in London on 4th November, 1943, on "Bonded Deposits on Economiser Heating Surfaces". An abridged report of the paper was published in "Engineering", 24th and 31st December, 1943.

Rylands and Jenkinson showed that the deposits with which they were dealing, that is those found on the economisers of coal fired boilers, consisted of the materials found in the ash of coal in combination with the sulphur compounds resulting from the burning of the coal, the binding agent being aluminium sulphate.

The bonded deposits found up to date in H.M. Ships not only differ in composition from those found in coal fired boilers and dealt with by Rylands and Jenkinson, but they differ in a very important respect. Sodium sulphate, the compound which constitutes the major portion of these deposits, is not a constituent of the fuel oil used. The temperature conditions at the points affected in the case of H.M. Ships are too high to allow the process of formation referred to by Rylands and Jenkinson to operate.

Samples of bonded deposits obtained from various ships were chemically examined and were all found to be similar in composition. Fig. 12 shows a specimen of bonded deposit taken from the tubes of a superheater in one of H.M. Ships, and Table V gives the results of analysis of two typical samples.

TABLE V.

	Per cent.	Per cent.
Loss on drying at 212 deg. F.	0·17	0·22
<i>Analysis of material dried at 212 deg. F.</i>		
Soluble in water	70·70	74·00
Insoluble in water	29·30	26·00
<i>Analysis of matter soluble in water</i>		
Silica calculated as SiO ₂	below 0·10	below 0·10
Iron " " Fe ₂ O ₃	" 0·10	" 0·10
Aluminium " " Al ₂ O ₃	" 0·10	" 0·10
Calcium " " CaO	1·50	2·57
Magnesium " " MgO	1·00	1·00
Nickel " " NiO	0·35	below 0·10
Vanadium " " V ₂ O ₅	below 0·10	" 0·10
Sulphate " " SO ₃	35·70	42·25
Chlorides	Trace	Trace
Sodium " " Na ₂ O	22·04	23·35
Potassium " " K ₂ O	3·20	1·83
<i>Analysis of matter insoluble in water but soluble in hydrochloric acid</i>		
Iron calculated as Fe ₂ O ₃	Per cent. 4·94	Per cent. 4·27
Aluminium " " Al ₂ O ₃	below 0·10	below 0·10
Calcium " " CaO	" 0·10	0·30
Nickel " " NiO	" 1·60	5·71
Vanadium " " V ₂ O ₅	14·80	5·80
The matter insoluble in water and in hydrochloric acid consisted of compounds of silica, iron, vanadium and nickel.		

This analysis shows up three important points, namely:—
(a) 70 per cent. of the deposit consists of material which is soluble in water.

Sea Water Contamination of Boiler Fuel Oil and Its Effects

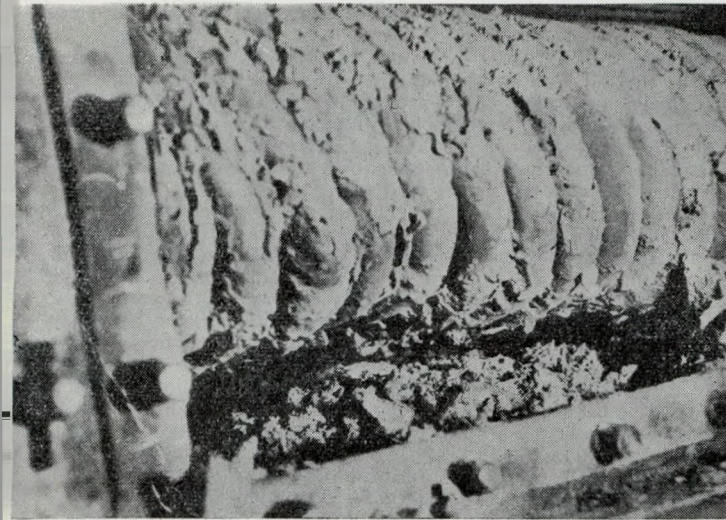


FIG. 13.

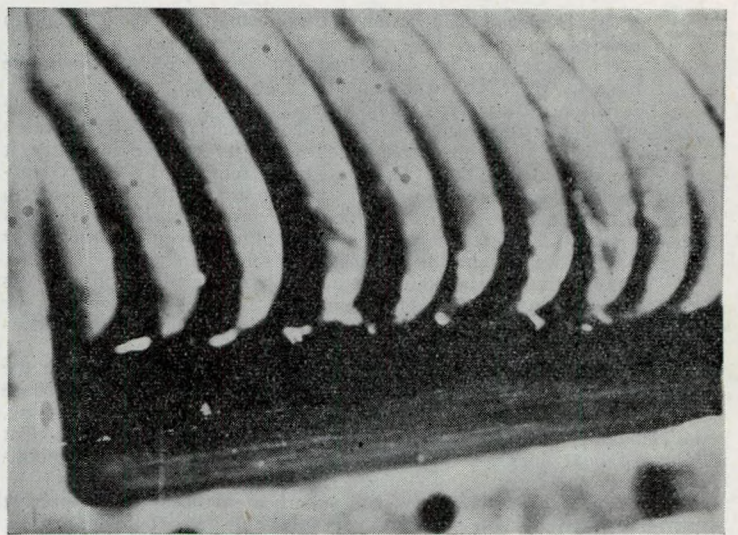


FIG. 14.

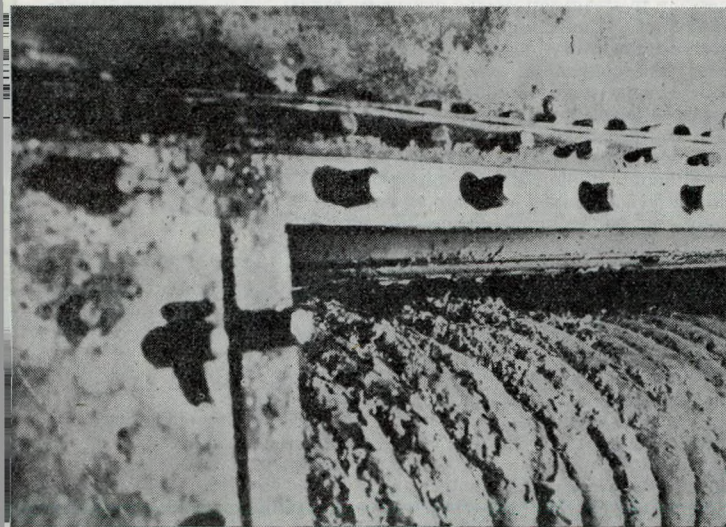


FIG. 15.

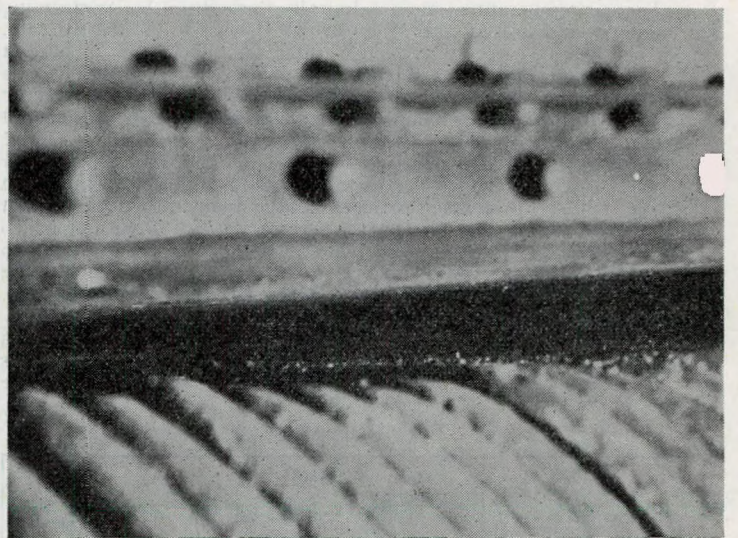


FIG. 16.

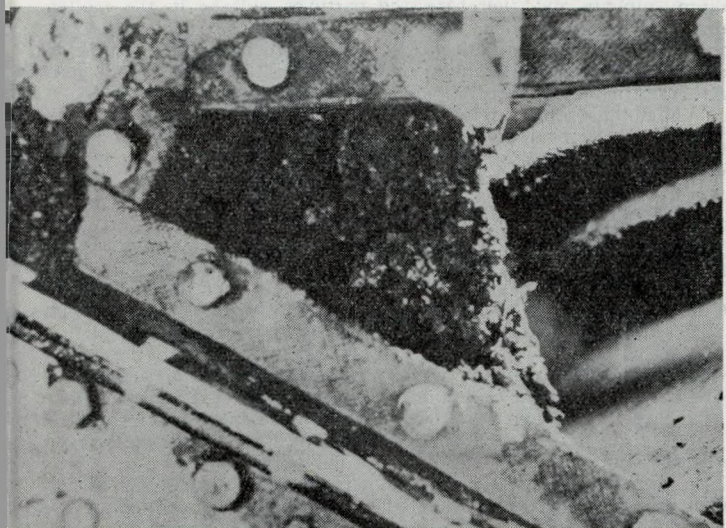


FIG. 17.

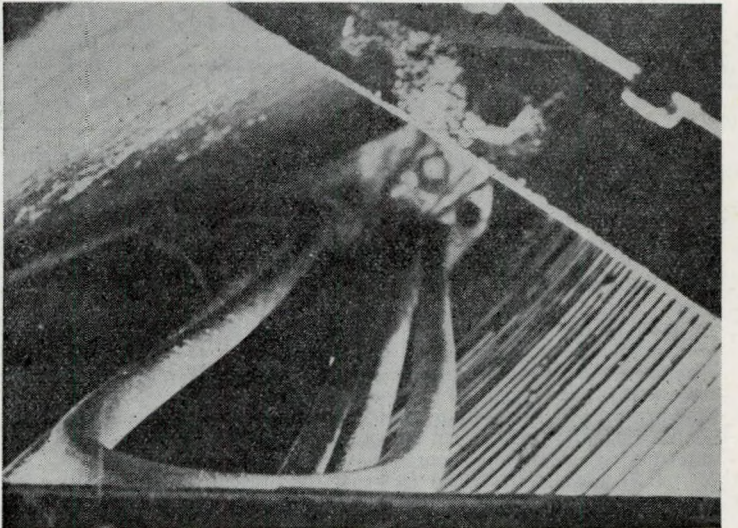


FIG. 18.

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(b) The soluble in water portion consists mainly of sodium sulphate.

(c) There are no compounds of iron present which are soluble in water, i.e. iron sulphate.

The absence of water soluble iron compounds indicates that the iron is present in the form of oxide and not sulphate.

In view of the high percentage of matter soluble in water it is to be expected that these deposits can be removed by water treatment and this has been found in practice to be the case. In an aircraft carrier these deposits, which had seriously choked the gas passages through the tube banks, were removed by means of water lancing and saws, except for the matter insoluble in water.

After lighting up the boiler the insoluble matter dried off and was easily removed by soot blower action; this indicates that without the material which is soluble in water the remainder of the deposit does not bond or adhere to the tubes.

This was confirmed in the laboratory where it was found that the bonded deposits readily fuse and melt when heated in a muffle furnace at light red heat, but when the sodium salts are removed by washing, the remainder, i.e. the matter insoluble in water, when maintained at light red heat does not fuse or melt but remains as an amorphous powder.

Figs. 13, 15 and 17 show the superheater tubes of an aircraft carrier choked by bonded deposits, while Figs. 14, 16 and 18 show the same tubes after water washing.

It has, therefore, been shown both on board ship and in the laboratory that the sodium salts are the binding agents.

The gas temperatures in an Admiralty three drum boiler steaming at high powers are of the order of 2,900 deg. F. in the furnace, 2,200 deg. F. at entry to the superheater and 1,600 deg. F. at exit from the superheater. As the melting point of sodium sulphate is approximately 1,600 deg. F. it will be seen that particles of sodium sulphate held in the gas stream will be in the molten state throughout the major part of their passage through the tube banks. These molten particles will, on making contact with the metal surfaces of the tubes, be cooled sufficiently to solidify the portion in contact with the tube whilst the surface exposed to the temperature of the hot gases will be molten, thus offering the necessary sticky surface to which further material will adhere and bond. Of the compounds found in the bonded deposits sodium sulphate is the only one which has the properties necessary for cementing the material together and, therefore, for forming these bonded deposits.

Consideration of the analyses of the ash of fuel oils given in Table VI and the analyses of bonded deposits given in Table V offers some interesting evidence regarding the source of the sodium sulphate in the deposits.

TABLE VI.

Crude Oil (filtered)			
	A	B	C
Ash Content per cent. ...	0.005	0.003	0.006
Analysis of ash calculated as percentage of ash:			
SiO ₂ ...	52.8	18.1	12.1
Fe ₂ O ₃ , Al ₂ O ₃ , TiO ₂ ...	13.1	37.1	18.1
CaO ...	6.1	8.7	12.7
MgO ...	9.1	3.8	0.2
V ₂ O ₅ ...	14.0	24.9	38.5
NiO ...	1.4	5.3	10.7
SO ₃ ...	2.6	1.0	7.0

During the processing of the crude oil in the refinery the lighter fractions are distilled off and the fuel oil, which is the residue and amounts to approximately 45 per cent., will, therefore, have an ash content of twice the amount shown in Table VI plus any material picked up during the processing, of which the bulk will most probably be iron.

The composition of the ash of the fuel oils given in Table VI shows that there are no sodium compounds present, although the composition of the ash of fuel oils from different sources may vary somewhat; where traces of sodium compounds are found the amount is so small as to be negligible in so far as it could affect the building up of these bonded deposits. It therefore becomes necessary to explain the presence of the sodium compounds in the bonded deposits, and the only explanation which can be found is that they are introduced with the fuel oil as sea water contamination.

It is a well established fact that the present day fuel oil readily forms a stable emulsion with sea water, and there is evidence to show that much of the fuel oil burnt in H.M. Ships during the war period was contaminated with sea water, the main source or causes of this contamination, as already stated, being leaking oil tanks, ballasting,

displacement of oil by sea water, and the supply of wet oil from tankers.

Having shown how the sodium compounds become associated with the fuel oil with which they are introduced into the furnace, it only remains to explain the conversion of the sodium chloride, the main salt of sea water, into sodium sulphate.

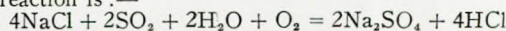
At this stage it may be desirable to refer to views which have been expressed by some investigators and which the authors consider to be unfounded. It has been suggested that the conversion of the sulphur dioxide in the furnace gases to sulphur trioxide is an essential feature of the subsequent formation of sodium sulphate. It has also been suggested that a catalyst is necessary to cause this conversion and that the vanadium compounds present in the ash of the fuel oil act as the catalyst. Supporters of this theory seem to consider the presence of vanadium compounds to be a pre-requisite condition to the formation of sodium sulphate, and suggest that without this catalytic action of the vanadium compounds the sodium sulphate would not form.

We would point out that the oxidation of sulphur dioxide to sulphur trioxide does not require a catalyst under the conditions which obtain in the furnace. If, however, a catalyst were required to accomplish the oxidation, oxide of iron is in plentiful supply in the furnace and its action as a catalyst is well known. There would, therefore, seem to be no evidence to support the contention that the presence of vanadium compounds is an essential or even a contributory feature in the formation of these bonded deposits.

In the gases resulting from the burning of fuel oil, sulphur dioxide, water vapour and oxygen are present, for it is unfortunately necessary to steam with some degree of excess air to ensure a smokeless funnel. These, together with the sodium chloride from the sea water, supply everything necessary for the formation of sodium sulphate. The conversion is a straightforward chemical reaction and is not dependent upon the complicated stages necessary in the formation of bonded deposits on the economiser heating surfaces of land boilers, which has been explained in detail by Rylands and Jenkinson, nor is the presence of a catalyst necessary.

Although sulphur dioxide alone does not itself decompose sodium chloride yet, if mixed with air and steam, sulphur dioxide will completely convert sodium chloride into the sulphate.

The reaction is :-



Having provided sufficient evidence to support the theory that bonded deposits found in the boilers of H.M. Ships, are due to sea water contamination of the fuel oil, it now remains to suggest the mode of formation of these deposits.

When fuel oil contaminated with sea water is burnt in the furnace the water is vaporized and the solids which were in solution now exist as dust suspended in the gas stream, together with the natural ash of the fuel oil. The size of the droplets of fuel oil sprayed into the furnace are themselves small and it, therefore, follows that any sea water which enters the furnace with the fuel oil as an emulsion must, when vaporized, leave its salts in minute particles. In this state they will readily react with the gases surrounding them, the sodium chloride being converted to sodium sulphate, in accordance with the reaction referred to. The temperature of the gases in which they are held in suspension is much above the melting point of sodium sulphate and, therefore, the particles will be in the molten state. As minute molten particles they will be carried in the gas stream and, as they meet, they will join together and so increase in size, in the same way as minute particles of water in the clouds join together to make raindrops.

Whilst the droplets remain minute they will be held by the gas stream and most of them will pass between the fire row tubes. As the gas stream passes the tubes a turbulence is set up which results in the droplets colliding, causing them to unite still further.

When larger drops have formed they will less readily be carried by the gas stream and their progress will more readily be interrupted by obstructions, hence the impingement of the molten drops on the boiler tubes.

The generator tubes and those of the superheater are well below the melting point of sodium sulphate, and wherever these molten particles impinge on these tubes they will flatten out, and the portion in contact with the metal surface will solidify, but the portion exposed to the hot gases will remain molten, wherever the gas temperature is above the melting point of sodium sulphate, and offer a sticky surface to which further molten particles and dust will adhere.

It is clear that molten particles and the dust which collects on the sticky surface will not only adhere but will bond.

As the thickness of the deposit increases the surface will be less influenced by the cooling effect of the tubes and consequently the surface layer will be more fluid and will offer a larger area upon which further particles can build up, this will increase progressively, and thus the rate of build up will increase progressively.

Sea Water Contamination of Boiler Fuel Oil and Its Effects

Practical considerations

Apart from the chemical aspect the following practical considerations would appear to have a considerable bearing in supporting the theory that sea water introduced with the fuel oil as an emulsion is responsible for the formation of bonded deposits.

The phenomenon is new, it only having come into prominence in H.M. Ships during the latter part of the 1939-1945 war.

Serious cases of choking of the gas passages by bonded deposits have been reported from :—

- Battleships,
- Aircraft carriers,
- Cruisers (modern),
- Cruisers (old).

No evidence has come to their knowledge regarding experience in destroyers.

All the classes enumerated have had occasion either to displace oil by water, or to ballast the fuel tanks with sea water, and in many cases, especially in the old cruisers, much trouble has been experienced from leaky fuel tanks. In addition there is little doubt that much wet oil was supplied to ships during the war period.

It has already been stated that the fuel oil latterly supplied to the fleet readily emulsifies when brought into contact with sea water, and that it is possible to burn oil containing even up to 10 per cent. of water without much evidence at the burners. Under these conditions there will be a continuous supply of salts of sodium to the furnace.

Why were bonded deposits not experienced in the years before the war? This might be attributed to the fact that war time conditions reduced the number of occasions on which external cleaning could be carried out. This suggestion might apply so far as the gas passages which can be reached by saws are concerned, but on the other hand there are numerous parts of the tube banks which cannot be effectively cleaned by saws and are only exposed on occasions of withdrawal of superheaters during periods of drill tests, retubing, etc. It is safe to say that examination of boilers at these periods did not formerly reveal accumulations of deposits of this nature in those parts of the boilers which could not be effectively cleaned by the normal methods.

The gas temperatures of modern boilers are no doubt higher than in pre-war boilers but the increase is not great, nor is this a contributory factor. What then is the difference between pre-war conditions and war time conditions which has caused the formation of bonded deposits?

Before the war water displacement and ballasting was not employed, furthermore the fuel tanks were normally free from leakage, and the oil supplied presumably met the specified water content of not more than one half per cent.

Of much greater importance is the fact that the type of oil supplied up to 1942 did not emulsify when brought into contact with sea water. If leakage into tanks occurred, the water readily separated and settled, and could be discharged overboard, or if it did reach the burners they usually became extinguished immediately.

These practical considerations would, therefore, appear to support the findings of the chemical investigation.

There can be no doubt that the bonded deposits found on the generators and superheaters of the boilers of H.M. Ships are due to the contamination of the fuel oil by sea water held in suspension in a finely divided state, and it is clear that the formation of these deposits can only be prevented by ensuring that the fuel oil reaching the burners is free from sea water contamination.

Methods of detecting the presence of water contamination of fuel oil

It has now been shown that sea water introduced into a furnace has deleterious effects which can only be avoided by ensuring that the fuel oil used is free from sea water contamination.

It is known that fuel oil containing as much as 11.6 per cent. of sea water has been burnt in H.M. Ships without the operators being aware of the presence of the water.

Attention has also been drawn to the fact that an emulsion can be diluted by adding more of the liquid which forms the outer or continuous phase, and that such dilution, whilst reducing the percentage of sea water in the emulsion does not reduce the total amount of sea water present. Obviously a ship steaming for 1,000 hours on oil containing 1 per cent. of sea water will put the same amount of sodium chloride into the furnace as when steaming for 100 hours with oil containing 10 per cent. of sea water.

It is, therefore, very necessary to have some means suitable for use on board ship, for detecting the presence, and estimating the amount of water in fuel oil.

In the days when fuel oil and water did not form a stable emulsion this could be done by using one of the several types of water detecting pastes. These pastes are a mixture of water soluble matter

such as glycerine or a concentrated sugar solution into which a coloured pigment has been incorporated to form a smooth paste. When a sounding tape or a piece of metal is smeared with such a paste and lowered into a vessel containing a layer of oil and a layer of water, the water soluble matter in the paste goes into solution in the water and as the coloured pigment has nothing to hold it on to the metal it falls away leaving a clean surface. The portion immersed in the oil being unaffected by the oil remains intact, thus leaving a clear line of demarcation giving the position of the interface.

Now, however, the position is vastly different as the water present may not be free but held in a fine dispersion throughout the oil as an emulsion, which behaves in the same manner as oil when water finding paste is immersed in it. In cases where the water is held in large droplets the water finding paste may have a slightly mottled appearance which is not easily detected, particularly when the line of demarcation is searched for by wiping off the oil with the fingers or some similar method.

In general, water finding pastes are suitable for detecting the presence of free water but they do not show water held in suspension in the oil in the form of an emulsion.

There is a standard laboratory method for the determination of water content of petroleum products such as fuel oil. The method depends upon heating the sample with a petroleum spirit of a high boiling range, the petroleum spirit acts as a carrier, the vapours from the mixture pass into a condenser and the condensed liquids flow into a graduated receiver where they readily separate. When the receiver is full the petroleum spirit overflows back into the petroleum spirit/oil mixture, heating is continued until the volume of the water in the receiver remains constant for five minutes.

This apparatus normally used in the laboratory consists entirely of glass. The condenser is of the water cooled glass-tube reflux type and, therefore, requires running water for the cooling operation.

The apparatus, although simple to manipulate, is unsuitable for use on board ship, the glass portions are too fragile and the necessity of providing running water to the condenser would present a difficulty. There is also the objection that when the test is completed there remains a mixture of petroleum spirit and oil which is not only highly inflammable but is also a nuisance to deal with. In the laboratory the petroleum spirit is recovered by distillation but this is not a practical proposition on board ship.

The authors have designed an apparatus suitable for use on board ship, and have developed a method which is a modification of

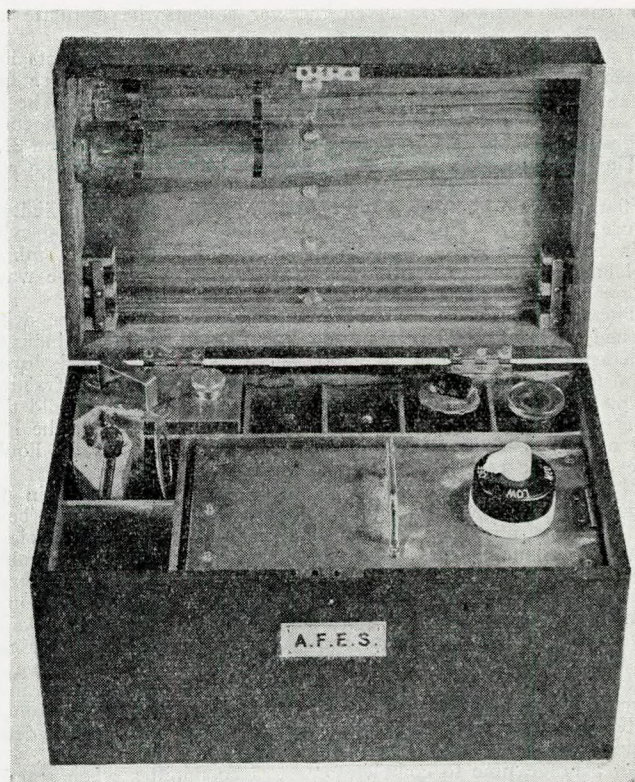


FIG. 19.—Apparatus stowed in box.

Sea Water Contamination of Boiler Fuel Oil and Its Effects

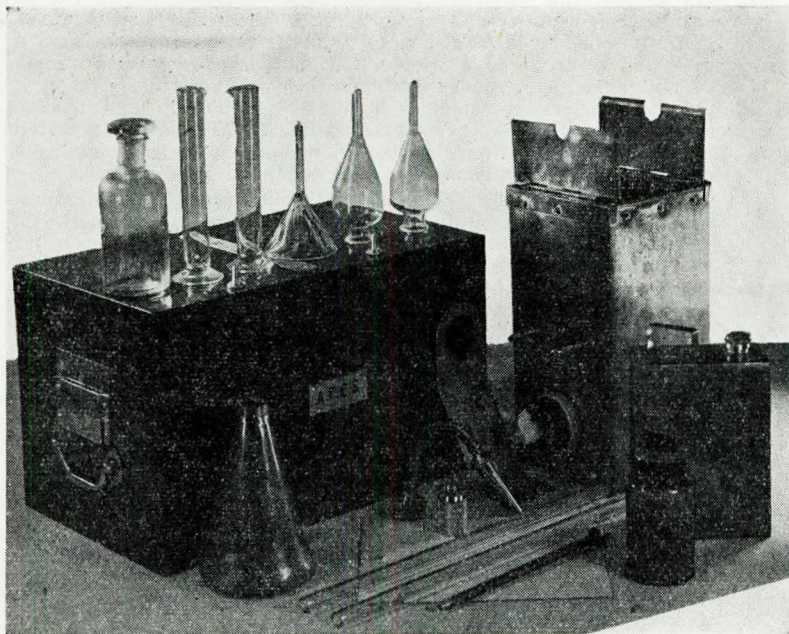


FIG. 20.—Component parts of apparatus.

the standard laboratory method. It is free from the disadvantages referred to above and gives results which are comparable with those obtained by the standard laboratory method.

The apparatus consists of a conical shaped, flat bottomed copper flask approximately 500 ml. capacity, the neck of the flask is threaded to fit into a coupling by means of which a swan necked tube is fitted onto the flask; at the other end of this tube is a gland connection to hold a boiler gauge glass. The free end of the boiler gauge glass is inserted in the neck of a graduated receiver.

The apparatus functions as a distillation apparatus, the copper flask being the distillation flask, the gauge glass the condenser, which is air cooled, and the graduated receiver collects the distillate and provides the means for measuring.

The heat is obtained by means of three electrical elements held between two metal plates and connected in parallel to a three heat snap switch indicating low, medium, high and off positions. The hot plate and switch are set in a lagged copper box which also functions as a draught shield. The apparatus is shown in Figs. 19, 20 and 21.

The procedure for making a determination of the water content of a sample is as follows:—

50 ml. of the sample is measured in the graduated cylindrical measure and poured into the distillation flask. The measuring cylinder is rinsed out with successive portions of about 10-15 ml. of petroleum spirit, using in all approximately 50 ml., and these washings are added to the flask.

The apparatus is next assembled as shown in Fig. 21. The switch is turned to the medium position until distillation begins, as indicated by condensate appearing in the gauge glass, when the switch is turned to low to prevent too rapid ebullition. When the lighter fractions have distilled over distillation will slow down. The heat should then be increased, with the switch at the medium and finally at the high position until distillation is complete, when the volume of the liquids in the graduated receiver should be approximately 50 ml.

If the sample under test contains water the liquids in the graduated receiver will be in two layers, the bottom layer being water and the upper layer consisting of the condensed petroleum spirit. The volume of this water is read off and this figure when doubled gives the water content of the sample as a percentage by volume.

The receiver is not graduated to measure accurately amounts greater than 3 ml. corresponding, in this test, to 6 per cent. of water, and normally on board ship no great accuracy is required in the case of an oil containing more than 6 per cent. of water. Should, however, a greater accuracy be required for amounts over 6 per cent. this can be obtained by repeating the test, using a smaller amount of the sample.

50 ml. of the petroleum spirit should be taken for every determination irrespective of the amount of oil used.

An average time to complete a test is 30 minutes when starting from cold.

If the apparatus is being used in a compartment where the temperature is so high that the condensation is inefficient and vapour

is passing out of the water gauge glass, an air current from a table fan played on to the gauge glass will effect a considerable improvement.

This apparatus has been used on board ship on many occasions and no difficulties have been met with. Even in rough weather where there has been considerable movement of the ship the method of securing the apparatus has proved satisfactory.

Sampling

This paper would be incomplete without reference to one of the most important aspects, namely that of sampling. It is extremely difficult to obtain a sample which is wholly representative of the contents of a tank.

Experience has shown that "layering" takes place in a tank of fuel oil contaminated with water, and conditions are met with which are contrary to natural laws. Being heavier than oil it would be expected that water would fall through the oil, finding its way to the bottom, but this is not always the case, especially when the viscosity is high and the settling period is short.

There are several forms of apparatus in use for taking samples of oil from a tank, most of which are lowered into the tank to the required depth and, by means of a sharp tug on the line an opening or closing device is operated; it is difficult under these conditions to say with certainty the precise depth at which the sample has been taken. In some cases the sampling pot is open on immersion and is closed by a tug on the line when the required depth is reached, and there is no guarantee that when the device is closed the oil entrapped is representative of the oil at the depth at which the apparatus closed.

An effective sampling vessel has been developed at the Admiralty Fuel Experimental Station and although it requires a jerk to operate the valve, the opening mechanism is so sensitive that it operates by lightly striking the supporting line, and samples can be taken from any required depth within an accuracy of something of the order of one inch. This apparatus has the advantage that, by having a balanced inlet valve to counteract the differing head of oil, the container can be lowered to the required depth before the valve is opened, and the valve closes as soon as the container is filled, thus ensuring that the contents are wholly representative of the oil at the point at which it is desired to take the sample.

In conclusion the authors wish to express their gratitude to Dr. A. S. C. Lawrence, now of Sheffield University, for his valuable help and useful criticism in the preparation of this paper.

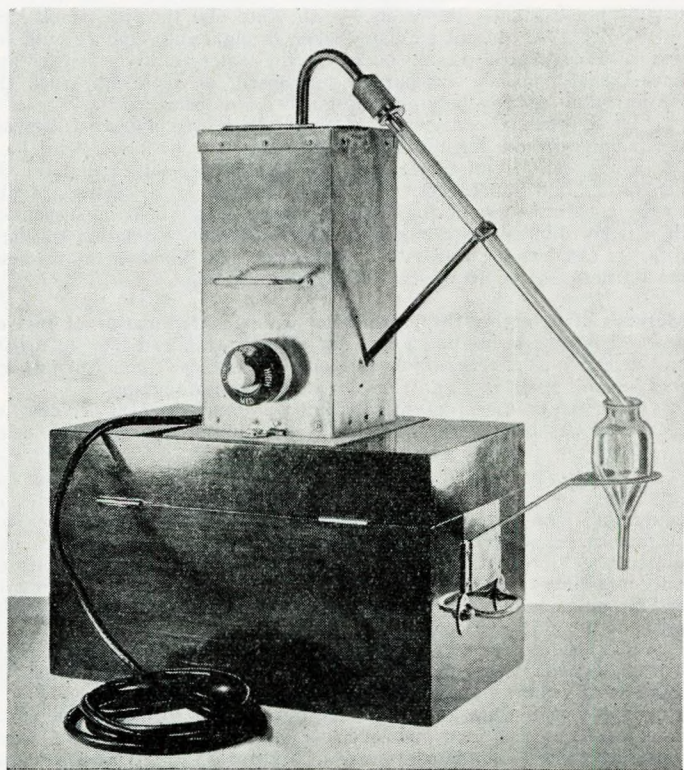


FIG. 21.—Apparatus assembled for use.

Discussion

Discussion

Rear-Admiral (E) G. H. H. Brown, C.B.E. (Vice-President) briefly outlined the way in which these problems had presented themselves, as he did not think that this had been brought out in the paper.

The effects were first felt in 1940 when H.M.S. Ark Royal complained of slugging of her brickwork. It was not unnatural to associate this trouble with the marked change in the class of fuel which H.M. ships were burning at that time: prior to the war the bulk of fuel supplied to H.M. ships was a high grade Persian fuel of low viscosity and of paraffinic type, having a low ash content, whereas Ark Royal had been operating in the Atlantic, burning fuel derived from the Netherlands West Indies, of much higher specific gravity and viscosity, the ash content of which was known to contain vanadium pentoxide. It was thought that the vanadium might be catalyzing a reaction resulting in the formation of a fusible slag. Investigation proceeded in this direction, and some time elapsed before it was realized that they were on the wrong track.

The scale of air attack to which the Fleet was exposed made it necessary greatly to increase the anti-aircraft armament. Full compensation for the added top weight was not always practicable, and it became necessary in some classes of ships to ballast fuel tanks when the amount of fuel remaining on board fell below about 50 per cent. of full stowage in order to maintain sufficient margin of stability to withstand action damage.

This brought sea-water into contact with the oil under conditions conducive to emulsification, and in one ship, after a spell of exceptionally bad weather, an emulsion was formed which proved quite unpumpable. This led to investigation of the causes of emulsification, which in turn disclosed that the slugging of brickwork previously experienced was due to the presence of sea-water in emulsion with the fuel.

The new battleships of the King George V class were fitted with a displacement system for transferring fuel from the wing fuel tanks to the service tanks, situated in the double bottom. The object of this system was to maintain underwater protection. A somewhat similar system was fitted in the large aircraft carriers, the Ark Royal being the first ship so fitted to go into service. This also brought sea-water into contact with the blanket of oil remaining at the top of the tank under conditions conducive to emulsification.

As the war progressed, deterioration in the fuel supply position and the increased offtake of the lighter fractions led to the use of oils of very much higher specific gravity and viscosity, both factors tending to slow up the separation of water from the oil, and having a greater soft asphalt content, which Dr. Lawrence had shown to be the primary cause of emulsification.

The build-up of bonded deposits in superheaters was not felt until a later stage. He had no doubt that it was present to some extent, but the deposits took time to build up, and it was not until the deposits had accumulated to such an extent as seriously to interfere with the passage of gases through the tube banks, that the trouble was reported.

Mr. J. P. Campbell (Member) said that the author's reference to the viscosities of fuel oil taken at 70 deg. F. had caused him to check up on the viscosities at 100 deg. F., and he found that a viscosity of 1,500 secs. Redwood I at 70 deg. F. was approximately equivalent to 500 secs. Redwood I at 100 deg. F. whilst the 800 secs. fuel at 70 deg. F., was approximately 300 secs. at 100 deg. F. He suggested it was customary to refer to viscosities at 100 deg. F. and that the authors should confirm and amend accordingly.

The authors referred to more vicious cracking of the fuel in the refining, and he suggested that, due to the higher temperature required in this process, the trouble being discussed was mainly attributable to the presence of naphthanic acids due to oxidation during the process of cracking. These might take the form of zinc naphthanate or copper naphthanate caused by the fuel making contact with brass valves, cocks or spindles before reaching the oil fuel unit. He added that fuel oil with a viscosity of 500 secs. Redwood I at 100 deg. F. was not a heavy oil.

The ships in which he was interested were burning a fuel with a viscosity of 900 secs. Redwood I at 100 deg. F. which was heavier than the Admiralty fuel oil to which the authors had referred, and he assumed that in refining it even more of the volatile fractions had been removed than the lighter fuel, and with this fuel it was seldom that the heating coils were used in the tanks although the ships operated in home waters. Those vessels operating from Dover used the Admiralty fuel oil for quite a lengthy period after the termination of hostilities, it being the only fuel obtainable at that port. No trouble was experienced with this fuel, one reason being that the bunkers were not part of the ship's structure, so there was little likelihood of sea water contamination.

He had recently had the privilege of inspecting the America, and found that the fresh water used at sea for domestic purposes and boilers was distilled aboard; on enquiring the reason for this, he was told it was to avoid what would have been the necessity of having to ballast the bunkers with sea water when empty, thus avoiding possible contamination of the fuel. For domestic purposes this water was aerated. His reason for introducing this was to suggest a means of removing a possible source of contamination, that of ballasting fuel tanks with sea water as a water distilling plant could possibly be accommodated in large naval vessels. This, of course, would not avoid the other source of contamination from leaky ships' structure or from the oiler itself.

It was unusual for marine engineers to have much experience of centrifuging boiler oil, and although he did make one Australian voyage on a motor ship using boiler oil, he unfortunately had no record of the viscosity; he did remember that the battery of centrifuges literally required continuous cleaning, and after extensive enquiries he could not contradict the statement that the emulsion referred to by the authors could not be separated by means other than the introduction of a de-emulsifying agent. An expert of centrifuging had advised him that it was easier to split salt water and oil than fresh water and oil.

Certain conditions had to be present for emulsions to form, and in the case of oil fuel emulsions, he suggested the emulsifying agents were mainly metal naphthanates. If oil and water (fresh or salt) were placed in a vessel, and those conditions were present, it was only necessary to stir the two constituents together to form an emulsion which would remain stable for an indefinite period.

A stable emulsion was composed of a large number of micelles which were stabilized by the emulsifying agents, and if one assumed a particle of water was surrounded by oil, and a greater concentration of substances known as emulsifying agents, which were mainly metal naphthanates, had collected at the oil water interphase, these were polar molecules and a fairly stable cell was set up.

One form of de-emulsifying agent consisted of a substance which, when introduced into the mixture caused a reduction of the total charge of the micelle; this agent, say trisodium phosphate, having a mobile ion of appropriate charge, the micelle no longer remained stable, and coalescence occurred, the water precipitating out. Slight stirring would increase the rate of precipitation. If too large a quantity of the de-emulsifying agent of that type was added, the charges in the whole micelle might be reversed and the emulsion might remain stable. Could the authors confirm these statements and had Teepol similar properties? The pumping of an emulsion could very often be facilitated by blowing compressed air into it. Could the authors give the analysis of the residue found in the filtration of the oil through the sintered glass disk at atmospheric temperature which they referred to as soft asphalt? He added that nujol was a petroleum bye-product similar to liquid paraffin.

Would the authors give their definitions of the Brownian movement.

Referring to the deterioration of furnace refractories, once the sea water was introduced with the fuel to the sprayer the trouble started, and one result of sea water being present in fuel oil was to increase the ash content, and the increased ash would consist mostly of sodium salts. 2 per cent of sea water in fuel oil would in many cases double the ash content. The first indication of trouble would be shown by a glaze forming on the back wall due to the fluxing action of the salt, and in this connexion the higher the percentage of alumina in the refractory, whether brick, cement, or concrete, the longer this action was delayed.

If there was a large sea water content as in the case quoted of cruiser "X" with her 11.6 per cent sea water contamination, of which the Engineer Officer appeared to be unaware, one would expect the sprayers to splutter a little, with possible pulsation of boiler casings tending to loosen the refractories, so breaking the bonding on brickwork and expediting the fluxing action. If only the acid content of the refractories could have been removed, it would, of course, be impervious to the salt water action, although this would not eliminate the deposits on the tubes. With this 11.6 per cent contamination one would expect the funnel gases to be discoloured, and a possibility that the air pressure would be increased, which would cause further trouble progressively.

He asked the authors whether chrome-ore refractories were less impervious to the salt action.

With regard to the formation of bonded deposits in gas passages, this would show in the formation of a carbonaceous deposit on the generating tubes, and would probably be thicker at the bottom of the tubes and drum, indicating that the deposit had been molten and run

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down. By this time it would be expected that a fall in temperature of the superheated steam had occurred, as the superheater tubes would be affected, and they invariably had a heavier deposit than the generator tubes. The reason for this might be any or all of the following:—

- (a) Temperature of the gas.
- (b) Velocity of the gas.
- (c) Temperature of tube itself (with steam inside would be higher than the generator tube temperature).
- (d) The closer pitch of superheater tubes (which would be smaller in diameter than the generating tubes).

It would be interesting to know whether two distinct deposits were found on the tubes, the outer being of oil fuel ash, found in all boilers, and the under deposit mostly sodium sulphates.

Regarding the removal of the bonded deposits there seemed to be a divergence of opinion amongst the experts, one authority stated that this was best accomplished by the old lance blower, using fresh water pressure instead of steam, as the resultant deposits on tubes caused by salt water in fuel were soluble in fresh water, preferably at a temperature of 150 deg. F. The hotter the water the quicker the deposit would be removed. The water pressure required was between 200 to 250 lb. per sq. in., and in a water-tube boiler this was no easy job for the operator.

The second authority recommended hosing down internally with cold water, using a fire hose and a reasonable water pressure, closing all means of ingress for air, and leaving overnight. A further application of fresh water the next morning had the effect of completely removing the deposit. He said that this method took advantage of the hygroscopic nature of deposit.

Before trying either method it was advisable to protect the brickwork from the water as much as practicable. After removal of the deposit it was essential to dry out the boiler as early as possible, then it was advisable to clean the tubes mechanically, where accessible, to avoid the possibility of any of the deposit remaining.

The method of testing an emulsion, as suggested by the authors, did seem somewhat complicated and lengthy, and from the practical marine engineer's point of view, it would be simpler if a method could be devised which would give a direct reading, such as an electric salinometer.

Finally he said he had discussed some of the author's statements with various authorities, all of whom were intensely interested, and from them, and, of course, the authors, he had personally gained a lot of valuable information. The trouble found by the authors was not confined to naval craft, as any ship burning oil fuel might experience this trouble at any time. He then asked whether all fuel oils with a viscosity at or above 500 secs. Redwood I at 100 deg. F. were likely to emulsify if mixed with water.

Under normal temperature and pressure, say, 200 deg. F. and 200 lb. per sq. in. what was the maximum amount of water expressed as a percentage, that could be present with fuel oil, the mixture to remain combustible?

Was the ratio of the sodium and magnesium found in the bonded deposit in the same proportion as that found in the sea water?

Mr. J. R. Jenkinson (Visitor) said that as part author of a recent paper* he would like to comment on the paragraphs dealing with bonded deposits.

He agreed with the authors that sulphur trioxide was not essential in the production of sodium sulphate. It was formed by the simple chemical reaction given in the text. The authors were particularly fortunate in having to deal with a deposit that was bonded with soluble sodium salts, a deposit that was very different from many of those found on economizers. Such deposits seldom contained more than 2 per cent of sodium salts, but usually contained other sulphates such as those of iron and aluminium. Many economizer deposits were bonded with insoluble substances. Trace elements in coal, as for example boron and phosphorus concentrated on economizer surfaces and might form up to 50 per cent of the whole deposit, and such compounds were insoluble in water. Similarly, even traces of sodium salts in oil or coal could concentrate on superheaters and produce deposits as described in the paper.

The deposits which formed in the various parts of a single boiler unit might have widely differing characteristics. These variations were caused by selective reactions, which depended on a number of factors. For this reason the authors were quite correct in suggesting that the complicated stages explained in detail by Rylands and Jenkinson were not applicable to the superheated deposits.

He agreed with almost all that had been said in this useful paper. He did, however, feel that as catalysts had been mentioned in the paper, full justice had not been done to their influence on the forma-

tion of sulphur trioxide. Many deposits depended on the action of sulphuric acid for their formation, and the amount of such acid in the gases was largely influenced by the action of various catalysts. It was perhaps a little misleading to say "We would point out that the oxidation of sulphur dioxide to sulphur trioxide does not require a catalyst under the conditions which obtain in the furnace". Equilibrium conditions in a furnace at 2,900 deg. F. would produce sulphur dioxide and not the trioxide. The subsequent formation of sulphur trioxide—of which there was ample evidence in many economizer and airheater deposits—was largely the result of the action of catalysts.

Mr. C. W. G. Martin (Visitor) said that those who, during the war, were brought in touch with the problem so graphically described by the authors had no illusions regarding its serious nature.

He believed that difficulties actually began in 1940, when some highly interesting cases of brickwork spalling were reported from certain famous warships. It was his impression that the chronological order of events was that this slugging or spalling of brickwork happened long before the cause was diagnosed. It was first thought to be due to a higher ash content, and particularly to vanadium which was isolated in the new fuel oil supplies in greater quantities than in pre-war material of different origin. As the authors stated, extensive laboratory tests proved that neither vanadium nor iron was the primary cause of the fusing of brickwork, and all cases were ultimately traced to war-time operating conditions making it impossible to keep sea water from the bunker tanks.

The authors had led them to believe that a change occurred in boiler fuels round about 1942, and that this was due to deeper cracking of crude residues. This rather overlooked an important point. Prior to the war most Admiralty supplies came from one source only. For obvious reasons this policy could not be maintained during the war, and fuels of various other origins were also used—particularly in the Western hemisphere. This produced certain consequences, one of which was higher viscosity and higher specific gravity. These higher viscosity fuels could still be classed as light fuel oils, but they were heavier than those used before the war, since the need for gas oil for other essential war efforts meant that distillation of the crude oil was carried to a somewhat farther point.

He emphasized that this was not necessarily due to the inclusion of more intensively cracked fuel oil; this viscosity change would have occurred in any case, and did, in fact, take place at refineries where there was no cracking carried out at all.

When it was realized that salt water, in emulsions or otherwise dispersed in the fuel oil, was the basic cause of trouble, certain materials were tried in an endeavour to set free this water. Before success was achieved with Teepol, several phenolic compounds, proprietary and others, were tried, but in spite of the sound theories which prompted their use these were finally shown to have merely a viscosity-reducing effect, achieved equally well with gas oil. Later efforts of a similar kind confirmed these results.

Reverting to the fusion of brickwork, he thought that a refractory of high alumina content would better withstand attack. The authors had stated that this was not likely, and it would be interesting to know how far it was tried.

It was of some interest to note that the U.S. Navy had very similar troubles in super-heaters, the slag found by Commander McCloskey† being three-quarters water-soluble. This was in striking confirmation of the figure of 70 per cent reported by the authors. Commander McCloskey suggested several remedies, including modification of the boiler, furnace, and burner design, with reduced water ballasting, improved settling and centrifuging.

It was observed that these difficulties had been reported from the Naval authorities, and one would naturally wish to know what all this meant to the Mercantile Marine. It was thought that difficulties which the Admiralty had encountered had not been reproduced to any serious extent in the Merchant Navy during or since the war.

The answer might have been that the Admiralty before the war used an extremely light grade, practically a Diesel fuel, and the change to one of three times the viscosity presented new problems. The commercial shipowner, on the other hand, often used fuel oil of more than ten times the maximum viscosity of 450 seconds Redwood I at 100 deg. F. permitted by the Admiralty. For some reason commercial vessels had been remarkably free from the troubles reported by the authors. There had been no significant change in commercial fuel oils in quite a few years, in spite of all the talk of new and intensive cracking; so that the chief engineers of the tramp and liner fleets need not anticipate that bunker "C" grade would promptly develop the trying habit of forming stable emulsions on the slightest provocation! Small quantities of sludge might still form, of course, and here the work of the authors might in due course help

* Rylands, J. R. and Jenkinson, J. R. 1944. Proc. I.Mech.E., Vol. 151, p. 291, "Bonded Deposits on Economizer Heating Surfaces".

† McCloskey, L. C. 1947. JI. Am. Soc. Naval Eng., Vol. 59, p. 146, "A Study of the Cause of Hard Slag Deposits on Firesides of Naval Boilers".

to find the universal desludging compound. That solution had still not yet been discovered.

Mr. A. Logan (Member of Council) said that while his company's vessels with water-tube boilers were operating very satisfactorily on "C" grade boiler fuel with a viscosity of up to 6,500 seconds, Redwood I at 100 deg. F., as a matter of interest he would mention that twice in recent months, chief engineers had reported liquid or molten bottoms in the furnaces, which were one or two inches in thickness and which moved in mass with the movement of the ship. The slagging appeared to be restricted to the floor of the furnaces, and it was found when the boiler was cool that the molten mass became a dark glass-like slag. Examination of the brickwork showed it was not seriously affected.

Analysis of the slag showed the presence of appreciable quantities of compounds both of vanadium and of alkali metal together with large proportions of silica and combined iron also the analysis showed that the deposited material was not of asphaltic nature.

Analysis	Percentage weight
Silica (SiO ₂)	36.6
Iron (as Fe ₂ O ₃)	40.8
Aluminium (as Al ₂ O ₃)	3.5
Vanadium (as V ₂ O ₅)	6.9
Sodium (as Na ₂ O)	8.3
Nickel	trace
Calcium	trace
Magnesium	trace

The similarity of the two cases led them to wonder if it was the result of certain characteristics of the grade of fuel as there was no difficulty in burning and no sea water contamination of the bunkers as shown by the usual water finding tests was apparent.

The analysis of the fuel gave the following characteristics.

Specific gravity at 60/60 deg. F. ...	0.999 (conf.)
Viscosity, Redwood I at 100 deg. F.	5.990 sec.
Viscosity, Kinematic at 100 deg. F.	1,480 cs.
Water	0.05 per cent weight
Sediment	0.13 " " "
Ash	0.11 " " "

Nature of Ash

Acid-insolubles	14.5 per cent weight (SiO ₂)
Vanadium (as V ₂ O ₅)	67.3 " " "
Iron (as Fe ₂ O ₃)	8.1 " " "

Apart from an unduly high specific gravity which might indicate the presence of cracked fuel, the results were normal.

Their findings were inconclusive, but in view of the similarity of their two cases to Case III cruiser "Z" described by the authors it seemed possible that water was present and had become homogeneous with the fuel. With this in mind further reports from vessels would be watched with interest.

A sample of the glass-like slag was shown to the authors, who agreed that it was the same as that found in the cruiser "Z" boilers.

The use of Teepol as a surface active agent in breaking emulsions of fuel oil and sea water, as presented by the authors was most interesting. The quantity required, i.e. 0.1 per cent, calculated on the water present, was certainly very small, for if it were estimated that 20 tons of sea water were present in 400 tons of bunkers, apparently all that was required to break and separate the emulsion was to heat the bunkers to 120-150 deg. F., and add about 4½ gallons of Teepol. Would the authors indicate how the Teepol should be introduced to the bunkers after it had been established by test that water was present and if the water was suspected, and lacking the necessary testing apparatus, whether it would be in order to introduce a percentage of Teepol, or was it only useful when an emulsion was definitely established?

While the serious damage to brickwork resulting from chemical reactions had been stressed, hard slag deposits on the fireside of the superheated tubes and the removal of the deposits was another cause of worry. Recently this problem had been the subject of a very interesting paper by Commander L. C. McCloskey of the U.S.N.R.* who agreed with the authors in that innumerable analyses of slag samples showed that the mixture was composed of ½ to ⅔ either of sodium sulphate or of sodium sulphate and vanadium pentoxide, and that this was due to the chlorides and carbonates from sea water reacting in the furnace with sulphur in the fuel. As apparently most of the slag was soluble in water McCloskey claimed that he cleaned several superheaters by sweating, i.e. circulating cold water through the tubes to cause air moisture to condense on the slag coating.

He asked if the authors could give any guidance on the removal of such deposits in view of their statement that they also found the

bonding of the deposits and lack of accessibility rendered removal by mechanical means impossible. Some American engineers advocated the use of proprietary eradicators which were injected into the furnace to keep the tubes clear of deposit.

McCloskey also stated that he had successfully cleaned the tubes by using a chemical spray followed by steam lancing, but confirmation of this had not been obtained.

Had any of the foregoing methods of slag removal been considered by the authors; if they had been tried, perhaps they would state the results obtained?

Dr. H. E. Crossley (Visitor) said that the Boiler Availability Committee was set up in 1939 at the instigation of the Electricity Commissioners, to investigate the causes for the loss of availability of water-tube boilers, and to make recommendations for the alleviation of the troubles found to be responsible. The committee consisted of representatives of the electricity generating industry, the manufacturers of boiler plant, the Central Electricity Board, and research organizations. The Chairman was Mr. M. H. Adams, Chief Engineer and Manager of the Lancashire Electric Power Company.

The activities of the committee had so far been concerned with power station boilers, as availability troubles were most acute with the larger plants. A considerable amount of progress had been made, and this had been reported to the electricity generating industry in bulletins and technical papers issued by the committee.

It would be realized from this brief explanation that the investigations of the committee had been limited to boilers fired by solid fuel, usually coal. The near future, however, might bring an increased use of oil in power stations, and all interested in the problem of boiler availability would be indebted to the authors. If it became necessary to separate oil-brine emulsions with land installations, the guidance given in this paper should be quite sufficient to ensure that the separation, and the removal of the aqueous phase, were accomplished without special difficulty, certainly with greater ease than on H.M. ships.

To some extent there was a parallel between investigations with power station boilers and the investigations described in the paper. There would also seem to be important differences between the effects of firing with oil and those of firing with coal. These points would be evident in his comments.

The observations on the effect of alkalis on refractory substances would probably be noted with interest by Messrs. Green and Clews and their co-workers of the British Refractories Research Association. They had published many papers on this subject, mostly in the Transactions of the British Ceramic Society and the Communications of the Institution of Gas Engineers. Other investigations of a related character had been carried out by T. L. Hurst†.

It was noted in the present paper that slag on firebricks had a high iron content, and it was suggested that this might be due to iron rust in the oil. The slag on the walls of coal-fired boilers usually had a much higher iron content than deposits occurring on the heating surfaces farther on in the boiler system, and one possible explanation would be that boilers acted as elutriators, with regard to the solid particles suspended in the flue gases; and it could be expected that the first particles to drop out of suspension would be the largest and heaviest ones. Such particles were usually rich in iron. This enrichment of slag in iron content, whatever the cause, meant that the determination of the fusion point of coal ash was of doubtful value for the indication of slagging propensities.

Mr. Jenkinson corrected any possible confusion between the nature of economizer deposits, as described by himself and Mr. Rylands, and the boiler deposits described in the present paper. They were members of the Boiler Availability Committee, and he knew they would agree that the commonest type of hard deposit occurring on the superheater tubes of modern stoker-fired boilers was fly-ash bonded by a matrix of the normal or acid sulphates of sodium and potassium. Committee Bulletins had given analyses of these deposits, showing similar compositions to those in Table 5 of the paper. The sodium and potassium were derived from the corresponding chlorides occurring in the coals burnt, and a correlation had been established between the amount of chlorine in the coal (representing the alkali chlorides) and the severity of this type of deposits trouble. Boilers fired by pulverized fuel did not develop bonded deposits of this kind, not even when burning salty coal, probably because the amount of fly-ash was too great to be bound into a hard mass.

He had referred to binding by normal or acid sulphates of sodium and potassium. The identity of the binding agent was important, as, for example, normal sodium sulphate melted and became sticky at 1,600 deg. F., whereas sodium pyrosulphate, the acidic type of compound, melted at 750 deg. F. Deposits accumulated more rapidly,

* Op. cit., p. 56.

† Hurst, T. L. 1940. Am. Refractories Inst. Bulletin No. 75.

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of course, on a sticky surface, and hence more acute trouble could be expected with pyrosulphates present than with normal sulphates.

Normal sulphates of sodium and potassium contained approximately equal parts of sodium and potassium oxides, and sulphur trioxides. The pyrosulphates contained about twice as much sulphur trioxide as soda and potash. The analyses in Table 5 showed appreciably more sulphur trioxide than soda and potash, and it might be presumed, therefore, that the binding agent contained pyrosulphates, melting at a temperature considerably less than 1,600 deg. F.

With regard to the mechanism of the formation of sulphur trioxide in boiler systems, members of the Boiler Availability Committee had put forward various explanations, such as the catalytic effect of iron oxide or iron sulphate on the oxidation of sulphur dioxide, and the direct oxidation of sulphur dioxide in a flame. For example, sulphur trioxide had been formed in the flame of a burning mixture of carbon monoxide, oxygen and sulphur dioxide. There was evidence to support the view that little or no sulphur trioxide was formed in the burning of pulverized fuel.

Referring to how the sodium and potassium compounds travelled in a boiler, considering that temperatures of 2,500-2,800 deg. F. were attained in boiler flames, and that alkali salts were vaporized at temperatures little higher than their melting points, it would seem most probable that the sodium and potassium compounds travelled in vapour form. The recommendations made by Commander L. C. McCloskey in his recent paper* might, therefore, fail to achieve all that was hoped, since these recommendations depended on the conception of alkali salts travelling as solid particles.

Mr. L. J. Culver (Visitor) said that in dealing with the formation of bonded deposits, it would seem possible to obtain sticky surfaces at temperatures of about 600 deg. F. if acid sodium sulphate were present with its much lower melting point. This would make the tube metal temperature a more important factor. Perhaps the authors could give their opinion as to whether the metal temperatures accounted for the more frequent choking of superheaters in comparison with generating tubes.

It was interesting to record that deposits of very similar composition had been found in coal-fired boilers; they occurred in the furnaces on radiant super-heater tubes. The metal temperatures were of the same order as those experienced by the authors, but the gas temperatures were much higher. In both cases the coal contained a sulphur content of 1.6 per cent with a maximum of 4 per cent, and the chlorides were due to concentration of recirculated water used for washing.

It had been observed from over a hundred boilers fitted in merchant ships that no case of this type of deposit was met except where pockets occurred which were not reached by soot blowers. These, of course, covered a wide range of boiler fuels. The soot blowers fitted on these ships were all of the single nozzle type. It would be a valuable addition if the authors could give information regarding the type and operation of the soot blowers fitted to the boilers giving trouble.

Mr. S. J. Watson, B.Sc.[Eng.], Wh.Sc., A.M.I.Mech.E. (Visitor) said that in the section of the paper dealing with bonded deposits, the authors seemed to be at some pains to support their contention that these deposits were caused by contamination of the fuel oil by sea water. It would have been interesting here to have had some comparable data concerning the nature and extent of deposits obtained when special precautions were taken to prevent sea water entering the furnace, and what measures were most effective for removing such deposits.

In this connexion an article was published in the technical press (*Boiler House Review*—September 1946) concerning the use of fuel oil in power station boilers, the moisture content of the fuel oil being 0.5 per cent. The description of the deposits formed on the super-heater tubes, made them appear generally similar in character to the deposits described by the authors, and in this case a thickness of $\frac{1}{8}$ in. of deposit was built up in six months steaming. Presumably in the cases cited by the authors, the deposits were much heavier than this. Did the authors find any appreciable amount of deposit in air heaters?

The paper brought to mind another case, although of a very different kind, and somewhat remote from the field of marine propulsion, where deposits in a boiler were attributed to the presence of salt in the fuel. This may have been of interest, because, being remote from the cases cited by the authors, it nevertheless supported their contentions. The case in mind occurred some years ago on a gas works, where hot coke delivered from horizontal gas retorts became contaminated with salt as a result of quenching with saline

river water. The coke was subsequently used in a water gas plant, where steam and air were alternately blown through a thick bed of incandescent coke, and the "blow" gases produced by the passage of the air through the fuel bed, passed through two vessels filled with chequer brickwork, and then through a waste heat boiler. This boiler consisted of a vertical cylindrical drum with about 300 3 in. vertical fire tubes between tube plates, through which the hot gases flowed downwards and were led away from the bottom of the shell to the stack. It was found that deposits occurred at the top ends of the tubes, and after about two months working, some 30 per cent of the tubes were completely choked. In that case it would be noted that before reaching the point of deposit, the gases came into contact with nothing but brickwork, so that the possibility of catalytic action of iron oxide occurring, as suggested by Rylands and Jenkinson, was ruled out, unless it occurred at the actual point of deposit.

The supposition that the deposits were due to salt in the coke was checked by operating with coke quenched with fresh water, when no deposits occurred. No serious fluxing of the brickwork occurred which could be attributed to the presence of salt.

The formation of deposits was a particularly interesting subject at the present time, in view of the interest now being taken in the use of boiler oil in Diesel engines and in gas turbines, where in either case deposits were to be avoided at all costs.

In his recent experiments with the use of boiler oils in Diesel engines, Mr. John Lamb relied upon centrifuging to remove water and impurities from the fuel oil, but according to the authors, emulsions were liable to be formed which were too stable to be broken by centrifuging. This suggested either that the treatment provided for boiler oil intended for use in Diesel engines must be complicated to guard against the contingency of having to break emulsions, or alternatively, that the range of oil which might be used in Diesel engines must be further restricted.

Finally he referred to the authors' method of breaking emulsions by the addition of a wetting agent such as Teepol, and asked if it was possible to employ this method at sea, or whether the motion of the ship would prevent separation of the water and oil. Also it would be interesting to know whether the Teepol added was drawn off with the separated water, or whether it remained in the oil, and if the latter was the case whether it would be likely to have any effect of its own on combustion, or on the boiler tubes or brickwork.

Mr. T. C. G. Thorpe (Visitor) said that similar deposits from marine boiler tubes had received attention from the oil industry both in the United Kingdom and in the U.S.A., and this work, in general, confirmed the findings presented by the authors. He felt that the mechanism of the chemical reaction leading to the formation of sodium sulphate had been treated too simply. Work in which he was associated showed that the boiler tube deposits consisted of two distinct layers. The inner layer, in contact with the tubes was almost entirely sulphates of sodium, and analysis indicated it to be largely sodium pyrosulphate ($\text{Na}_2\text{S}_2\text{O}_7$) and, or alternatively sodium hydrogen sulphate (NaHSO_4). It was probable that this material which had a low fusion temperature was the original tacky deposit which later collected other inorganic ash constituents, such as the vanadium compounds which formed a large proportion of the outer layer of this deposit. His opinion seemed to be confirmed both by Dr. Crossley's and Mr. Cambell's remarks.

Mr. T. S. Aikman (Visitor) asked the authors if the analyses tests in Table 4 on the sample of slag on surface of the brick, sample C, were taken on one small sample, or were the statistical average of a number of tests. He was worried about the high iron oxide content, and if this was the result on one piece, he suggested that it was abnormally high due to either:

- (1) The accidental inclusion of an iron nodule from the fireclay itself.
- (2) The dripping of a dissolved bolt head or even a dripping from a soot blower nozzle or other iron part liable to oxidation or actual melting.

He suggested that a longer life would be obtained from a higher refractory brick such as "Sillimanite". There might have been arguments against the use of this, especially in Naval boilers, due to the raw material having to be obtained from abroad.

With the advent and increased use of stud-type boilers the same corrosion troubles should not arise, as was not only the "P.K.N." or "Plastic Chrome Ore" more highly refractory, but it was kept frozen by its close contact with the actual boiler tubes.

Mr. R. Sefton (Visitor) asked whether the authors had obtained factual evidence to support the implication that the severity of cracking of oils was connected with ease of emulsification with sea water. He asked in particular:

* Op. cit., p. 56.

Discussion

- (1) Whether variations in behaviour were shown between oils of the same grade but different origin, with regard to ease of emulsification, and response to the action of Teepol. If so, whether these had been related to any particular properties, e.g. soft asphalt.
- (2) Whether the removal of soft asphalt by filtration through a sintered glass disk resulted in a filtrate which did not emulsify with sea water, was a general effect.
- (3) Whether a method of determination of soft asphalt in fuel oils had been evolved by the authors.

Mr. R. G. C. Richardson (Member) said that the contamination of oil with sea water would undoubtedly affect combustion together with the deterioration of brick work, and also be partly responsible for the deposits on the heating surfaces, but it would be erroneous to conclude all deposits were due to such contamination.

The information given in the paper had been obtained from Naval practice and his experience had been that deposits had always been greater in Naval boilers than in boilers of the Merchant Navy.

It was suggested firstly, that deposits would occur on the heating surface of water boilers whether or not fuel oil was contaminated with sea water and the heavy deposits on the Naval boilers stated by the authors might have been due in part to the following:—

- (1) Absence of settling tanks in Naval vessels.
- (2) The operation of Naval boilers under extreme ratings and conditions when sudden demands for steam were made, but (and this implied no criticism of Naval practice) under these conditions the combustion might not have been perfect.
- (3) In wartime conditions from which it was assumed much of the particulars in the paper had been obtained, soot blowers had not been used as often as they should, possibly for security reasons.
- (4) The amount of sea water introduced in the furnace with the air, where it was possible to have air heavy with sea water as distinct from sea air.

It would be of great interest, therefore, to the Merchant Navy engineers, if the authors would supply some further information on the foregoing.

Possibly the scope of the paper was not to include the removal of the deposits on the heating surface of the boilers and perhaps it might be of interest to members to learn of various suggestions which had been made for firstly, the elimination, and secondly, the removal of these deposits.

Great care and attention had to be given to the conditions and adjustment of the burners and cleanliness of the atomizing plates, as no doubt, the better the combustion the less chance of deposits. Soot blowers should not be considered an accessory but a vital part of the boiler installation, and treated as such. Furthermore, in the design of boilers, great care should be given to the position and number of soot blowers to be fitted, to ensure that as much of the boiler and superheating surface as possible was swept by the steam.

A proper sequence of using the blowers should be adopted as follows:—

- (1) Air heaters or economizers, to clear exit passages.
- (2) Superheaters.
- (3) Boiler surface.
- (4) Superheaters.
- (5) Air heaters or economizers.

Many suggestions had also been made with regard to the removal of deposits, such as the application of chemicals and spraying and lancing of the superheater surfaces by warm water. It could well be imagined the amount of water it would be necessary to use would find its way between the brickwork and casing plates, and the removal and drying out of this water constituted quite a problem.

It was always necessary to dry out the boilers after washing as soon as possible.

Commander McCloskey suggested, in his paper, that it was possible to remove deposits from superheaters by circulating iced water through the elements and thereby causing a film of moisture between the outside surfaces of the tubes and the deposits which cracked it off. If this was so, there was no question that this was a very simple and clean operation and, furthermore, reached all the surfaces of the superheater elements, and not only part of the surface, as occurred when spraying on the outside, as usually it was only possible to approach the superheater from the furnace side in water-tube boilers.

A further suggestion was, that external washing of the heating surface was done by pumping the boiler full of hot distilled water, and using this via the soot blowers instead of steam. Each blower was operated ten times and from the actual tests of this method it was found that most of the tubes were clean to the bare metal. The results here were, of course, similar to that noted previously

in that the amount of water left in the furnace, and which found its way between the brick work in the casing, was most objectionable. This test was carried out by the ship's crew.

Finally, as it appeared the removal of the deposits was difficult owing to the disposition of the surfaces affected, this could possibly be facilitated if the superheated elements were readily detachable from the boiler.

BY CORRESPONDENCE

Commander (E) L. Baker, D.S.C., R.N. (Member) wrote that the first cases of serious deterioration of furnace refractories and of formation of bonded deposits in the superheater came to his notice in 1941 when two cruisers operating in the North Sea area experienced sudden and serious trouble, resulting in one instance in an increase in the gas pressure loss through the boiler bank to three times its original value.

It was necessary to remove and retube the superheater as no other means were known at this time of removing the deposit. The analysis of the deposit was:—

Vanadium	...	...	...	...	10 per cent
Iron	...	...	...	...	8 " "
Sodium	...	...	...	...	14 " "
Calcium	...	...	...	...	2 " "
Magnesium	...	...	...	...	0.8 " "
Nickel	...	...	...	...	2 " "
Silica	...	...	...	...	3 " "
Carbonaceous matter	...	...	...	...	1 " "
Sulphur	...	...	...	...	15 " "
					as sulphate ion
Chlorine	...	...	...	...	0.2 per cent
Moisture	...	...	...	...	remainder
Soluble in water	...	...	...	...	64 per cent
Fusion temperature	...	...	...	...	710 deg. C.

The slag coating on the floor of the boilers reached as much as 3in. thick and was sufficient to interfere with combustion. At about this time it was proposed in all seriousness from the Fleet that consideration should be given to the design of slag tapping pockets on the boiler floors so that the slag formed could be run off whilst still molten.

He could confirm that oil containing at least 10 per cent water could be burned satisfactorily in the furnace of a boiler; no doubt the authors would recall the occasion during the shore trial of a boiler in 1943 when the explanation of the low efficiency obtained on one day was found to be the very high water content in the particular load of fuel being burned. No signs of the combustion troubles usually associated with water were observed by the many experts present.

The maintenance of brick work, particularly on the sides and back of the furnace reached such serious proportions during the Pacific war that there was at least one ship in which the lining thickness was doubled in order to reduce the frequency with which bricks required renewal.

With reference to the sodium sulphate particles held in the gas stream it should be noted that, although the gas temperature at the exit from the superheater might be 1,600 deg. F., the temperature of a particle of sodium sulphate suspended in a gas stream at that temperature would not be 1,600 deg. F., due to radiation. Indeed, if the particle were held stationary so that the gas heated it by convection to the maximum possible extent, the loss due to radiation would still be of the order of 300 deg. F. This, however, did not detract from the general validity of the argument advanced, but did offer a satisfactory explanation as to why these deposits were never found beyond the superheater zone, since it was quite clear that the temperature of the particle would be well below its melting point at exit from the superheater under all normal conditions of operation of current Naval boiler designs.

Capt. (E) N. J. H. D'Arcy, R.N., M.I.Mech.E. (Member) wrote that he had a period of service in the East Indies just after the war in which his ship covered many thousands of miles at speeds from 20 to 25 knots. He experienced remarkably little trouble with the refractories of furnace walls and floors, and there was no evidence of choking of gas passages through the tube nests. Fuel was obtained from both commercial and Admiralty sources, at least two of which he believed supplied, at about this time, fuel to an aircraft carrier which experienced very severe choking of the gas passages. On no occasion did they flood fuel tanks for stability or other reasons, and that in spite of her age and service the hull of the ship was almost entirely free from leakage from the sea. This would seem to indicate that if modern boiler fuels were kept quite free from salts, serious troubles in the direction of choking and slagging need not be expected.

He would like to sound a note of caution. The authors appeared

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to give all the blame for slagging to salt and none to the metallic oxides. The effects had been observed of iron and its oxides on bricks in the days before the war when they did not try to burn salt water and few worried their heads about vanadium pentoxide. He thought it was still important, even if burning dry fuel, that furnaces should be scrupulously clean and freed from the rust which fell into them during the external cleaning process, and that all uncooled metal parts such as brick bolt heads should be completely protected against the impingement of furnace gases. Oxides from such sources were more likely to cause slagging than those contained in the fuel because the former were in contact with the refractories whereas most of the latter would pass through the tube nests without touching the brick work.

There was a good deal of effort now being expended in developing techniques to burn residue fuels in Diesel engines and in gas turbines. He could not call to mind (in normal designs of either of these two types of engine) any metal part of which the temperature was not considerably below the freezing temperature of sodium sulphate. One could therefore expect if water-oil emulsions were burnt in these engines, deposits on pistons, cylinder heads, exhaust valves and exhaust ports of Diesel engines and at the exit ends of combustion chambers, on turbines and in heat exchangers of gas turbines. This was a point of particular moment for gas turbines when it was remembered that any loss of efficiency in the compressor turbine was approximately trebled at the power output shaft.

It was perhaps not too optimistic to hope that if residue fuels absolutely free from salt were burnt, little trouble from deposits need be expected. Gas velocities in both types of engine were high, and dry ash should be carried through to exhaust if there was no sodium sulphate about to which it could stick.

It seemed essential that fuels must be entirely freed from sea water before burning whether in a gas turbine, Diesel engine or under a boiler. It would have been preferable for many reasons to dry the oil before issue to ships, but unless it could be confirmed that residues which had been dried by "Teepoling" did not re-emulsify when again mixed with sea water, it seemed essential that the necessary equipment for treatment must be carried in ships.

He would like the authors to reply to the following questions:—

- (1) Would fuel dried by Teepol re-emulsify when again mixed with sea water?
- (2) If residues were diluted with distillates would the resulting mixture still emulsify *pro rata* with the proportion of residue in the mixture?
- (3) Was there any falling off in the efficiency of combustion at high forcing rates due to the presence of sea water in the fuel? (This was particularly important from the gas turbine aspect).

Dr. A. S. C. Lawrence (Visitor) wrote that the $\text{SO}_2 + \text{O} \rightleftharpoons \text{SO}_3$ reaction had been discussed frequently with complete disregard for the fundamentals that sulphur dioxide and oxygen only combined at a slow rate and that above 450 deg. C. dissociation set in again was true. In boiler tube deposits, the salt was sodium sulphate and not sodium sulphite. To explain this, it has been assumed that catalysts were responsible. A catalyst by definition and by the second law of thermodynamics could not alter the equilibrium concentration; it acted only by accelerating the rate of equilibration. This appeared to have been forgotten by Mr. Jenkinson. If fly ash acted as catalyst in this manner, it could do so only below the temperature of complete dissociation, and there should be a progressive increase of concentration of sulphur dioxide (or sulphuric acid) in the gases along the decreasing temperature gradient along the flues. None could be formed in the furnace. Another consideration entered here: the gases had a high velocity but, as they carried the catalyst with them, time of contact was the whole time spent in passage between flame and funnel. He had made a rough calculation which made this about 5 secs., a time which should be sufficient for equilibration with an active catalyst below 450 deg. C. if there was sufficient oxygen.

Boilers did not normally burn sulphur dioxide as fuel, and the equilibrium which was concerned was for the systems: CO_2 , CO , H_2O_2 , SO_2 , SO_3 . He suggested that examination of this system might show surprising results, very different from those given by the $\text{SO}_3 \rightleftharpoons \text{SO}_2 + \text{O}$ alone.

When Na_2SO_4 was present, the equilibrium was entirely altered since the liquid salt formation was a continuous removal of oxides of sulphur from the gaseous system in which they would reform in equilibrium proportions. Salt in effect scrubbed sulphur dioxide out of the flame gases and the sodium sulphite must then be oxidized to sulphate. Sodium sulphite itself decomposed between 600 and 700 deg. C. to Na_2SO_4 and Na_2S ; above 700 deg. this reaction seemed to stop and at 900 deg. $\text{Na}_2\text{SO}_3 \rightarrow \text{Na}_2\text{O} + \text{SO}_2$. This latter reaction proceeded very slowly and might be ignored.

The assumption had been made tacitly that all the sulphur was present as SO_2 . If only a small amount remained undissociated, it would account for the deposits found. Burning 1,000 tons of oil containing 2 per cent. of sulphur would produce 88 tons of sodium sulphate; 1 per cent. of seawater in 1,000 tons of oil would contain sufficient sodium only to form 0.3 ton of deposit. These figures showed that only a small amount of total sulphur was trapped as bonded deposit, and suggested that bad cases required well above 1 per cent. of sea-water.

Taking the summer figure for suspended matter in the air above large cities, the total in the air entering a boiler during the burning of 1,000 tons of oil was only about 10lb. This did not include the extra salt which might be found at sea under conditions of low humidity, but it did show that the large mineral secretions in furnaces originated in the ship.

He saw no reason why water in the oil should affect its primary combustion, nor that any difference should be seen at the funnel. The most time-consuming factor and difficult part of this work had been to persuade users of fuel oil that their oil was contaminated by seawater when all the tests known to them showed that it was dry. He thought that the interest shown in this paper was a clear sign that the meeting had served a most valuable purpose in removing a false sense of security resulting from reliance upon obsolete tests.

Lt. Com'r (E) H. S. Salt, R.C.N. (R) (ret.), (Member) wrote that although the cases cited by the authors were for the larger type of warship, they could be assured that similar conditions were encountered in the Royal Canadian Navy in frigates, corvettes and mine-sweepers.

Parallel with investigations as to the cause, every effort was made to prolong the life of the brickwork in spite of the slag formations being encountered. Where side wall bricks of size 18in. by 9in. (Admiralty Pattern Nos. 32, 33, 386, etc., Plain or Wildish) were used, breaking of the bricks usually occurred quite early in operation. When two 9in. by 9in. (Admiralty Pattern Nos. 21a, 24, 25, etc.) were substituted for each 18in. by 9in. brick, heavier slag formations were carried without breakage.

To eliminate, as far as possible, side wall slag formations, and consequent spalling, new brickwork was given a "spraying" process. The material used was "Super-Thermo-Stucco", a high grade refractory plastic; it was diluted slightly with pure fresh water, and applied by means of an air gun using 100lb. per sq. in. compressed air, and resulted in skin penetration of dry brick to a depth up to $\frac{1}{4}$ in. This plastic had high non-slagging and non-spalling properties, but while side wall slagging was cut down considerably the condition noted by the authors as regards molten slag on the furnace floor still existed. Cast Quarls were substituted for the usual throat assemblies (Admiralty Pattern Nos. 391 to 394 and 395 to 398), the material used being a dry refractory castable and going under the trade name of "Kast Set". These were cast in special sheet iron moulds, and prior to installing were wash coated with diluted "Super-Thermo-Stucco". This type of throat assembly outlasted all standard R. N. and R. C. N. brick types, and was highly resistant to carbon and slag formations and spalling.

Brick failures, due to slagging, would, as the authors pointed out, probably continue and in this respect it was suggested that the Admiralty could well give attention to simplifying their present brickwork designs.

In the case of Tribal Class destroyers, the original drawings supplied by the R.N. to the R.C.N. listed twenty-four separate Admiralty Pattern numbers of bricks for each boiler installation. U.S. practice for boilers of a similar type would call for only four separate pattern numbers (U.S.) and the probable use of plastic throats.

The Authors' Reply to the Discussion.

The Authors' Reply to the Discussion

Eng'r Rear-Admiral C. J. Gray and Mr. Wycliffe Killner wrote in reply that before dealing with individual contributions to the discussion they wished to emphasize that the paper dealt exclusively with the troubles experienced in H.M. ships during the war period when burning fuel oil.

From references made by some speakers it would seem that the problem was regarded as one of bonded deposits experienced when burning coal to be similar to those described in the paper. The cases were, of course, entirely different, and although the importance to engineers of the effects obtained when burning coal were fully realized, they were not in a position to discuss this aspect.

Admiral Brown's remarks were appreciated; he outlined the manner in which the problems presented themselves, which was of great value to the paper as it gave an insight to the problem from an angle which the paper did not deal with fully.

In reply to Mr. Campbell the figures recorded in Table I for viscosity at 70 deg. F. and 100 deg. F. were correct.

The suggestion that the cause of emulsification was the copper and zinc salts of naphthenic acid was unacceptable for several reasons. Higher temperatures of cracking did not produce correspondingly high yields of naphthenic acids; full emulsifying power was shown by fuel oils containing no organic acid. If the origin of the zinc and copper was that suggested by Mr. Campbell, 100 tons of emulsion containing 20 per cent of water would require to have consumed something of the order of a hundredweight of assorted brass fittings.

All combatant ships of the Navy, even down to corvettes, obtained the whole of their water for domestic purposes and make-up feed from evaporating plant, except when it was convenient to replenish the limited storage capacity from shore.

The water drops in emulsion were not micelles. There was no charge on the water droplets in the systems which they examined although the literature frequently stated that there was. They knew of no case in which phase change had been recorded in an emulsion by changing the sign of the charge.

Brownian movement was described in the larger books on colloid chemistry; e.g. Freundlich's Colloid and Capillary Chemistry.

If the water was all finely emulsified and there were no large "slugs", it was known that no spluttering would occur at the sprayers up to a water content of at least 12 per cent.

They had not had any experience with chrome-ore refractories.

There was no reason why there should be any carbonaceous matter associated with deposits on boiler tubes. Sodium sulphate was not hygroscopic under normal conditions: on the contrary, the decahydrate effloresced normally since its equilibrium vapour pressure was higher than that normally present in the atmosphere. The anhydrous salt absorbed water to form the hydrate, which existed below the temperature of 32.4 deg. C. The conditions for McCloskey's treatment by circulating iced water through the tubes necessitated that humidity in the furnace must have been maintained as high as possible by a supply of steam, but that the temperature of the deposits to be dissolved must not be allowed to exceed 32.4 deg. C.

In reply to Mr. Campbell's questions, firstly they regarded all heavy fuel oils as likely to emulsify and secondly they could not state the maximum water content burnable. Trials carried out at Haslar showed that an oil containing 25 per cent of water could still be burnt, although the combustion was unsatisfactory and there was much evidence of the presence of water at the burners.

The method of determining the water content in the emulsion developed and used by themselves might have been a little lengthy, but it was not particularly complicated, and had been used extensively at sea in certain ships. It had, at any rate, the virtue of giving correct answers, and so far as was known no other instrument of this nature for use at sea existed.

The production of an instrument to give instantaneous readings had been under investigation for some time.

The ratio of the sodium and magnesium found in bonded deposits was, in general, in the same proportion as that found in sea water.

Mr. Jenkinson had referred to the simple nature of the deposits with which they had dealt. It was fortunate for them that these deposits were simple ones and not complicated like the ones dealt with by Messrs. Rylands and Jenkinson. They complimented Mr. Jenkinson on his and Mr. Rylands' very excellent piece of work, and added that they themselves were in agreement with those findings.

They pointed out that their own problems were associated with the burning of fuel oil, and that these problems differed entirely from the problems met with when burning coal.

Mr. Martin seemed to assume that emulsification troubles were due to increase of viscosity *per se* and therefore that cracking was not necessary for the appearance of the trouble. The first assumption was not correct, although a certain minimum viscosity was re-

quired for easy emulsification. Cracking greatly aggravated emulsification but was not essential so long as the oil contained enough asphalt. They knew of no sound theories behind the use of phenolic substances to break emulsions. The statement that they merely had a viscosity reducing effect, achieved equally well with gas oil, was incorrect.

A short trial was carried out in the summer of 1947 in a battleship in which all the oil fuel to one boiler was checked throughout for dryness. In the absence of water contamination a number of new firebricks fitted for the trial showed no signs of glazing, and no noticeable deposits formed on the tubes.

Boilers steamed on shore at the Admiralty Fuel Experimental Station, where the oil was dry and the possibility of contamination of the fuel oil by sea water did not exist, had not formed deposits over a period of several years steaming.

Mr. Logan's remarks took a form to which they had become familiar throughout this work; "We have had no trouble with our oil but . . ." followed by a description of the trouble. This was almost invariably due to reliance upon methods for detecting water which failed when the water was finely divided as it was in true emulsions.

Many cases of slagging similar to that referred to had been found in several of H.M. ships. In a ship recently examined 4½ inches of hard glass-like slag was found on the floor of the furnace; underneath this the floor bricks were found to be intact, but the slag had penetrated into the upper layer of them. In such cases it was obvious that the slag was the result of chemical reaction between refractories and materials which had found their way into the furnace. Although there might not have been difficulty in burning the fuel oil, and no sea water contamination of the fuel oil was found, the sodium compounds present in the slag suggested that sea water had at some time got into the furnace and, together with the iron compounds, reaction with the furnace refractories had taken place which had resulted in slag formation. Many cases had been met with where the slag formed on the furnace walls had run down to the floor forming a molten mass. In reply to Mr. Logan's queries they would suggest pouring the Teepol through any available opening, and agitate it if possible. With regard to the quantity, there was a maximum which should not be exceeded.

Reference had been made to the work of L. C. McCloskey, and it was agreed that McCloskey's deposits were similar to those dealt with in the paper, in that the major portion consisted of sodium sulphate and, because of its solubility in water, McCloskey found that the deposits could be removed by water washing.

McCloskey advanced a theory that the incidence of these deposits was due to incorrect burning of the fuel oil, allowing unburnt fuel to reach the superheaters where it was cracked or vapourized, leaving a sticky surface which collected ash from the fuel oil burnt, and this unburnt fuel was suggested to be the bonding agent. He appeared to neglect the high percentage of sodium salts in the deposits and the part they could play in the building up of the material to choke the gas passages. If McCloskey's theory was correct then these bonded deposits must build up when dry oil was burnt, and the sodium salts which constituted the bulk of the deposits were of no consequence, except to add bulk to them, but this was not the case. The sodium salts were an essential feature, in that they provided the sticky surface, and without them the bonded deposits found on the superheaters in H.M. ships did not form. There was only one possible source of supply of such large quantities of sodium salts found by McCloskey, and that was sea water contamination of the fuel oil.

Replying to Dr. Crossley, reference had already been made to the high iron content in sample C. Samples A, B and C were quoted to show the difference in their characteristics, and to show a case in the early stages of slagging, where the sodium salts were present largely uncombined with the firebrick. The dark glass-like slag from cruiser Z was a typical finished slag and showed the sodium compound in combination with the constituents of the firebricks, and it would be noted that the amount of iron present in this sample was very much less than in sample C.

It was agreed that the binding agent in the bonded deposits contained pyrosulphates. They had not been able to carry the investigation to such a point as to enable them to do more than suggest the mode of formation of these bonded deposits. Sufficient information had, however, been obtained to enable them to state with some degree of accuracy whether a deposit had come from the fire rows, superheater or economizer, and this information supported the mode of formation which was suggested in the paper.

With reference to Mr. Culver's contribution, they did not think the metal temperatures accounted for the more frequent choking of superheaters in comparison with generator tubes. The information

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available seemed to indicate that the size of the molten particles appeared to be a factor which exercised a controlling influence on where they would deposit. The ones which were relatively large, and therefore less influenced by the gas stream, were more likely to hit the generator tubes and the smaller they were the further they were carried in the gas stream, provided they were not caught by a sticky surface. When oil heavily contaminated with sea water was burnt, deposition on the generator tubes was found to have taken place.

As these deposits were bonded they could not be removed by soot blowers of any type.

The soot blowers fitted in H.M. ships were of the single nozzle type. They had no record of the soot-blowing routine carried out by the various ships, but it was possible that this varied considerably and was probably affected by operational considerations in war-time.

They did not understand Mr. Thorpe's complaint of the simplicity of their treatment of the mechanism of the chemical reaction leading to the formation of sodium sulphate.

They considered that the layering of deposits was not general, although, of course, it might have occurred on changing the type of fuel being burned.

Referring to Mr. Aikman, the high iron content of sample C was abnormal, and no doubt due to adventitious iron from inside the furnace and not from the ash of the fuel oil used. They were most concerned about the large amount of iron appearing in some cases.

They did of course, realize that the dripping of a brick bolt head or other iron part could cut a deep gutter through its own brick and through those below it, but this was a local action, and the type of slagging referred to in the paper was of a more general type.

The questions raised by Mr. Sefton would be answered in the forthcoming paper by Dr. Lawrence and Mr. Killner.

In reply to Mr. Richardson, the use of settling tanks did not solve this particular problem, for once sea water had become emulsified in fuel oil the emulsion remained stable until suitably treated with a wetting agent.

The operating conditions of boilers in H.M. ships under extreme ratings and conditions when sudden demands for steam were made were simulated during the extensive shore trials of prototype boilers, and also when steaming the experimental boilers at the Admiralty Fuel Experimental Station, and no signs of bonded deposit formation had been found.

It was possible that in some cases soot blowers might not have been used as often as they should, but these bonded deposits were of

They agreed with the comment about air intakes wet with sea water, and were looking into this matter as well as the opposite case of air, under very dry conditions, carrying fine suspended crystals of salt.

such a nature to allow them to accumulate despite frequent and regular operation of soot blowers.

The removal of these bonded deposits was a troublesome matter but it had been carried out successfully in H.M. ships by water-washing.

It was of course, necessary to protect the furnace brickwork as much as possible, and to drain off the surplus water; further the subsequent lighting up of the boiler should be done slowly to give the bricks time to dry out. If time permitted the use of drying stoves was recommended.

They agreed with the remarks on the positioning and the use of soot blowers, but would point out that the boilers of naval vessels, except for the most modern, fitted with economizers, were only supplied with soot blowers in the furnaces.

With reference to the many questions about the emulsion problem and the investigation work which had been carried out, Dr. Lawrence and Mr. Killner had prepared an account of this work for publication in the near future the subject being so large that justice could not be done to it in short answers.

By 1943 it was recognized that this was a highly specialized problem of surface chemistry and colloids, the services of Dr. Lawrence were therefore obtained through the Admiralty Chemical Advisory Panel. This co-operation resulted in an exhaustive enquiry into the nature of emulsions and their treatment.

In brief, the cause of the emulsification was found and the mechanism of breaking emulsion by the addition of wetting agents made clear. It therefore became possible for the first time to lay down a procedure and dosage determined by the measurable properties of each emulsion and wetting agent. The general conclusion reached was that *any* wetting agent would break *any* emulsion (provided there was a difference of density between the oil and water) unless there were substances present, other than water and oil, which might react with the wetting agent and inactivated it. They were led to the conclusion that the idea of specificity of particular wetting agents for particular oils was without foundation and that any such apparent effects were actually due to unrecognized adventitious im-

purities. Teepol was used in most of their experiments, not because it was the only wetting agent which broke these emulsions, but mainly because of the co-operation of the makers in the matter of supply. The process of breaking emulsions should not, therefore, be called "Teepolizing" as had been suggested. These conclusions arose from a very large amount of work carried out in the laboratory and successfully applied on a large scale.

Commander Baker's experiences were similar to their own. The case quoted of the shore trial of a boiler in 1943 was well recollected. In this case a boiler efficiency trial was in progress and an unexplained drop in the efficiency was eventually traced to a water content in the fuel of 8 per cent. As stated by Commander Baker the presence of this quantity of water was not indicated by any change in the quality of the combustion, nor was there any evidence of trouble at the burners.

They were glad to have confirmation from such an experienced sea-going officer as Captain D'Arcy that troubles from slagging and choking need not be feared if the modern boiler fuels were kept quite free from salts.

It was essential that furnaces should be scrupulously cleaned and freed from rust, and that all uncooled metal parts, such as brick bolt heads, should be completely protected against the impingement of furnace gases. Iron oxide was not appreciably corrosive in an oxidizing atmosphere, but under reducing conditions formed silicates, which were highly corrosive. Replying to Captain D'Arcy's questions they wrote that:—

- (1) When a wetting agent was used to break an emulsion it passed into the water and the dry oil recovered would emulsify with a fresh lot of sea water.
- (2) Diluting residues by distillates might have reduced troubles somewhat but it might also have increased them. Dilution without complete knowledge of the composition of both residue and distillate was dangerous and not to be recommended.
- (3) There would, of course, be a falling off of combustion efficiency in so far as the heat released from a measured quantity of contaminated fuel was concerned, the falling off being in proportion of the percentage of water present. Beyond this it was doubtful if small quantities of water would have much effect on burning efficiency.

They read with much interest in Commander Salt's contribution that similar troubles were experienced in the Royal Canadian Navy. They also noted the steps taken to minimize the deterioration of furnace refractories.

CORRESPONDENCE

The Burning of Boiler Fuel in Diesel Engines

By JOHN LAMB

Mr. W. A. Green wrote that his personal concern was chiefly with the problems arising in connexion with the injection of heavy fuel oil into the engine cylinder.

The author had demonstrated that the two essentials to enable such fuel to be burned efficiently were firstly super centrifuging and secondly to maintain the temperature of the fuel at such a figure that its viscosity approximated to that of normal Diesel fuel at ordinary temperatures.

In view of the comparatively small rate of flow of fuel to the individual cylinders it seemed likely that its temperature when actually passing through the nozzle orifice was determined by that of the nozzle rather than by that of any pre-heating it might have received. He would therefore suggest that both Diesel fuel and the heavy oil were at very nearly the same temperature when actually injected. Their behaviour in the combustion chamber would therefore be different. This would support the author's statement on p. 4 that there were indications of reduced atomization with Admiralty fuel.

The author and Mr. van Asperen of Messrs. Werkspoor had given him some figures relating to the fuel injection pump and its cam, from which he had calculated that the discharge velocity from the nozzle was about 200 metres per sec. They had found on engines of medium size, running on pool gas oil, that a better figure was 300 metres per second.

They had further determined by experiment the relationship between nozzle orifice diameter and the penetration of the resulting spray in the combustion chamber. These results were embodied in Fig. 35.

Scaling from Fig. 2 and using Fig. 35 he would have selected a nozzle orifice diameter of 0.7 mm. This would have the effect of raising the calculated discharge velocity to approximately 300 metres per sec., and as the author stated on p. 11, better results were

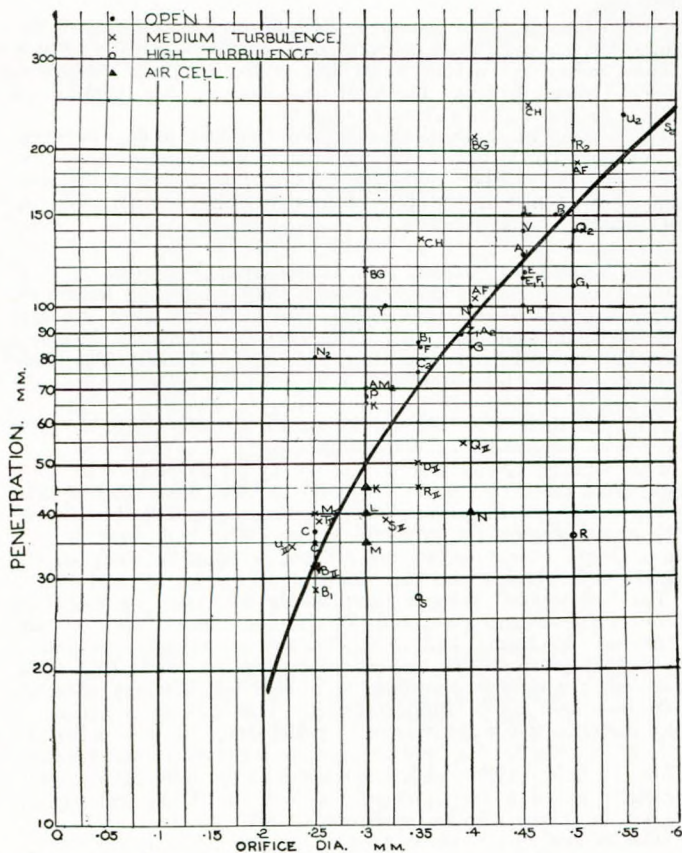


FIG. 35.—Effective spray penetration and orifice diameter of nozzles for internal combustion engines

actually achieved with such a nozzle. With Diesel fuel he would expect the corresponding injection pressure to be about 7,000lb. per sq. in.

Since the boiler fuel actually used was heated to bring its viscosity to that of Diesel fuel the increase of pressure should not be very great.

The author mentioned that the high-pressure filters were found to set up a back pressure of 1,000lb. per sq. in. and were later removed. This suggested that there might be serious parasitic resistance elsewhere.

The author told him that the fuel delivery pipes were of 6 mm. bore. The corresponding flow velocity would be 33.5 metres per sec. They preferred to keep this velocity below 30 metres per sec. and he suggested that delivery pipes of 7 mm. or 8 mm. bore might have reduced the pressure at the pumps to an acceptable figure.

Another possible point of resistance was at the seat of the needle valve. Judging from Fig. 4 the nozzle was of standard design internally, in which case the flow area at the seat would be 7.4 sq. mm., with a needle lift of 1.5 mm. In comparison the orifice area was 4.5 sq. mm. and the restriction at the needle seat seemed to be undesirably high. Possibly a modified nozzle design would improve matters by reducing resistance at this point and thus raising the pressure at the orifice and improving the atomization.

Incidentally, the author stated on p. 11 that no simple means was available to measure the maximum injection pressure. This made him ask whether the author was familiar with the Bosch maximum pressure indicator. It was similar in general principle to the well-known Okill maximum pressure indicator for use in engine cylinders. It could be made up from a standard injection nozzle and could be calibrated statically against a pressure gauge.

Mr. G. J. Lugt of Werkspoor, Amsterdam (Visitor), wrote that since the reading of this paper the new Werkspoor two-cycle supercharged engine had been subjected to a test of two periods of 120 hours each continuous running on boiler oil of the same properties as used on the M.S. Auricula.

At the end of the first period the injectors were taken out and photographed (Fig. 36) and the wear of the piston-rings was

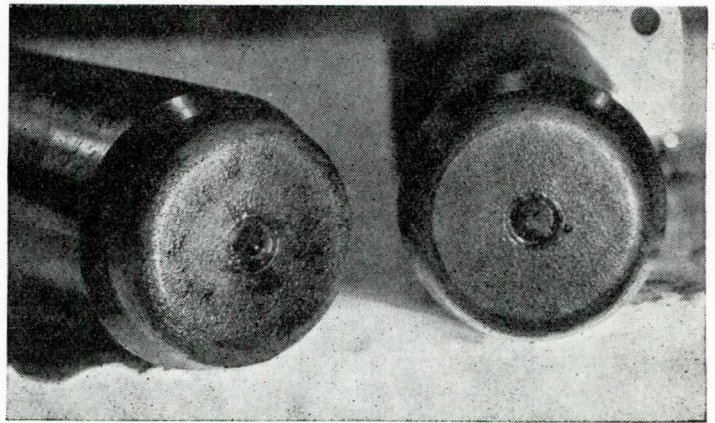


FIG. 36.—View of the injectors after 120 hours running.

measured by gauging the gap. As could be seen from Fig. 36 the tips of the injectors remained quite clean and after the second period still showed no signs of any carbon formation worth mentioning. The wear of the rings was negligible. In opening up the engine no carbon or sludge of any description was found which he thought might safely be attributed to the straight-through scavenging system and to the high scavenging (supercharging) pressure which kept the crank-case oil from travelling upwards along the cross-heads and the pistons. The lubricating samples taken before and after the test showed hardly any difference in composition and specific weight.

At the mean indicated pressure of $7\frac{1}{2}$ kg. per sq. cm. (106lb. per sq. in.) the exhaust was absolutely invisible throughout the test and he felt certain that if the fuel-pumps had permitted it, a higher load could have been carried safely. A modification should be made to the temporarily fitted turbo-compressor as it was intended for a four-cycle Buchi supercharged engine, so as to make it entirely suitable. This arrangement made it impossible to bring all the available energy in the exhaust gases to good use. A compressor working at the point of its highest efficiency would be able to give more air at a higher pressure. With a new runner fitted it might reasonably be expected that the mechanical efficiency of a 6- or 9-cylinder engine would increase to about 90 per cent. This remarkably high figure could be attributed to the very small friction losses (no camshaft, chain or gearing) and to the fact that a large part of the task of the scavenging-air pumps had been taken over by the turbo-compressor.

This test was considered as an irrefutable proof that this engine was fully qualified to run on boiler oil provided the oil was treated before its use as indicated by the author and kept at 75-80 deg. C. during the running.

A special arrangement of the fuel-pumps and the fuel-valves made the dual system of boiler oil for ordinary running and Diesel-oil for starting and manoeuvring entirely superfluous. This feature simplified the installation considerably, the only addition to it being the purifying and clarifying, and the heating apparatus.

Finally the engine was subjected to a slow running test of six hours duration. Slightly more soft coal deposit was found on the injector tips and all the holes were open but the deposit burned away clearly when the engine was fully loaded for a short time.

Mr. John Lamb in reply to Mr. Green wrote that if he correctly interpreted the meaning of the fourth paragraph, the reasoning was that the temperature of the fuel valve nozzle or atomizer controlled the temperature of the fuel passing through the atomizer holes. Such might be the case when the engine parts had reached their normal working temperature, but when operating the "Auricula's" engines at a reduced output it was demonstrated that the atomizer needle did not re-seat so smartly when running on the more viscous fuel as when running on the lighter Diesel fuel, hence the deposit found between the atomizer tip and the exhaust valve pocket.

The atomizer in use was of the usual CAV/Bosch pattern in which the cooling water was carried to within a very short distance of the atomizer holes. The efficient cooling of this part did affect the viscosity of the fuel passing through the atomizer holes. As shown in Fig. 19 of the paper, he was arranging to pre-heat the fuel valve with hot water when running at slow speed on viscous fuel, solely to allow the atomizer needle to re-seat as smartly as when the engine was operating on Diesel fuel under similar conditions.

Mr. Green had apparently missed the point regarding the reason for pre-heating the fuel, as the main purpose for pre-heating the

Additions to the Library

heavy fuel was not to assist atomization, but to reduce the excessive pressure encountered in the fuel delivery piping and fuel pumps.

Regarding discharge velocities, whilst he did not doubt that for a particular medium sized engine operating on gas oil the velocity of 300 metres per second might be more suitable than the 200 metres per second used in the "Auricula's" engine, he considered that the results obtained during his experiments did not justify any alteration of the existing fuel pump operating cams.

He viewed with some concern the suggestion to increase the velocity of heavy fuel sprays by as much as 50 per cent, as it was not improbable that the increased penetration resulting might cause the fuel sprays to strike the crown of the piston, bearing in mind the slower burning rate of this grade of fuel.

Tests carried out with an atomizer having 0.737 mm. diameter holes showed that maximum injection pressures were considered too high for the existing fuel pump operating gear. The actual injection pressure for the 0.737 atomizer using Diesel oil was 5,000 lb. per sq. in. He agreed that larger bore fuel delivery pipes might prove an advantage, but as the small clearance strainers were serving no useful purpose, all fuel having been purified before it reached them, their retention was superfluous and removal brought about the desired reduction in pressure.

Originally, the lift of the atomizer needle in use on the "Auricula" was 1.0 mm. Several tests were carried out using different lifts, and it was finally decided to standardize on a 1.5 mm. lift. The tests revealed that there was no marked difference in the maximum fuel pressure when the lift exceeded 1 mm., and the reason for adopting 1½ mm. was to provide a margin when burning more viscous fuels and to allow for any slight inaccuracies during manufacture.

So far as could be established by practical means the needle valve seat did not produce any undue resistance to the passage of the fuel.

The instrument ultimately placed on board the "Auricula" for recording maximum fuel pressure worked on the same principle as the Bosch indicator mentioned by Mr. Green. The instrument provided a useful guide to the conditions prevailing in the fuel delivery system, but as the results depended largely upon the individual operator he would much prefer an instrument, in the operation of which the human element did not play a major part.

Finally, whilst conducting his experiments he had to keep in mind the large number of existing engines which would have to be provided with suitable gear to fit them for burning viscous fuel oils, and his aim was to keep the cost for such gear at a minimum. He agreed that the combustion efficiency might be very slightly improved by the introduction of re-designed parts, but the performance of the "Auricula" engine had shown that such modifications could be little more than refinements and were not in his opinion justified.

In reply to Mr. Lugt he wrote that the two tests of 120 hours each, with the new two-cycle engine operating on boiler fuel purified in the manner recommended by him, were most interesting. Having followed these tests very closely he could confirm that continuous full power running with this type of engine on boiler fuel without any mechanical difficulty arising could be confidently expected.

The supreme test when running on boiler fuel was, as mentioned in the paper, when running at reduced power, and as it very often happened that dead slow running for periods longer than six hours was necessary it would be interesting to know how long this engine would run at about half-rated power before the accumulation of deposit on the injector tips became so great that the fuel sprays and consequently combustion were adversely affected.

JUNIOR LECTURES

THE COMBUSTION TURBINE

At the Junior Section lecture on "The Combustion Turbine" given by Mr. J. Calderwood (Member of Council) at the L.C.C. School of Engineering and Navigation on Monday, 9th February 1948, the chair was taken by Mr. W. Laws, the Principal of the college.

There were over 150 students present, including many marine engineers studying at the school for their certificates, who were thus enabled to listen to a description, and take part in a discussion, on what may be the marine engine of the near future.

Mr. Calderwood, after giving an outline of the history and development of the combustion turbine, described in detail a high pressure dual cycle, being a combination of both open and closed circuits. He then had to answer a large number of leading questions which provided a very interesting discussion.

Mr. T. A. Bennett (Member of Council) proposed, and Mr. T. W. Longmuir (Member) seconded a vote of thanks to the lecturer, which was carried with acclamation, and a very pleasant evening ended with a vote of thanks to the chairman.

On Wednesday, 18th February 1948, under the auspices of the Institute, Mr. J. Calderwood (Member of Council) presented a lecture on "The Combustion Turbine" to students of the Merchant Venturers' Technical College, Bristol. The chair was taken by Rear Admiral(E) G. H. H. Brown, C.B.E. (Vice-President).

The meeting was not well attended, due, no doubt, to the extremely cold weather. The lecture was given in an interesting and instructive manner, and the number and scope of questions asked at the conclusion showed that it had been followed with close attention by those present.

MARINE LUBRICANTS AND LUBRICATION PRACTICE

On Thursday, 26th February 1948 a very interesting lecture on "Marine Lubricants and Lubrication Practice" was given by Mr. G. M. McGavin and Mr. H. J. Nicholson, M.I.Mech.E. (Member) at the Municipal Technical College, Bootle, Liverpool. The chair was taken by Mr. John Cormack, B.Sc., M.I.E.E. (Principal of the College).

Although there was only an attendance of thirty, Mr. McGavin presented his lecture with much enthusiasm.

The lecturer briefly traced the history of lubricants in three phases, from the early days of mankind to 1850, from 1850 to 1895, and from 1895 to the present day, showing how with the advance of the marine engine, the problems of lubrication had changed from quite a simple operation to a very complex scientific study of the modern marine engine and the necessity of correct lubrication.

The "oil wedge" principle was simply illustrated by means of sketches. The various characteristics and qualities of lubricants and the use of detergents and inhibitors was explained. Interesting figures were given of the present production of lubricating oil in U.S.A. and the estimated production in 1950 which was a reflection on the increased use of lubricating oil. The lecturer concluded by giving the reasons for the present world shortage of lubricating oils.

Following the lecture, several questions were put to and answered by Mr. Nicholson, who while professing to be "only a five eight engineer" showed a very profound knowledge of the subject, and fully satisfied those who had questions to ask.

The proceedings were brought to a close by a hearty vote of thanks to Mr. McGavin and Mr. Nicholson.

JUNIOR SECTION DANCE

Although the attendance was greatly below that of the previous occasion, those members and friends who attended the third and last dance of the session, spent an enjoyable evening at the Institute on Saturday, 21st February 1948. Stanley Bloomfield's Band was in attendance, and Mr. F. D. Clark (Associate Member) performed the duties of M.C.

ADDITIONS TO THE LIBRARY

Presented by the Publishers

Modern Oil Engine Practice

(Third Edition). By J. H. Chaloner, C. B. M. Dale, B.Sc., M.I.Mech.E., H. C. Lawrence, C. H. Paulin, M.I.Mech.E., M.I.Mar.E., T. D. Walshaw, B.Sc.(Eng.), D.L.C.(Hons.). Edited by E. Molloy. George Newnes Limited. London, 1947. 662 pp., with over 500 illustrations, 30s. net.

This very informative book of reference has certainly been kept up to date in the 1947 issue. Each section is written by an author who has a special knowledge of the plant described, giving full particulars in most cases of the main features in construction which, in his opinion, are of outstanding merit.

Most of the manufacturers' running and maintenance instructions are quoted separately, so that much good advice and many recommendations are repeated, but naturally opinions disagree on some points. Some of the particulars given could be obtained from manufacturers' instruction books, but being gathered together in this volume with other information it is available in a very convenient form.

The development of the different types of engines is well set out in a practical form, cutting out the theory and formula element to a large extent.

The chapter on torsional vibrations deals with this important problem in very clear and understandable language. It is rightly emphasized that this matter should be considered in all types of installations.

The whole work is of great use to anybody interested in what is being done in the Diesel field, as stationary, marine and automobile type engines are all discussed upon. How to maintain efficiency and avoid trouble is dealt with in detail, although it is feared that most users do not find time to do all the checking and dismantling recom-

mended by the manufacturers in the section on routine inspection and maintenance.

Modern Air Conditioning, Heating and Ventilating

By Willis H. Carrier, E.E., D.E., Board Chairman, Carrier Corporation, Syracuse, N.Y., Realto E. Cherne, B.M.E., District Chief Engineer, Carrier Corporation, Syracuse, N.Y. and Walter A. Grant, A.B., B.S., M.E., District Chief Engineer, Carrier Corporation, Philadelphia, Pa. Sir Isaac Pitman & Sons, Ltd. London, 1946. 538 pp., profusely illustrated with charts, diagrams, examples and tables, 25s. net.

This publication was first issued in December 1940 and since then has been used as a standard reference book for air conditioning engineers and students. The authors have had very wide experience in air conditioning as applied in the United States of America, and the data and information given in this work are therefore of extreme value.

The general principles underlying all applications of air conditioning are thoroughly discussed and illustrated, but as is usual with books on this subject, the problems which are dealt with and the data given are applicable only to buildings. For example, in Chapter 12, which deals with the design of duct work, it would not be possible to apply the information given to installations on board ship as the cross-sectional area of the ducts suggested could not be accommodated in the average vessel, and any marine engineer endeavouring to apply the fundamental principles as outlined would encounter considerable difficulty from a practical point of view. In Chapter 4 the authors deal with the economics of applying air conditioning, and while their approach is valuable from the point of view of a normal building problem, it could not be readily applied to the same problem on board ship, despite the fact that the fundamentals such as are outlined on pages 60-61 are applicable in both cases.

While appreciating, therefore, the immense value of this publication to different applications, certain data given may create a false impression if applied to problems within the province of the marine engineer.

The Junior Institution of Engineers Journal and Record of Transactions

Volume LVII. Sixty-Sixth Session, 1946-47.

Bulletin de l'Association Technique Maritime et Aeronautique

Bound Volume No. 46—Session 1947.

Munro's Engineers' Annual, 1948

James Munro & Company, Ltd., 16 Carrick Street, Glasgow, C.2. 159 pp., illus., 3s. 6d. net.

This is the thirty-seventh edition of the annual and to borrow a preface from one of this publisher's best sellers, "A technical book that runs into thirty-seven editions requires no preface"!

This has always been a popular booklet among sea-going engineers and its natural home is on the short bookshelf at the foot of the bunk. It contains as usual selected articles and lectures on subjects of interest to the marine engineer, notes on the Ministry of Transport examinations, and useful tide and other tables.

The illustrations are well reproduced and altogether it is what one would expect from a publisher of such long and varied experience.

The Motor Boat and Yachting Manual

(Fourteenth Edition). By the Staff of "The Motor Boat and Yachting". Published for Temple Press Ltd., Bowling Green Lane, London, E.C.1, by The English Universities Press, Ltd. London, 1948. 334 pp., 185 illustrations, 8s. 6d. net.

This edition of what has come to be an extremely popular book originally conceived some twenty years ago has been so extensively re-written as to present what is virtually a new volume.

It is not a book which makes much appeal to the experienced motor boat owner or yachtsman nor to the established boatyard or engine builder.

The chief appeal is directed to the yachtsman and amateur boat-builder in the elementary and secondary classes. As such, the manual serves a useful purpose in expounding the basic principles of hull design, boat construction and installation of machinery, and prospective owners will doubtless find considerable food for thought in considering the various alternatives which are expounded.

The book also contains plans and building instructions for six various types of small boats including a cabin launch, a runabout and a hydroplane.

Other chapters include a description with photographs of a selection of light coastal force craft as built for the 1939-45 war, and also chapters on propellers and propulsion systems, transmission, navigational hints for small craft, sailing and sail plans, and a new chapter

on the legal aspect of motor boating. Selected lists of models produced by most British manufacturers are detailed in respect of petrol, paraffin, high-speed Diesel and outboard engines, and the book concludes with comprehensive lists of Yacht Clubs and boatyards around the British Isles.

Elementary Fluid Mechanics

(Second Edition). By John K. Vennard, Associate Professor of Fluid Mechanics, Stanford University. New York: John Wiley & Sons, Inc. London: Chapman & Hall, Ltd. 1947. 333 pp., 198 illustrations, 24s. net.

This book provides a study of the subject of hydraulics taking account of the knowledge of fluid mechanics obtained from developments in the related field of aero-dynamics.

Early chapters deal with fundamentals and fluid statics and the book proceeds to deal with flow phenomena of an ideal incompressible fluid interpreted in terms of flow patterns, although the mathematics of potential flow are omitted. The principles of compressible flow are illustrated by the flow of such fluid through nozzles. This is followed by a useful chapter on the momentum principle as applied to jet reaction etc. leading to a simple treatment of the theory of water turbines and pumps. The difference between the flow of an ideal fluid and an actual fluid are stressed. The actual flow in pipes and open channels are then dealt with in detail. The book then discusses the principles of similarity and concludes with a description of fluid measurements and an account of the lift and drag arising from the flow past immersed objects.

A useful feature of the book is a bibliography leading to more advanced study. A number of numerical examples are given throughout the text, but the value would have been greater if the answers had been given to the problems.

The book represents a first course in hydraulics of University standard and should provide a very useful introduction to more advanced and more mathematical works on the same subject.

Theory and Practice of Alternating Currents

(Third Edition). By A. T. Dover, M.I.E.E., A.A.I.E.E., Head of Electrical Engineering Department, Battersea Polytechnic, London. Sir Isaac Pitman & Sons, Ltd. London, 1947. 586 pp., 326 illustrations, 25s. net.

The original intention of the author, when undertaking this work, was to write a single volume general textbook dealing with the theory and practice of alternating current electrical engineering. As the work progressed, however, it was realized that the scope of the subject was too great for adequate treatment in a single volume. Accordingly, the volume is devoted to general principles, circuits, polyphase systems, non-sinusoidal wave-forms, the magnetization of iron, instruments, measurements, and an elementary treatment of the initial conditions in the simpler electric circuits.

The author is of opinion that a thorough grounding in the principles of alternating currents is essential before proceeding to the study of alternating current machines and apparatus. This portion of the subject has, therefore, been treated on a broader basis than is the case in some textbooks.

In connexion with the worked examples in the text, analytical, graphical and complex algebraic methods of solution have been employed. In some cases alternative methods of solution are given in order to show the student the steps involved in the application of the alternative methods.

In the present (third) edition of this book new chapters have been added dealing with single-phase transformers, three-phase transformers, single-phase and polyphase alternators, three-phase induction motors, transmission circuits, symmetrical components.

The original text has been revised and the collection of examples (with answers) has been extended. These examples, which are additional to the worked examples in the text, now comprise 250 numerical exercises, and have been carefully selected and graded. They have been taken mainly from the examination papers of the University of London [B.Sc.(Eng.)], Institution of Electrical Engineers, and City of Guilds of London Institute, but exercises suitable for National Certificate courses have been included.

Textbook of the Materials of Engineering

(Seventh Edition). By Herbert F. Moore, Emeritus Research Professor of Engineering Materials, Engineering Experimental Station, University of Illinois. Member, American Society for Testing Materials. With a Chapter on Concrete by Harrison F. Gonnerman, a Chapter on Crystalline Structure of Metals by Jasper O. Draffin and a Chapter on Plastics by William N. Findlay. McGraw-Hill Book Company, Inc. New York and London, 1947. 488 pp., 151 figs., 36 tables, \$5.00.

This book is primarily for the instruction of students who intend

Membership Elections

to become structural or civil engineers and it will provide a firm foundation for their more advanced studies. It will also be of value to the non-specialist engineer who requires a general knowledge of the materials of construction to assist him with his daily problems.

To the marine engineer the three chapters on the failure of metallic materials will appeal, but it will surprise many whose knowledge of Kipling is limited to "McAndrew's Hymn" to know he is credited with outlining the modern theory of fatigue of materials.

The larger part of the book deals with metals ferrous and non-ferrous, and gives in an interesting manner the information available for the preparation, processing and finishing of the ordinary metals, as well as the use of the rarer minerals in producing metals for specific purposes.

In discussion of the failures of materials, the author mentions that "factor of safety" is a misleading term, giving a false sense of security and suggests that "factor of uncertainty" would be more suitable.

He points out the value of the endurance limit tests for repeated stresses and discusses fully the effects of reversibility speed and duration on the values obtained.

The non-metallic materials are treated at more or less length in accordance with their importance, and valuable information is given.

Materials are no longer purchased in a haphazard manner, having to conform to standards of quality and strength. To meet this demand, specifications are prepared and a technique of testing has been evolved. The various machines and tests are described at length and the limitations of each are fully discussed.

Finally there are sets of questions on each chapter, and the serious reader who can answer them all will feel his time well spent.

The book is well illustrated and numerous graphs and tables are interspersed with the text, and from the extensive bibliography the reader will have ample resources to further his studies.

Introduction to Wireless

By W. E. Pearce, B.Sc. G. Bell and Sons, Ltd. London, 1948. 243 pp., profusely illustrated, 7s. 6d. net.

This admirable little book has been needed for a long time and whilst of no special value to marine engineers it is most valuable to any student, schoolboy or adult, who wants to know something about wireless and how to set about the study of it, but who is daunted by the average highly mathematical approach.

The author has succeeded in explaining, by means of ingenious analogies and experiments, much which is usually only dealt with mathematically. One or two of them are perhaps likely to lead to a young student drawing a false conclusion, or at least, learning a half truth and in some instances, the author has somewhat skimmed his descriptions. For instance his descriptions of batteries and telephones are not all that they might be. These are, however, minor blemishes in an excellent little book which can be strongly recommended to anyone who wants to know how wireless works.

The Model Shipbuilder's Manual of Fittings and Guns

By Captain A. P. Isard, A.M.I.Mech.E., with a foreword by Percival Marshall, C.I.Mech.E. Faber and Faber, Ltd. 1946. 318 pp., 184 figs., three photographs, 16s. net.

One is impressed with two things in this work, firstly the author has written it in alphabetical order—a great advantage to the reader as he is able to refer to the parts without a lot of reference, etc., and secondly he gives a wealth of detail to each item which is described in very clear, understandable language, and one is able to visualize at once the shape, etc. of what he wants to construct. This is more useful than pages of description, etc. The manual is also profusely illustrated with very neat and clearly drawn sketches.

The author's remarks are appropriate re silver plated steam winches and cargo derricks which one sometimes sees on a model—completely spoiling the whole effect. A ship model should be as true and lifelike to its prototype as possible. Many an otherwise excellent model has been spoiled by the wrong materials and colour used.

The author has also given a very good survey of guns and their mountings, also clearly illustrated, and made the description doubly interesting by an historical account of gunnery since its inception.

The model maker who possesses this manual and by carefully reading and following its descriptions etc. should produce a good model.

MEMBERSHIP ELECTIONS

Date of Election, 1st March 1948

Members

Brian Ussher Alcock, Com'r(E), R.N.	Archibald Caldwell, Hedley Chapman, M.B.E.
Edward Joseph Brady.	William Robert Covedale.

Denys Philip Crossley. Clifford George Dando. Robert William Davies, M.B.E., D.S.C., Lieut.(E), R.N. Samuel Dickinson, O.B.E. John Gordon Shaw Ferguson. David John Leslie Foster, Lt. Com'r(E), R.N. Frederick John Green. Frederick William Hayes. William Allen Haynes, Com'r(E), R.N. Robert Heddle. Oliver Johnstone. Hierouim Knap. Arthur Alastair Matheson Latto. Norman Vivian Lawrence, Lt. Com'r(E), R.N. Rupert Munton. Frank Roy Nicholls. Henry Irvine Nicholson. Leonard William Palmer. James David Mathers Peter. William Dalgleish Pryde. William George Robbie. James Robinson. William Turnbull Stevens. Robert Mark Wallace. James Wilson. Harold Edgar Woodward.	Bhalchandra Pilajirao Paradkar, Lieut.(E), R.I.N. Stanley George Pearce, Lieut.(E), R.N. George Charles Bertram Pledøer, Lieut.(E), R.N.V.R.(ret.). Edward Clark Ranson. John Gray Richards, Lieut.(E), R.N. William Rouse. Thomas K. Y. Tam. Robert William Thacker. Chin-I Tien, Lieut.(E), C.N. Edward Wiltshire Ward, Lieut.(E), R.N. Kenneth Watson. Desmond Wright, Lieut.(E), R.N.
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Associate Member
Thurstan Hurst.

Associates

Henry Norman Ainscow.
Chi-Chung Chang,
Lieut.(E), C.N.
John Albert Clark.
Richard Anthony Harding
Dring,
Lieut.(E), R.N.
Terence Marsland Green.
Alan Kenneth Hall,
Lieut.(E), R.N.
Leonard William Hornshaw.
John Simpson Irvine.
Yeh Liang,
Lieut.(E), C.N.
Robert Hugh Owen Jones.
Ralph Noel Kinder.
Thomas Lachlan Mackie.
David Gayford Mansfield.
Peter Leslie Milne.

Students

Roger Briars Berry
Mid.(E), R.N.
Robert Henry Crowther.
Keith Dennis Oborn Wake,
Mid.(F) R.N.

**Transfer from Associate
Member to Member**
George Norrie Forbes,
Lieut.(E), R.I.N.(ret.).

**Transfer from Associate to
Member**

Alfred William Easton.
Norman George.
William John Hipwell.
William Martindale MacLean.

**Transfer from Graduate to
Associate**
William Douglas McKay.

**Transfer from Student to
Associate Member**
Anthony Oliver Gaunt,
Lieut.(E) R.N.

**Transfer from Student to
Associate**
Fred Hutchinson Bland,
Lieut.(E) R.N.

**Transfer from Student to
Graduate**
Geoffrey Noel Fisher.

PERSONAL

L. P. BARKER, D.S.C. (Member) has been appointed executive engineer assistant of Messrs. Brooke Marine, Ltd., Oulton Broad, Lowestoft.

G. T. CHAMPNESS (Member) has resigned from Lloyd's Register of Shipping, and has been appointed refinery engineer in the Production Department of the Anglo-Iranian Oil Company, London.

A. MILNE (Member) has been appointed engineer manager of Messrs. Swan, Hunter and Wigham, Richardson, Ltd., Dry Docks, Wallsend-on-Tyne.

J. T. MOORE (Associate Member) has been appointed chief engineer of the English Electric Company, Stafford, in succession to Mr. A. D. Sloan, who retired at the end of 1947.

R. MOTHERSDALE (Member) has been appointed to the staff of the Anglo-American Oil Company's Fuel Oil Department in the northern counties.

L. H. W. WRIGHT (Associate) has been appointed marine superintendent of Shipping and Coal Company, Ltd., Newcastle-on-Tyne.

W. M. YOUNGSON (Member) has been appointed engineer-salesman at the Newcastle Branch of Messrs. Ferguson and Timpson, Ltd.