Some Results Obtained From a Fuel Oil Water Washing Plant in Studies of the Fouling of Marine Superheaters

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The steady upward trend in steam superheat temperature has increased the frequency of the occurrence of hard bonded deposits of fuel oil ash in marine superheaters.

While the rate of formation of these deposits is influenced by boiler design and operation variables, neither of these factors is readily changed once a vessel is in service. Considerable attention has therefore been given to the possibility of modifying the characteristics of the fuel oil ash. One approach is the water washing of fuel oil to minimize its sodium content, and thus reduce the formation of low melting sodium compounds which form the basis for deposit formation.

Practical experience of the fuel oil water washing process indicates that it is a sensitive technique unsuitable for general use aboard ship. On the other hand, in the case of a marine boiler of superheat temperature 850 deg. F. (454 deg. C.) simply centrifuging the fuel oil gave appreciable reductions in superheater fouling, comparable with those achieved by the more complex water washing procedure.

With regard to future boiler plant, superheater fouling could be avoided by attention to the aerodynamic factors which influence deposit formation, and by ensuring that combustion is complete before the gases enter the tube banks.

INTRODUCTION

Occasional instances of the formation of hard bonded deposits of fuel oil ash in the tube bundles of marine boilers have arisen throughout the history of oil-fired marine watertube boilers, but these events have increased in frequency in recent years, and some shipowners now regard the external cleaning of boiler tubes at relatively short intervals (two or three months) as an inevitable routine operation.

In 1958, as their contribution to the solution of this growing problem, the author's company initiated a full investigation of the causes of deposit formation in superheaters and of means of combatting it, these studies being carried out both in laboratory and on working plant.

The variables involved in this working programme can be placed in three categories, namely:

i) plant design:
   a) thermodynamic;
   b) aerodynamic;

ii) plant operation:
   a) combustion;
   b) soot blowing;
   c) load cycle;

iii) fuel characteristics:
   a) ash composition;
   b) additives;
   c) ash reduction.

These factors are to some extent interdependent, but it is proposed to discuss them in the order set out above, thus indicating the trains of thought which lead up to the full scale fuel oil water washing trials which are the main subject of this paper. These trials have been described in some detail in the hope of stimulating a full discussion of the fuel oil water washing process, since the results obtained appear to disagree with other published information on this subject.

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FACTORS INFLUENCING DEPOSIT FORMATION

The influence of plant design and operation upon the formation of superheater deposits has recently been discussed in detail elsewhere[1], and these aspects therefore require only brief discussion here, emphasis being placed upon facets peculiar to the marine boiler.

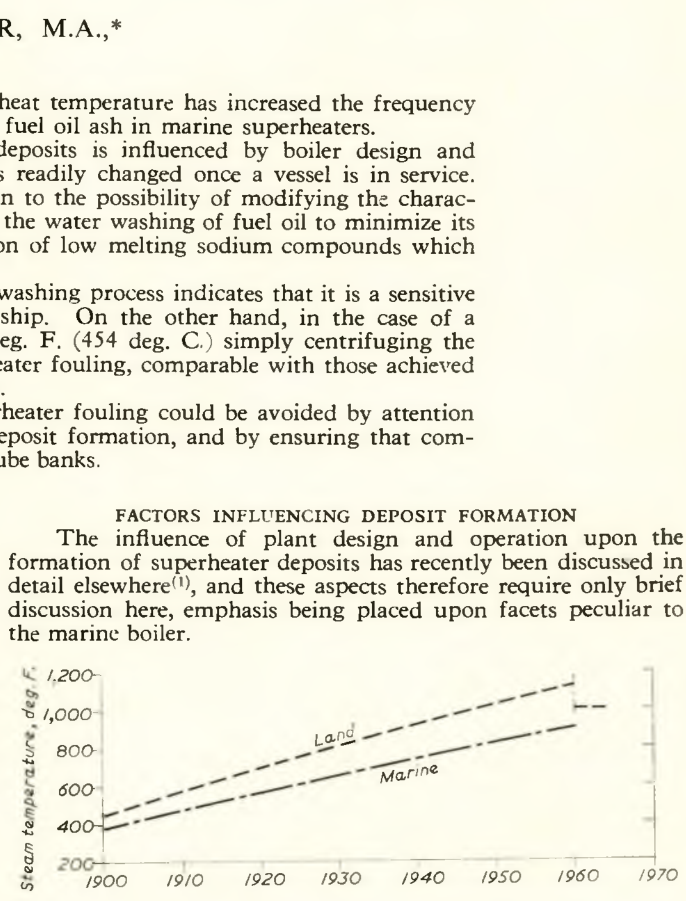


FIG. 1—*Trends in steam temperatures in land and marine boilers*

Thermodynamic Design

The advantage in plant thermal efficiency to be gained by raising steam conditions is well known. Steam temperature in marine plant has increased steadily, but at a lower rate than in land based plant (see Fig. 1), due to differing technical and economic circumstances, and the paramount importance of reliability in marine installations[2]. This trend implies a similar increase in the surface temperatures of superheater tubes exposed to the combustion gases. This surface temperature is approximately 100 deg. F. (56 deg. C.) above the steam temperature, and is of definite significance in determining the rate of ash fouling.

Broadly speaking, experience of boilers, gas turbines, turbocharged Diesel engines and free-piston engines enables one to state that no progressive ash fouling should occur on surfaces operating at temperatures below about 850 deg. F. (454 deg. C.). If such trouble is encountered then the solution should be found in the combustion conditions of the plant, as discussed later. In the range of surface temperatures above about 850 deg. F. (454 deg. C.) deposition may be loose or bonded with a definite tendency for bonded, troublesome deposits to become more common as the surface temperature is raised. Most modern marine steam plant come in this temperature category. In this range the aerodynamic design of the superheater is probably as important as the quality of combustion. At surface temperatures above about 1,100 deg. F. (593 deg. C.) the possibility of fouling being accompanied by corrosion cannot be ignored, but temperatures in this region should only be encountered on uncooled members such as superheater supports.

Aerodynamic Design

The fundamental principles of particle motion in a gas stream are well known, e.g. reference[3], but while it is possible to calculate the probability of particles coming into contact with a tube surface it does not follow that the particle will adhere to the surface. This is a function of the local temperature, the composition of the particle and the state of the surface, as is discussed later.

Laboratory studies have therefore been made of deposition rates, using a range of gas velocities from 20 to 70ft./sec. all other variables being held constant at values typical of boiler operation. This work showed that the rate of fouling was proportional to the gas velocity.

Other laboratory studies[4] have shown that fouling rates are influenced by the geometric layout of the tube bank; under almost all operating conditions, in-line arrangements were shown to be less vulnerable to fouling than staggered bundles.

Inspection of boilers of various designs in both marine and land installations has confirmed these laboratory studies, indicating the importance of selecting low gas velocities and in-line tube arrangements in order to minimize fouling rates. These factors, which should be taken into account when plant is ordered, imply that the superheater will not be of the minimum size and price, but it is contended that these considerations will be easily outweighed by increased boiler availability and reduced maintenance charges.

Interaction of Thermodynamic and Aerodynamic Factors

The interaction of the factors dealt with above can be illustrated by examples from the field. Inspections have been made of two land boilers of similar output, each having a steam temperature of about 990 deg. F. (532 deg. C.), i.e. surface temperatures about 1,100 deg. F. (593 deg. C.); the maximum gas velocities in the superheaters were approximately 15 and 45ft./sec. The former superheater was merely dusty after 11 months' operation, while the latter required cleaning at intervals of two or three months.

In the marine field, where gas velocities through tube bundles of the order of 60ft./sec. are common, serious fouling can occur at steam temperatures as low as 850 deg. F. (454 deg. C.), i.e. at surface temperatures of about 950 deg. F. (510 deg. C.).

The extreme case is the gas turbine in which gas velocities are considerably higher; rapid fouling can occur at surface temperatures as low as 900 deg. F. (482 deg. C.) but it is negligible below 850 deg. F. (454 deg. C.).

It would thus appear that there is a rough correlation between "safe" values of gas velocity and surface temperature which can offer very low fouling rates. The immunity to fouling enjoyed by many higher temperature land plant may thus indicate a useful trend for future marine boiler design.

Combustion Conditions

The importance of completing the combustion process before the gases reach the superheater bank has long been known[5] but is still not always achieved in practice.

Even when combustion is completed within the furnace, combustion conditions can still influence deposition rates. In tests carried out in the author's company's laboratories, it has been shown that changes in the fuel spray particle size caused the type and quantity of ash deposited on specimen tubes to vary. These tests were carried out at a constant air/fuel ratio and in all cases complete combustion was achieved. However, it was observed that coarsening of atomization caused the overall rate of deposition to increase, and the deposits tended to be more granular and more concentrated on the upstream sides of the tubes. This result is of direct practical value since spray particle size is a function of the quality of the oil burner equipment originally installed in the ship, and of the care expended on its operation and maintenance.

Comment is frequently made, e.g. reference[6], on the high furnace ratings achieved in marine boilers compared with land boilers. While the higher surface/volume ratio of the smaller marine boiler is a contributory factor, the combustion process itself influences the ratings attained. Work in the author's company's laboratories has shown that, under fixed conditions of air velocity through the register and constant air/fuel ratio:

$$V \propto F^{\frac{3}{2}}$$

where V = Flame volume
and F = Fuel flow rate.

This is a result of the increased difficulty of obtaining intimate mixing of air and fuel as the quantities are raised.

Thus, in land plant where the fuel quantity handled by a single burner may be as much as 6 tons/hr.[7], flame size is inevitably many times greater than in a marine boiler where single burners rarely handle more than 1,500lb./hr.

Nevertheless cooling surface requirements, and the fact that many oil-fired land boilers were originally designed for coal, imply that land boiler combustion zones are appreciably larger than necessary for the completion of combustion, whereas in marine plant comparatively little extra volume is provided. Consequently any minor deterioration in combustion quality in a marine plant is more likely to cause fouling, than would a comparable change in combustion on a land plant.

Soot Blowing

The first layer of deposit in most cases consists of loose dry particles lightly attached to the tubing, since the melting points of most ash components are above the tube surface temperature (see Table I). Regular soot blowing can remove this layer, if care has been taken to provide sufficient efficient soot blowers during construction of the boiler and they are properly maintained.

If the first layer of deposit is ignored, fouling may accelerate since, due to its low conductivity, the outside of the deposit will be at a higher temperature than the tube surface. At this higher temperature a greater proportion of the ash may be in a sticky or molten form (see Table I). Ash thermal conductivities of 1-4 B.t.u./hr.-sq ft.-deg. F./in. have been measured[1] compared with values of the order of 180 B.t.u./hr.-sq. ft.-deg. F./in. for superheater tube materials, thus indicating the importance of even a thin deposit layer.

Load Cycle

A boiler which is operated at its full rating continuously for long periods is more vulnerable to ash deposition than a unit at a more moderate loading because of the unfavourable influence of higher gas velocities and temperatures, higher metal surface temperatures (due to higher rates of heat transfer per unit area of tubing) and the greater probability of long flames. The importance of this factor has been shown by comparisons of the boiler fouling rates suffered on a ship operating on similar duties over two periods each of one year. The vessel consumed an average of 53 tons/day of fuel oil during loaded voyages one year against 58 tons/day the following year. Although the difference in consumption was less than 10 per cent, the rate of fouling in the earlier year was only 50 per cent of the later.

In contrast to merchant marine boilers which operate continuously at or near their rated output for the greater part of every voyage, burning high viscosity fuels, naval boilers have very low average loadings, using their full rating for about 1

TABLE I.—MELTING POINTS OF SOME DEPOSIT COMPOUNDS.

Compound	Melting point deg. F. (deg. C.)	Difference between melting and freezing points deg.F.(deg.C.)[9]	Frequency of detection*
Aluminium oxide Al_2O_3	3,720 (2,049)		2
Aluminium sulphate $Al_2(SO_4)_3$	Decomposes at 1,420 (771)		3
Calcium oxide CaO	4,660 (2,571)		3
Calcium sulphate $CaSO_4$	2,640 (1,449)		2
Ferric oxide Fe_2O_3	2,850 (1,566)		1
Ferric sulphate $Fe_2(SO_4)_3$	Decomposes at 895 (479)		3
Nickel oxide NiO	3,795 (2,091)		2
Nickel sulphate $NiSO_4$	Decomposes at 1,545 (841)		3
Silicon dioxide SiO_2	3,130 (1,721)		2
Sodium sulphate Na_2SO_4	1,625 (885)		1
Sodium bisulphate $NaHSO_4$	480 (249)†		3
Sodium pyrosulphate $Na_2S_2O_7$	750 (399)§		3
Sodium ferric sulphate $Na_3Fe(SO_4)_3$	1,005 (541)		2
Vanadium trioxide V_2O_3	3,580 (1,971)		3
Vanadium tetroxide V_2O_4	3,580 (1,971)		2
Vanadium pentoxide V_2O_5	1,245 (674)	55 (31)	1
Sodium metavanadate $Na_2O.V_2O_5$	1,165 (629)	20 (11)	2
Sodium pyrovanadate $2Na_2O.V_2O_5$	1,185 (641)		3
Sodium orthovanadate $3Na_2O.V_2O_5$	1,560 (849)		3
Sodium vanadyl vanadates $Na_2O.V_2O_4.5V_2O_5$	1,155 (624)	25 (14)	1
Sodium vanadyl vanadates $5Na_2O.V_2O_4.11V_2O_5$	995 (535)		2

*The numbers in column 4 have the following significances:
1. = Commonly found
2. = Occasionally found
3. = Rarely or never found

†Decomposes at about 480 deg. F. §Decomposes at about 860 deg. F.

per cent of their lives, and burn fuels of much lower viscosity. Consequently it has been found possible to design naval boilers for gas velocities considerably higher than those acceptable for merchant marine service. While appreciable fouling does occur in naval boilers[8] the low average load factors and lower fuel ash contents keep the mean rates of fouling to tolerable levels. Unfortunately these factors do not always receive sufficient consideration when new designs of merchant marine boilers are evolved from naval practice. As already suggested, closer attention to land practice might be advantageous.

Discussion

From the foregoing it is evident that the initial design of a boiler plant can have a considerable bearing upon its tendency to fouling, and that the operation of the boiler is also of significance. Unfortunately, once a vessel is in service, if superheater fouling becomes troublesome, no appreciable changes to the boiler are possible due to the capital expenditure and the loss of revenue suffered while the ship is out of service. Deposition may be retarded by the less expensive alternative of improving the quality of combustion, or by a slight reduction of operational speed, but in many instances this is not acceptable.

Thus, while the foregoing data should be of assistance in selecting future boiler plant, the problem of ash deposition in existing boiler plant remains. When confronted with such difficulties, some boiler manufacturers have not hesitated to attribute the problem to vaguely defined "deteriorations in the quality of fuel oils during recent years". While fuel characteristics, which are discussed next, are certainly one factor contributing to deposit formation, the main cause of the increasing frequency of fouling troubles is the more critical conditions under which these fuels are used. Recent years have seen a general trend towards higher superheat temperatures, smaller combustion spaces and more tightly packed superheater banks, all of which contribute towards a high probability of troublesome deposit formation, as already indicated. During the same period there has been no upward trend in the ash contents of fuel oils; in fact recently discovered crude oils have remarkably low ash contents. Neither has there been any decline in the combustion characteristics of fuel oils.

Nevertheless, it is logical, in a study such as that now under discussion, to examine fuel characteristics to find whether any simple and economic contribution to the solution of the problem of fouling is available.

Ash Composition

Many different elements have been detected in the ash of fuel oils, but, in addition to sulphur, the following are in general the most significant so far as superheater fouling is concerned; aluminium, calcium, iron, nickel, silicon, sodium and vanadium. Of these the last two have received most attention due to their ability to form complex compounds of low melting temperature. Table I shows melting point data for these and other possible ash constituents, together with a rough indication of the frequency with which they have been detected in deposits examined in the author's company's laboratories. Whether these compounds are formed in the gas stream or by reactions of simpler compounds on the tube surface is in many cases still a matter of conjecture. A point of particular interest is the finding (Table I and reference[9]) that in the case of several compounds which may be present in ash deposits, the solidifying temperatures are appreciably lower than the melting temperatures, which may help account for the observation that deposits are frequently formed at surface temperatures below the melting points of the constituents of the deposits.

It is not proposed to review the lengthy and often contradictory literature concerning the roles of different ash elements in deposit formation, an admirable summary of much of this work being available[10], but merely to point out that, in Table I, all the compounds listed as having melting temperatures below 1,200 deg. F. (649 deg. C.) contain sodium. In addition, examination of deposits occurring in superheaters in the field shows that the layer of deposit nearest the tube (i.e. the initial bond of the deposit) is usually rich in either sodium vanadyl vanadate ($Na_2O.V_2O_4.5V_2O_5$) or sodium ferric sulphate ($Na_3Fe(SO_4)_3$), or is a mixture of these compounds. This suggests that, in the surface temperature range up to 1,200 deg. F. (649 deg. C.) sodium is probably the root cause of fouling. Laboratory studies of the influence of sodium and vanadium on deposit formation are discussed in the Appendix.

Additives

The use of additives has received considerable attention ashore in both boilers and gas turbines[10], the aim being to inhibit fouling by raising the ash melting temperature well above the surface temperature. Only limited successes have been achieved however, since although it is possible to form high melting vanadium compounds (by the addition of magnesium for example[11]), it has not been found possible to achieve similar results with sodium. In fact the reverse is the case since the author's company's laboratories have identified a range of low melting mixed sulphates of sodium and magnesium[1]. The combined use of magnesium and aluminium has yielded the most promising results[12] but practical exploitation of this information aboard ship awaits the availability of cheap oil-soluble forms of these metals. Ashore it has been found possible to meter solid additives or water-soluble materials with reasonable reliability, but it would not appear reasonable to attempt similar practices in the more difficult surroundings of a ship's engine room.

A further disadvantage to the use of additives is that such an approach increases the total ash burden of the gas stream, so that if the additive is not highly effective it may actually increase the rate of fouling.

Ash Reduction

The logical alternative to additives is that the ash content of the fuel oil should be reduced, particularly since sodium, the root cause of fouling, is not amenable to treatment by additives.

Ash removal is frequently suggested to the oil companies. Since the ash content of a residual fuel oil is, in general, less than 0·1 per cent, this imposes a major problem of precision chemical engineering particularly as it concerns a product being consumed at a rate of thousands of tons per day. Nevertheless this problem has been examined in detail and it can be stated that such fuels could be made available, but the additional cost of processing, segregation and distribution would inevitably have to be carried by the customer, since the low price of residual fuels is due to the fact that the requirements of major applications do not subject them to restrictive specifications, thus minimizing processing costs. The oil industry, and particularly the author's company, were in the forefront in investigation of fuel ash problems when these arose fifteen years ago in connexion with the industrial gas turbine, e.g. references[1, 12, 13] and this experience is now being employed in the study of the allied problems of superheater fouling. In the case of marine applications, a further consideration, as in the case of heavy fuel oil treatment for marine Diesel engines, is that the risk of contamination of the fuel before its eventual use greatly reduces the value of any prior treatment ashore, particularly since the most likely contaminant is sea water.

It was therefore decided that a detailed study should be made of the fuel oil water washing technique for the removal of sodium by plant operators[14] to assess whether this was an effective, practical and economic method of eliminating superheater fouling.

PREVIOUS EXPERIENCE OF SODIUM REMOVAL BY FUEL OIL WATER WASHING

The water washing process consists basically of the intimate mixing of the fuel oil with water and a suitable emulsion breaker. Water-soluble sodium compounds contained in the oil dissolve in the water, and the resultant solution is separated from the oil by centrifuging and/or gravity settling. One such system is shown in a simplified form in Fig. 2.

This process was applied to fuels for gas turbines by the General Electric Company in the United States of America some ten years ago. Although much has been published concerning the results in the gas turbine of using this process, e.g. references[14, 15], little was said concerning the practicability of the water washing technique until it was installed in the g.t.s. *John Sergeant*[16, 17]. It was then stated that the earlier voyages were carried out using a special fuel, and that heavy fuel oil for the plant would require to be "washable"[18]. No definition was given of this characteristic. Consequently the water washing process did not appear practical for general shipboard application, although sodium contents could be reduced to below 10 p.p.m. by a two-stage centrifuging process applied to selected bunkers.

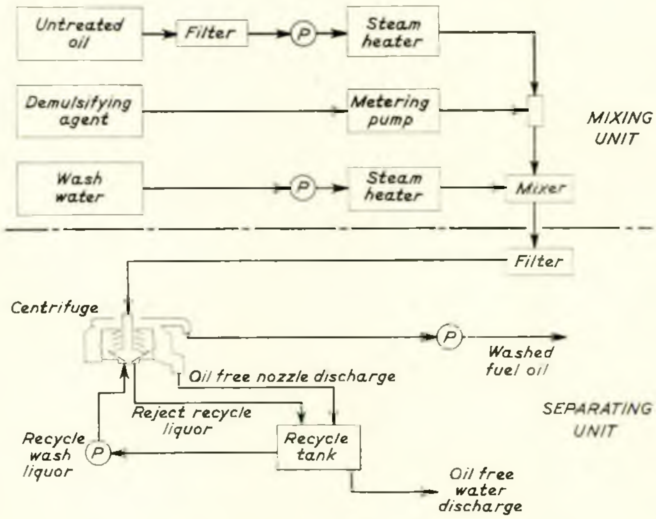


FIG. 2—*Single-stage fuel oil washing system*

This unattractive picture was changed in 1960 by the publication[19] of results obtained with a single-stage washing process aboard the s.s. *Atlantic Seaman*. In this case it was found that fuel oils, irrespective of their origin, could be effectively water washed provided their specific gravities did not exceed 0·985. (This limit can be raised by increasing the specific gravity of the wash water by using a magnesium sulphate solution, but this is not attractive due to the extra cost and complication). The average sodium content of the washed oil was 20 p.p.m. (equivalent to 27 p.p.m. Na_2O), representing an average removal of 67 per cent. Striking improvements in boiler cleanliness were achieved, and the resultant reductions in boiler maintenance and repair costs relative to the first cost of the water washing plant and the running costs (in particular the demulsifying additive) showed the process to be economically attractive.

A realistic conversion of the published cost figures from dollars to sterling is not possible due to the widely differing price and wage structures on the two sides of the Atlantic. Assessment of the results was also complicated by the fact that the *Atlantic Seaman* used the exceptionally high superheat temperature of 1,020 deg. F. (549 deg. C.). Nevertheless, the results achieved aboard the *Atlantic Seaman* and the fact that the only limitation placed on the fuel was the maximum specific gravity of 0·985, presented water washing in a completely different light.

It therefore appeared logical that the author's company, being both a major shipowner and a world-wide supplier of ships' bunkers, should assess this process.

PLANNING THE TRIAL

Reason for Choosing a Sea Trial

The purpose of the trial was to determine whether fuel oil water washing was effective in countering superheater fouling and, if so, to decide whether it could be recommended to shipowners as an economic process capable of operation by the normal engine room staff without disruption of their routine duties.

Since the trial was essentially practical in its aims, it was decided that it must be carried out aboard ship, and not in the calm of a research laboratory. This decision implied some loss of precision in control of the trial and the inconvenience of attempting to maintain close contact with an active vessel, but since the possibilities of the process had been demonstrated elsewhere[14, 15, 16, 17, 18, 19], these limitations were completely outweighed by the need to obtain realistic first hand data under typical merchant ship operating conditions.

The ship selected for the trial was the s.t.s. *Partula*, a recently built 18,000-ton bitumen carrier. The steam conditions of the two main boilers were 850 deg. F. (454 deg. C.) and 500lb./sq. in. Throughout her life the boilers had required periodic cleaning of the superheaters sometimes at intervals as short as two to three months. Considerable losses of plant efficiency resulted from low average superheat temperatures overall. The *Partula* therefore offered a good opportunity for assessing the savings possible by use of fuel oil water washing.

Outline of Trial Method

In view of the many factors which influence fouling, it was evident that an accurate assessment of the effects of water washing could not be obtained by comparing fouling rates from the *Partula* with those of her sister ships, or with those obtained on the same vessel in previous years. It was therefore decided to divide the ship's fuel system so that although her two boilers would still be fed with fuel from the same bunker tank, the starboard boiler would receive untreated fuel, while the port boiler received fuel which had passed through the water washing plant. This modification would cause no change in the method of control of the boilers themselves, but irrespective of the bunkers supplied to the ship, the two boilers would be fed with identical fuel, apart from the effects of the washing process. Thus, if care were taken to operate the two boilers under identical conditions, a comparison of their fouling rates would give a valid assessment of the influence of water washing, without any loss of operational flexibility of the ship in the course of her normal duties. A bypass line would be included in the system, so that in emergency the water washing plant could be isolated from the main fuel system. Furthermore these relatively simple modifications would imply that the ship would be permanently suitable for comparative trials, involving fuel variables such as additives if future developments warranted such investigations.

Selection of Equipment

Inevitably the installation of additional gear in an existing engine room raises problems, but discussions with Sharples Centrifuges Ltd., whose American parent company had supplied the gear used aboard the *Atlantic Seaman*, indicated that the mixing unit (see Fig. 2) could be supplied as a single assembly requiring a floor space of about 13ft. × 4ft., and the separating unit (see Fig. 2) about 4ft. × 4ft. This floor area could be provided on the port side of the main turbine level by eliminating one of the access ladders to the lower engine room, but this was considered acceptable as three alternative ladders were still available. Although this site was not ideal, access to the plant would be reasonable and its control panel would be visible from the manœuvring platform.

In view of Messrs Sharples' previous experience in the United States of America, and on the basis of the above dimensional restrictions, an order was placed for the water washing equipment. The separating unit was based upon the Sharples DHM-1 "Gravitrol" centrifuge[20] which was rated at 1¼ tons/hr. for water washing duties. This was slightly more than the fuel requirements of one boiler, but it was agreed that the mixing unit should be capable of handling a fuel flow rate of 2½ tons/hr., i.e. the total requirement of the two boilers, since this change made little difference to the size or price of the unit. Thus, dependent upon the outcome of the trial, it would be a simple operation to install a second separating unit in order to feed both boilers with water washed fuel.

Sodium removal rates of the order of 70 or 80 per cent were expected using 3,500 sec., Redwood I at 100 deg. F., fuel oil, provided the specific gravity did not exceed 0·98.

Programme of Trial

While the water washing gear was in process of manufacture, detailed planning of the trial programme took place.

The effectiveness of the water washing process in removing sodium from the fuel could only be determined by regular sodium determinations on samples of fuel drawn before and after treatment. While this delicate analysis was found possible aboard the *Atlantic Seaman*[19], this technique could not be regarded as suitable for routine shipboard use. It was therefore considered more practical and realistic to follow the procedure used aboard the *John Sergeant*[17] where water determinations on samples of treated fuel were used to assess the effectiveness of the process, although experience later showed the limitations of this approach. Nevertheless the measurement of water content aboard ship is entirely practical, and enables rapid deductions to be made concerning the maximum proportion of the fuel sodium content which could possibly have been extracted. It was appreciated that absence of sodium determination facilities aboard might retard the initial setting of the equipment, but the ultimate test instrument was the boiler itself. Fuel samples would nevertheless be collected for analysis ashore.

Since it was essential to the trial that the two boilers should operate under similar load cycles, with similar combustion quality, equipment would be supplied for the measurement of the performance of both boilers. Operating data would be recorded at regular intervals.

Before the trial began, both boilers were to be thoroughly cleaned and all burners equipped with new tip components to ensure similar conditions at the outset of the trial. The burners of the two boilers were to be kept apart throughout the trial.

It was considered essential that, after careful training, the ship's engineers should themselves operate the gear without outside assistance in order to obtain realistic data on the reliability of the plant, and the practicability of its wider use aboard ships suffering superheater fouling. To this end, a marine engineer, then on shore duties, was assigned to the project, his main duties being:

a) To become thoroughly acquainted with the water washing equipment during manufacture.
b) To operate it aboard ship during the initial running period.
c) To train the ship's engineers in the operation of the gear in order to hand over the whole project to them in the minimum practical period (it was estimated that

FIG. 3—*General view of water washing plant*

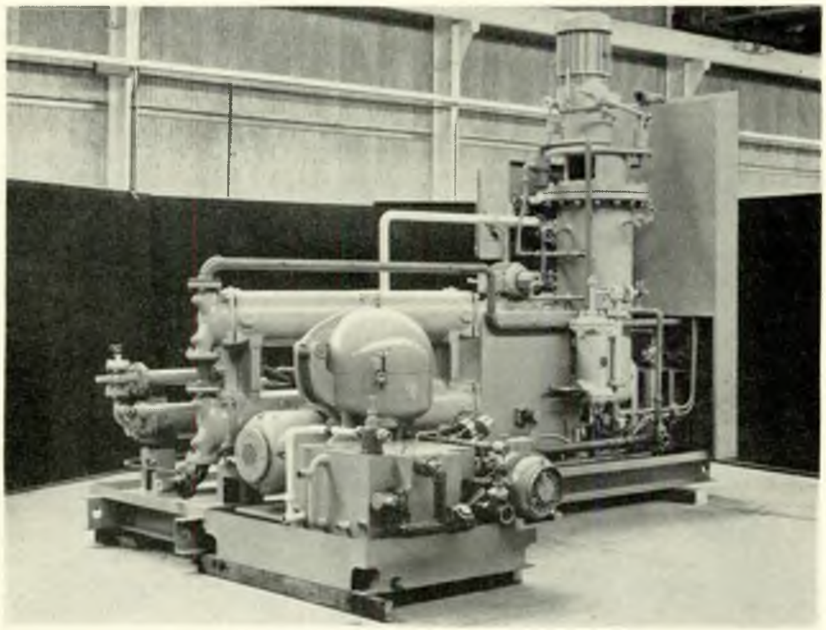


FIG. 4—*General view of water washing plant*

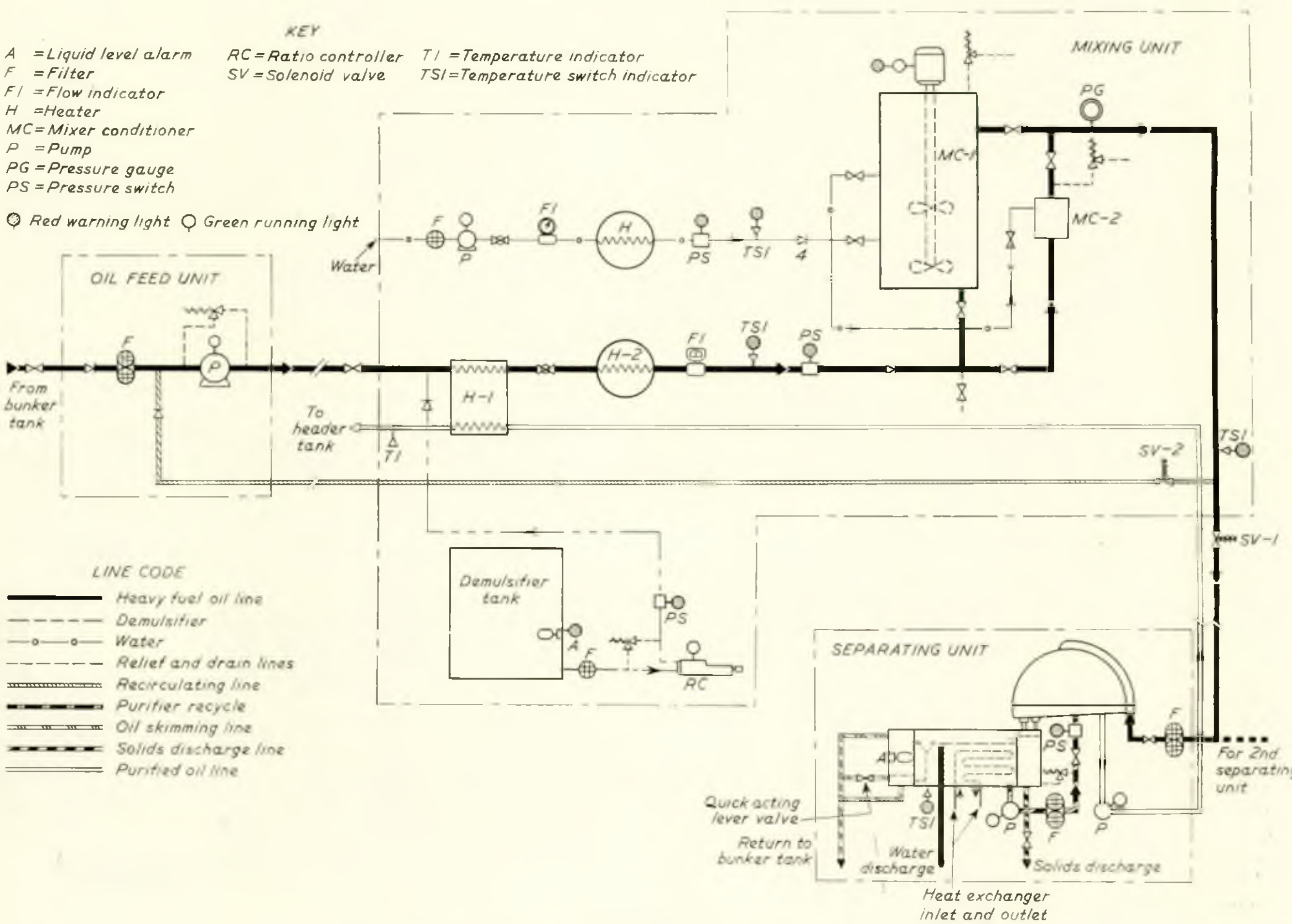


FIG. 5—*Flow diagram of fuel oil water washing plant—s.t.s.* Partula

this would be between six and eight weeks after installation aboard ship).

FEATURES OF THE FUEL OIL WATER WASHING EQUIPMENT

General views of the gear as assembled in the maker's works are shown in Figs. 3 and 4. When mounted aboard ship the separating unit was on the other side of the mixing unit and about 4ft. away from it. Fig. 5 shows the flow diagram for the equipment.

A detailed discussion of each component and its function is unnecessary since the principles of the process are described elsewhere[19, 20] and Fig. 5 is largely self-explanatory. Brief comments should be made on a few special features however.

The fuel was normal bunker fuel oil of maximum viscosity, 3,500 sec., Redwood I at 100 deg. F., subject to the one additional restriction that its specific gravity should not exceed 0·98. This fuel was preheated to 200 deg. F. (92 deg. C.) in heaters H-1 and H-2. Heater H-1 was a regenerative heater taking heat from the treated oil. This complication was adopted, not on grounds of thermal economy, but because the treated fuel was passed to the port settling tank and not direct to the port boiler. This meant that it was possible to build up a reserve of treated fuel so that the gear could be taken out of service for adjustment without the necessity of burning unwashed fuel in the test boiler. At the same time it was essential from safety considerations that the treated fuel in the settling tank should be at a temperature below the minimum flash point 150 deg. F. (67 deg. C.) and this was most readily achieved by the regenerative heater H-1.

Two oil/water mixers were provided and were installed in parallel for comparative tests. MC-1 was a conventional paddle and baffle type mixer driven by a 10 h.p. electric motor through a variator having a range from 240 to 1,900 r.p.m. This component was about 8ft. high and determined the overall height of the plant. The alternative, MC-2, with which promising results had been obtained in France was a compact jet type water injector with no moving parts, both of which features made it highly attractive.

The plant was equipped with a comprehensive alarm system, so that in the event of either failure of a component or variation of a critical temperature or pressure to an unacceptable level a klaxon would sound. At the same time the light system on the schematic control panel (see Fig. 3) would indicate the location of the fault. Automatic shut-down of the entire plant was not provided in view of its proximity to the main manœuvring platform, but any major maloperation would cause solenoid valve SV-1 to close and SV-2 to open thus putting the mixing unit on recirculation to cease production of improperly treated fuel. At the same time under certain circumstances mixer MC-1 would shut down to prevent "over mixing" of fuel and water. (The recirculation line was also used when starting up from cold to prevent insufficiently heated fluid from being passed to the separating unit).

OPERATING EXPERIENCE WITH THE FUEL OIL WATER WASHING EQUIPMENT

After a very brief series of shop trials, the equipment was installed aboard *Partula* in the course of a routine docking on the Tyne during April 1961. Further shore trials would have been highly desirable to establish the operating characteristics and capability of the plant, but due to delays in deliveries of components for which the centrifuge manufacturer was in no way responsible, these were not possible without postponement of the sea trials for several months awaiting the docking of a similar vessel. It was therefore agreed to install the unproved gear in the light of experience elsewhere by the manufacturer's associates. At the same time the subdivision of the fuel system already discussed, was carried out.

Installation of the equipment caused no difficulties, but, as appears inevitable on such occasions, start-up was marred by the inexplicable failure of standard components of proved designs. Solenoid valve SV-1 (see Fig. 5), burned out within three hours and SV-2 followed within 24 hours; both were replaced by manually operated gate valves. The water flow meter also failed in a matter of hours. No further reference will be made to later failures of minor components of the gear, these being irrelevant to a discussion of the water washing process, although intensely irritating to the personnel concerned.

The demulsifying additive recommended by the manufacturers in the light of experience of their French associates was S.I.D.A.C.-TA-2.

The operation of the plant can be considered in three distinct phases, between which modifications were made and marked improvements in performance were obtained.

The First Voyage

Due to the brevity of the shop trials and the component failures occurring during the initial start-up of the plant already mentioned, the short period available in dock on the Tyne and the first voyage to Curaçao were taken up by familiarization with the plant and the establishment of conditions under which reasonably smooth operation was possible.

Using the mechanical mixer (MC-1 in Fig. 5) it was found very difficult initially to keep the centrifuge in operation as the recycle tank overflow line tended to clog with emulsion causing the level in the tank to rise and operate the high-level trip. Reducing the recycle ring dam size and changing to the jet type injector (MC-2) improved the situation, but it was not possible to use more than 3 per cent of wash water without passing an excessive quantity of emulsion from the centrifuge causing the recycle tank to overflow. (The wash water flow rate had been expected to be between 5 and 10 per cent of the fuel flow rate).

Some fuel samples were collected under these conditions and the ship sailed. When the analyses of these samples became available, it was seen that the rate of sodium removal was only 15-20 per cent. This suggested that the jet injector was not giving a sufficiently intimate mix of the fuel and water, and the ship was cabled suggesting that further attempts should be made to increase the quantity of wash water to 10 per cent, and to use the mechanical mixer.

The plant, which had operated smoothly with the (ineffective) jet injector, gave considerable difficulty when the mechanical mixer was brought into service again, and in spite of changes in the centrifuge components and variations in the operating temperatures, considerable quantities of emulsion were formed.

TABLE II.—TYPICAL RESULTS OF FUEL OIL WATER WASHING: FIRST VOYAGE.

Sample No.	Mixer No.	Untreated fuel		Washed fuel	
		Sodium (p.p.m. Na_2O)	Water (per cent. vol.)	Sodium (p.p.m. Na_2O)	Water (per cent vol.)
1	MC — 2	46	0·1	45	1·1
2	MC — 2	54	0·3	50	1·6
3	MC — 1	50	0·2	43	8·0
4	MC — 1	47	0·4	47	8·4

Fuel samples collected during this voyage were analysed at Curaçao and typical results are shown in Table II. These showed that the rates of sodium removal being obtained were of a low order, and that the centrifuge was incapable of separating the intimate oil/water mixture given by the mechanical mixer. This and the persistent accumulation of emulsion in the recycle tank suggested that the demulsifying additive might not be fully effective.

A programme of assessment of demulsifying additives was therefore considered necessary and work was put in hand in the laboratories of both the equipment manufacturer and of the author's company. The results of this work were not available while the *Partula* was in Curaçao, nor was any alternative additive available there, so that the continued use of S.I.D.A.C.-TA-2 was inevitable.

During this voyage it also became evident that the recycle tank and the oil scum pipe were too small to handle the emulsion which might form.

Modifications to the Plant and Results Obtained

Space does not permit a full discussion of the two series of modifications made to the plant, and of the corresponding improvements in performance, but these are summarized in Tables III and IV. After the second series of modifications, plant operation was smooth and high rates of water removal were achieved. One fuel sample was hurriedly analysed for sodium content ashore, showing over 80 per cent sodium removal.

It was therefore decided that the gear should be handed over to the ship's engineers who had been carefully instructed in its operation, and the supernumary engineer was therefore withdrawn. The correctness of this decision was confirmed by the results of the latest series of trials which became available shortly after, these being shown in Table IV and Fig. 6. The most definite result of this work was that, of the three mixer speeds used, the lowest (715 r.p.m.) yielded the lowest residual sodium and water contents in the fuel.

At the mixer speed of 715 r.p.m., sodium and water removal both increased steadily with additive concentration as shown in Fig. 6. At higher speeds the results were somewhat

TABLE III.—TYPICAL RESULTS OF FUEL OIL WATER WASHING: MODIFIED PLANT

Modifications to plant after first voyage:—

1) Enlargement of recycle tank; fitting of baffles to improve oil/water separation; drain pipe diameter increased.
2) Jet type injector MC—2 removed from system.
3) Demulsifying additive Tret-O-Lite DS-424 substituted for S.I.D.A.C. TA-2.

Sample No.	Results obtained with modified plant							
	Plant settings				Results of fuel analyses			
	Mixer speed (r.p.m.)	Demulsifier addition rate (per cent vol.)	Water addition rate (per cent vol.)	Recycle water temperature deg. F. (deg. C.)	Ash content (per cent wt.)	Vanadium (as V_2O_5, p.p.m.)	Sodium (as Na_2O, p.p.m.)	Water (per cent vol.)
5		Unwashed fuel	—		0·07	135	92	0·05
6	450	0·02	8	125 (52)	—	—	80	3·0
7	600	0·02	8	155 (68)	—	—	78	1·4
8	600	0·03	8	130 (54)	—	—	79	1·2
9		Unwashed fuel	—			205	98	0·05
10	600	0·035	8	150 (66)	—	—	89	1·5
11	780	0·02	8	145 (63)	—	—	79	2·5
12	780	0·03	8	145 (63)	—	—	35	5·2
13		Unwashed fuel	—		0·06	207	98	0·04
14	780	0·03	8	145 (63)	—	—	67	3·8
15	600	0·03	8	136 (58)	0·05	198	85	1·8
16	450	0·03	8	136 (58)	0·04	217	5(?)	1·2
17		Unwashed fuel	—		0·05	199	92	0·4
18	350	0·03	8	138 (59)	0·05	193	42	2·2

Remarks:—

1) Equipment operated smoothly without emulsion formation.
2) Results show random variations, suggesting plant operation irregular in some respect.

TABLE IV.—RESULTS OF SYSTEMATIC TRIALS OF PLANT IN FINAL FORM.

Second series of modifications to plant:—

1) Smaller demulsifier pump fitted to improve precision in additive injection (fouling of additive feed line removed).
2) Faulty seal in centrifuge rectified.

Sample No.	Results obtained with plant in final form:							
	Plant settings				Results of fuel analyses			
	Mixer speed (r.p.m.)	Demulsifier addition rate (per cent vol.)	Water addition rate (per cent vol.)	Recycle water temperature deg. F. (deg. C.)	Ash content (per cent wt.)	Vanadium (as V_2O_5, p.p.m.)	Sodium (as Na_2O, p.p.m.)	Water (per cent vol.)
19		Unwashed fuel			0·105	630	110	0·50
20	1,010	0·02	9·6	140 (60)	—	—	58	3·05
21	1,010	0·03	9·6	140 (60)	—	—	45	2·65
22	1,010	0·04	9·6	140 (60)	—	—	55	2·25
23	1,010	0·05	9·6	140 (60)	—	—	46	2·00
24	1,010	0·059	9·6	140 (60)	—	—	37	2·10
25	850	0·03	9·6	140 (60)	—	—	36	2·30
26	850	0·04	9·6	140 (60)	—	—	36	2·10
27	850	0·05	9·6	140 (60)	—	—	33	2·15
28	850	0·059	9·6	140 (60)	—	—	33	2·25
29	715	0·01	9·6	140 (60)	—	—	58	2·45
30	715	0·02	9·6	140 (60)	—	—	33	1·35
31	715	0·03	9·6	140 (60)	—	—	39	1·30
32	715	0·04	9·6	140 (60)	—	—	35	1·35
33	715	0·05	9·6	140 (60)	—	—	21	1·25
34	715	0·059	9·6	140 (60)	—	—	17	1·15

Remarks:—

Plant constantly supervised by two or three engineers to ensure constant conditions.

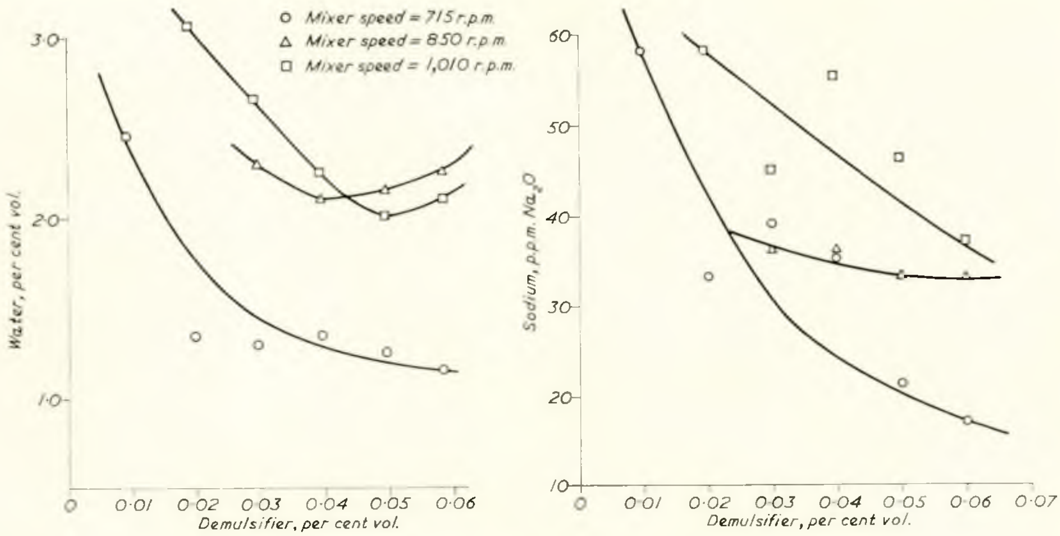


FIG. 6—*Results of systematic trials of plant in final form*

less regular, but the general trend and level of these results indicated that the plant was operating correctly.

In the ideal theoretical case of all the sodium in the fuel being taken into solution by the wash water, there should be a linear correlation between the rates of water and sodium removal from the fuel. An estimate of the extraction efficiency can be made by comparing these two rates, the data of Fig. 6 being plotted against each other in Fig. 7.

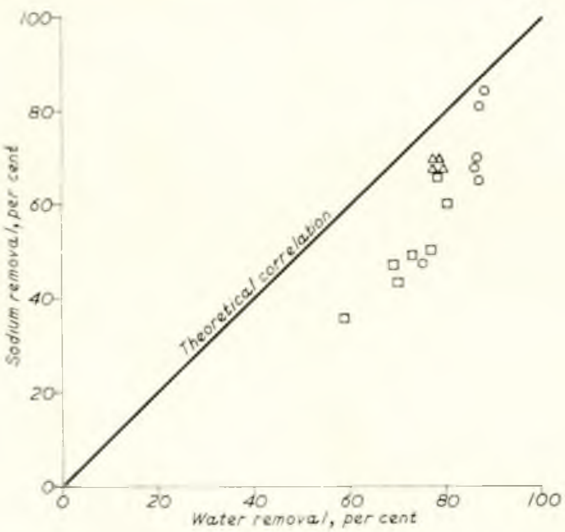


FIG. 7—*Comparison of sodium and water removal rates*

Results of Crew Operation of Plant

From mid-August 1961 until the end of January 1962, when the *Partula* returned to the Tyne for docking, the water washing gear was operated by the ship's engineers.

During this period of 5½ months minor mechanical difficulties were experienced, and these caused the plant to be shut down on a number of occasions, although they were not directly associated with the water washing gear.

In order to minimize demands on the time of the ship's engineers, few variations of operating conditions were investigated, but the results obtained showed wide variations, typical results chosen at random being given in Table V. The scatter of these results under nominally constant operating conditions presumably reflects the sensitivity of the process to minor changes in conditions, and indicates the need to optimize operation after each bunkering.

TABLE V.—TYPICAL RESULTS OF FUEL OIL WATER WASHING: PLANT IN FINAL FORM

Plant settings:
Mixer speed: 715 r.p.m.
Demulsifier rate: 0·05 per cent (vol.)
Wash water rate: 10 per cent (vol.)

Sample No.	Untreated fuel		Treated fuel		Remarks
	Sodium (p.p.m. Na_2O)	Vanadium (p.p.m. V_2O_5)	Sodium (p.p.m. Na_2O)	Per cent. sodium removed	
35	85	348	37	56	Plant operated by ship's engineers in addition to normal duties.
36			46	46	
37	74	420	59	21	
38			50	32	
39			31	58	
40			46	38	
41	77	300	52	32	
42			40	48	
43			54	30	
44			47	39	
45			53	31	
46			44	43	
47	103	518	51	51	
48			53	49	
49			59	43	

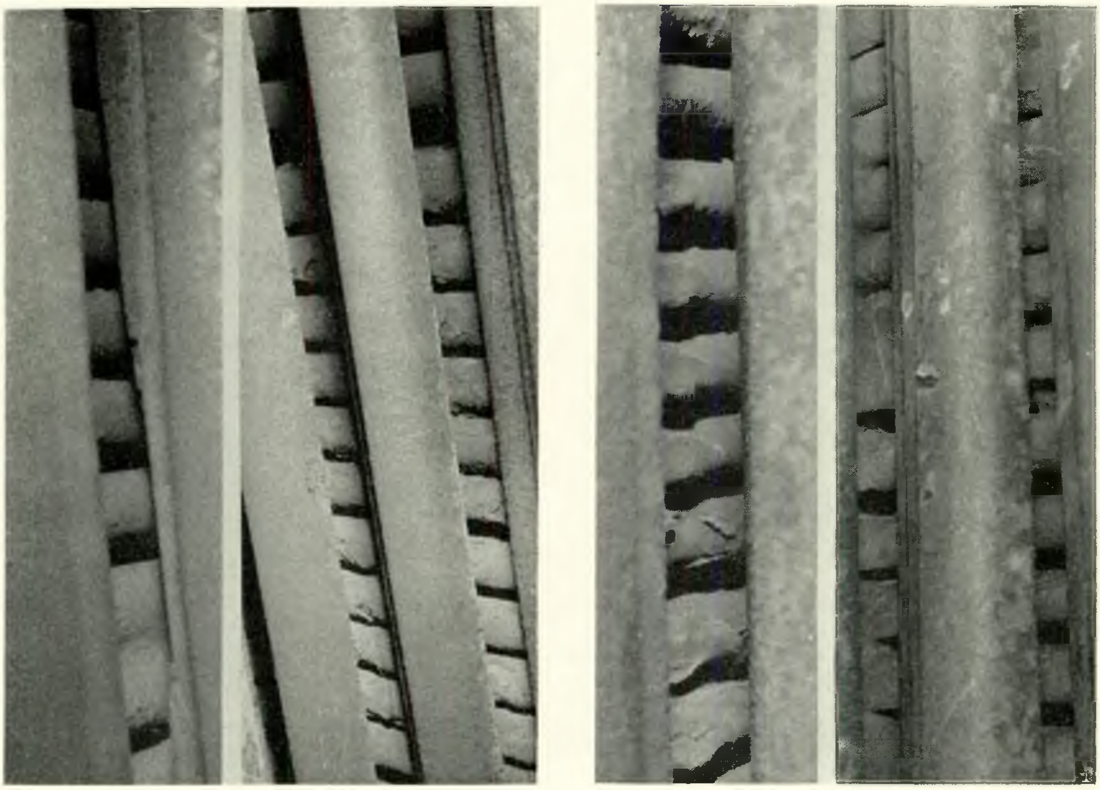
Note: Occasional checks showed vanadium reductions of the order of 10 per cent. but these were considered of no operational significance

INSPECTION OF BOILERS

In view of the moderate rates of sodium removal achieved while the plant was operated by the ship's engineers in addition to their normal duties (Table V), and the fact that failures of auxiliary components made unwarranted demands upon their time, the fuel oil water washing trial was terminated when the *Partula* returned to the Tyne for docking at the end of January 1962.

Both boilers were opened up for inspection and comparison of their condition. The port (test) superheater was appreciably cleaner than the starboard superheater, although the latter had twice been cleaned at sea since the ship had left Hamburg during the previous July. Typical views of the two superheaters, looking through the screen tubes, are shown in Fig. 8. Furthermore the deposits in the port superheater were mainly soft and readily removed revealing clean tubing; in isolated areas hard fused deposits were seen. In contrast the starboard superheater was fairly heavily fouled with hard, fused deposits requiring appreciable force to dislodge them.

Subsequent analysis of samples of these deposits indicated



(a) Port (test) superheater (b) Starboard superheater

FIG. 8—*Condition of superheater tubes after water washing trials*

TABLE VI.—EXAMINATION OF DEPOSIT SAMPLES FROM WATER WASHING TRIAL

	Port boiler (washed fuel			Starboard boiler (unwashed fuel)
Sample No.	1	2	3	4
Physical analysis:				
Melting point deg. F. (deg. C.)	1,184 (640)—1,220 (660)	1,184 (640)	1,157 (625)	1,562 (850)
Percentage water soluble	17·2	18·4	9·9	9·8
Percentage loss on ignition at 1,112 deg. F. (600 deg.C.)	1·7	1·4	1·4	0·6
Chemical analysis:				
Percentage V as V_2O_5	62·1	77·1	83·1	43·5
Percentage Na as Na_2O	6·7	10·6	9·1	3·8
Percentage Ni as NiO	15·6	1·6	1·1	20·9
Percentage Si as SiO_2	Nil	Nil	Nil	approximately 30·0 (part of this may have come from the refractories, but in this case one would have expected Al_2O_3 to have been detected also).

X-RAY DIFFRACTION PATTERNS OF DEPOSIT SAMPLES

Sample No.	Compounds identified
1	$Na_2O.V_2O_4.5V_2O_5$ + weak lines which may have been V_2O_5 and $3NiO.V_2O_5$
2	$Na_2O.V_2O_4.5V_2O_5$ only
3	$Na_2O.V_2O_4.5V_2O_5$ only
4	$3NiO.V_2O_5$ and cristobalite (SiO_2) + possibly $Na_2O.V_2O_4.5V_2O_5$ + 2 unidentified lines.

a marked difference in their chemical composition, as shown in Table VI. The deposits from the port superheater were almost entirely composed of sodium vanadyl vanadate ($Na_2O.V_2O_4.5V_2O_5$) whereas those from the starboard superheater were a complex mixture, which would have a much wider range of melting temperatures. As discussed in the Appendix, the breadth of the range of melting temperatures of ash compounds is of definite significance in determining the extent of deposit formation.

Taking into account the fact that the water washing plant was in service for about 70 per cent of the steaming time since it was modified, and that the general level of sodium removal was of the order of 40-50 per cent, it appeared that some factor other than sodium removal must have played a part in the results observed. This additional factor was considered to be the cleansing of the fuel from suspended materials of high melting temperatures, e.g. sand, a point which is rarely mentioned in discussions of fuel oil water washing (see Appendix).

Throughout the trial the ship's engineers had noted that the flames in the port boiler were consistently shorter and "cleaner" than those in the starboard boiler. (Similar results had been reported from the *Atlantic Seaman*[19] but the engineers had not been told of this observation). Inspection of the boilers' refractories confirmed this report, those in the port boiler being much less coated with fused slag; there was also much less carbon on the floor of the port boiler compared with the starboard. As shown by recent work[21] sodium plays a much more important part than vanadium in the slagging of refractories, so that even moderate reductions of sodium levels could contribute to the improved conditions of the refractories, although not to the smaller carbon deposits. These latter may have been influenced by the small amount of asphaltic material removed from the fuel, although it has been suggested[22] that the centrifuging process improves the combustion characteristics of fuel oil by dispersing the asphaltic material more uniformly and in finer particles throughout the bulk of the fuel.

FURTHER TRIALS WITH CENTRIFUGED FUEL

In view of the results of the inspection just described an immediate decision was taken to run a further trial aboard *Partula*, in which the fuel would be simply centrifuged as opposed to water washed. For this experiment only the separating unit (see Fig. 2) was required and the mixing unit was therefore removed from the ship. This change greatly simplified operation.

Many studies are available of the effect of centrifuging fuel oil prior to its combustion in marine Diesel engines, e.g. reference[23].

The purpose of the present trial was to assess the effect on superheater fouling of eliminating suspended high melting materials, e.g. sand, from the fuel, and also of removing any temporary very high sodium contents due to contamination by sea water.

This further trial was run for a period of approximately ten months, starting with nominally clean superheaters. During this period the port (test) boiler was cleaned once, but as the superheat temperature was reported to have dropped by only 10 deg. F. (6 deg. C.) the reason for this cleaning is uncertain In the same interval the starboard boiler was cleaned twice and was in definite need of a third cleaning, the superheat temperature having fallen by about 100 deg. F. (56 deg. C.).

As in the previous trial the port (test) superheater was cleaner than the starboard, and the deposits were more brittle and easily removed, but in this case the difference was less striking.

For various reasons, particularly failures of auxiliary components, the centrifuge was again out of service for an appreciable proportion of the trial period. An additional trial has therefore been put in hand to obtain more definite data on the effects of fuel centrifuging.

DISCUSSION OF RESULTS

As already stated the original purpose of these trials was to determine whether fuel oil water washing was effective in countering superheater fouling, and if so to decide whether it could be recommended to shipowners as an economic process capable of operation by the normal ship's engine room staff without disruption of their routine duties.

The main finding was that, after a series of modifications the water washing plant was capable of removing more than 80 per cent of the fuel sodium content when it was under the constant supervision of skilled operators (see Table IV), but that in the hands of the ship's engineers, who had a full schedule of other duties, removal rates varied from 30 to 60 per cent (see Table V). Thus, while the manufacturer's claim of 80 per cent sodium removal was substantiated, similar performance was not achieved in normal operation of the plant.

It is furthermore doubtful whether the present physical method of sodium removal will ever be capable of regularly removing 80 per cent of the sodium from fuel oil since a recent laboratory examination of over 100 samples, collected world wide, showed that on the average only 73 per cent of the fuel sodium content was removable by the most thorough laboratory washing process. The actual results ranged from under 30 per cent to 100 per cent, and in 17 per cent of the cases the residual sodium contents of the samples after water extraction were over 50 p.p.m. (as Na_2O). The average sodium removal rate of 67 per cent obtained aboard the *Atlantic Seaman* is in good agreement with the figure of 73 per cent obtained from laboratory works.

With regard to the effect of fuel oil water washing on superheating fouling, a very definite improvement in the condition of the test boiler was obtained, but comparable results were given by the relatively cheap and simple process of centrifuging the fuel oil. It must be pointed out that these results have been obtained only on one boiler of one particular type having a modest superheat temperature (850 deg. F.) (454 deg. C.), and further work under other conditions is desirable. Nevertheless, on the basis of the present work, it would appear reasonable that, in any further work, centrifuging alone should first be assessed, and that the more expensive and sensitive water washing technique should only be considered if centrifuging is found not to yield the desired results.

The improvements in superheater condition obtained aboard the *Partula* are less than those reported from the *Atlantic Seaman*[19], but it must be remembered that in this latter case the superheat temperature was 1,020 deg. F. (549 deg. C.) in contrast to the figure of 850 deg. F. (454 deg. C.) applicable to the *Partula*. Although the Atlantic Refining Company have subsequently installed water washing equipment on several new vessels, it is noted that they have reverted to the more conventional superheat temperature of 850 deg. F. (454 deg. C.).

In addition to the improvements in superheater condition achieved by either washing or centrifuging, two subsidiary benefits were found, namely a 50 per cent reduction of atomizer wear rates and the improvement in the condition of the refactories already mentioned.

In view of the fact that water washing showed little advantage over centrifuging, it is perhaps somewhat academic to consider the economics of the process, but the following figures may be of interest.

From the results shown in Table IV, it is considered that a demulsifier addition rate of 0·05 per cent (volume) is necessary, compared with a figure less than 0·02 per cent on the *Atlantic Seaman*[19], and this higher figure represents a cost of about 2s. 6d. on each ton of fuel oil. The plant also consumed fresh water at a rate of 10 per cent (volume) of the fuel flow rate, and the electric power consumption was about 10 kW when treating fuel at a rate of about 1¼ tons/hr. The prices attributed to these services will vary widely from vessel to vessel, but they are in any case additional to the figure of 2s. 6d./ton for the demulsifier.

The cost of the equipment and its installation in the *Partula* was approximately £15,000, but this figure is somewhat misleading since it should be possible to obtain apparatus capable of handling much higher flow rates than the present 1¼ tons/hr. for a relatively minor price increase. For example the *Atlantic Seaman* apparatus cost $43,500 (about £15,500) although installation absorbed another $34,900 (about £12,500), and this set can handle over 4 tons/hr. of fuel oil.

In contrast, for normal centrifuging without water washing equipment rated at 1¼ tons/hr. would cost only about £3,500 including installation, and the running costs would be very low indeed, considerable volumes of experience of this subject being available from heavy fuel burning Diesel engines. Whether this additional expenditure is justified depends on the outcome of the further trials now in progress, the rate of fouling occurring in the vessel under consideration and the cost of this fouling (decreased thermal efficiency, cost of cleaning, loss of earning time, etc.).

CONCLUSION

Looking to the future, two distinct cases must be considered, namely the elimination of superheater fouling from those existing vessels suffering such trouble, and the prevention of similar difficulties in new construction.

In existing installations considerable improvements in superheater condition are possible by raising the standard of combustion. This may imply the replacement of out-worn or abused components, or alternatively the retraining of staff to take full advantage of the equipment in their charge. Regular and thorough soot blowing is also essential. In many cases this is not possible since the heads of the soot blowers are quickly burned away because they are not (or cannot be) fully retracted when not in use. In multi-boiler installations, it is preferable to operate all units at a moderate output, rather than holding one boiler in reserve while the remainder operate at their nominal ratings. While attention to points such as these may alleviate trouble, the fact remains that there are boilers in service which, due to their over-compact superheater design, are very vulnerable to fouling. In these extreme cases it may be of interest to investigate the effects of fuel centrifuging.

With regard to new construction, the design factors briefly discussed at the beginning of this paper should receive due consideration. Land experience of steam temperatures over 1,000 deg. F. (538 deg. C.) shows that temperatures up to at least 1,000 deg. F. (538 deg. C.) are practicable without serious superheater fouling provided care is taken in the design of the superheater from aerodynamic aspects. There is therefore no need to halt the present upward trend in marine steam temperatures provided similar precautions are taken.

The furnace volume must be sufficient for the completion of combustion before the combustion gases enter the tube banks, not only while the combustion equipment is new but also when it has deteriorated somewhat due to fair "wear and tear". (At the same time engine room staff should appreciate the importance of maintaining combustion equipment in the best possible condition).

The superheater bank should be designed for moderate gas velocities, say 30-40ft./sec., and should be so arranged that the velocity pattern is uniform over the cross-section area of the tube bundle thus avoiding dangerous velocity peaks. Research has already been made into the aerodynamics of tube banks and their tendency to fouling[4] and this work should be extended.

Both the above factors imply that future boiler plant should be somewhat larger than present day designs, and they would therefore no doubt also be somewhat more costly. With regard to the increased size, this could be accommodated by a slight re-arrangement of engine room layout; in the present author's limited experience of engine rooms, the boiler plant usually appears to be excessively cramped while at turbine level a comparatively spacious layout is not uncommon. Concerning the higher initial cost of a boiler of slightly more conservative rating, this extra investment should easily be justified by increased boiler availability, and decreased maintenance charges for refractories and tubes damaged while attempting to remove hard deposits.

It is lack of appreciation of considerations such as the above which has necessitated examination of such costly alternatives as the fuel oil water washing process.

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REFERENCES

1) TIPLER, W. 1962. Laboratoriums-und Betriebs-Untersuchungen uber Asche-ablagerungen und Korrosion beim Betrieb von Dampfkesseln und Gasturbinen mit Schweren Heizol". D.G.M.K., Karlsruhe. To be published in "Erdol und Kohle".
2) BAUER, H. G. 1962. "Post War Developments and Future Trends of Steam Turbine Tanker Machinery" Trans. I.Mar.E., Vol. 74, p. 411.
3) RICHARDON, E. G. 1960. "Aerodynamic Capture of Particles". Pergamon Press, First edition.
4) PROFOS, P. and SHARAN, H. N. 1960. "Effect of Tube Spacing and Arrangement upon the Fouling Characteristics of Banks of Tubes". Sulzer Technical Review, No. 4, p. 34.
5) McCLOSKEY, L. C. 1947. "A Study of the Cause of Hard Slag Deposits on Firesides of Naval Boilers". Jnl. Amer. Soc. Naval Eng., Vol. 59, No. 2, p. 116.
6) DRANSEIFLD, F. and GRAY, J. L. 1962. "Land Practice in Modern Steam Plant". Trans.I.Mar.E., Vol. 74, p. 141.
7) MUSAT, G. and WAGONER, C. L. 1962. "Liquid Fuels for Power Generation with Steam". A.S.M.E. paper No. 62-FUS-10.
8) INCHES, R. M. 1962. "Boiler Cleaning with particular reference to Experience by, and Practice in the Royal Navy". Trans.I.Mar.E., Vol. 74, p. 289.
9) PHILLIPS, N. D. and WAGONER, C. L. 1961. "Use of Differential Thermal Analysis in Exploring Minimum Temperature Limits of Oil Ash Corrosion". Corrosion, Vol. 117, No. 8, p. 102.
10) NELSON, H. W. *et al.* 1959. "A Review of Available Information on Corrosion and Deposits in Coal and Oil-Fired Boilers and Gas Turbines". Pergamon Press, First edition.
11) NILES, W. D. and SANDERS, H. R. 1960. "Reactions of Magnesium with Inorganic Constituents of Heavy Fuel Oil and Characteristics of Compounds Formed". A.S.M.E. paper No. 60-WA-278.
12) TIPLER, W. 1957. "Practical Experience with the Use of Residual Fuel Oils in Gas Turbines and the Influence of Additives against Fuel Oil Ash Deposition and Corrosion". Congrès International des Machines à Combustion (C.I.M.A.C.), p. 683.
13) BOWDEN, A. T. *et al.* 1953. "The Problem of Fuel Oil Ash Deposition in Open Cycle Gas Turbines". Proc.I. Mech.E. (A), Vol. 167, p. 291.
14) BUCKLAND, B. O. and SANDERS, D. G. 1955. "Modified Residual Fuels for Gas Turbines". Trans. A.S.M.E., Vol. 77, p. 1,199.
15) BUCKLAND, B. O. 1958. "The Effect of Treated High-Vanadium Fuel on Gas Turbine Load, Efficiency and Life". A.S.M.E. paper No. 58-GTP-17.
16) McMULLEN, J. J. 1958. "The Trials and Maiden Voyage of the Gas Turbine Ship *John Sergeant*". TransI.Mar.E., Vol. 70, p. 45.
17) TANGERINI, C. C. and FOSTER, A. D. 1958. "The Bunker C Fuel Oil System of the Gas Turbine Ship *John Sergeant*". S.N.A.M.E., Chesapeake Section, 3-4-1958.
18) McMULLEN, J. J. 1958. Author's reply to discussion of reference (16).
19) WALLS, W. A. and PROCTOR, W. S. 1960. "Reduction of Fireside Deposits in Marine Boilers". S.N.A.M.E., Philadelphia Section, 21-10-1960. Also Jnl. Inst. Pet. 1962, Vol. 48, p. 105.

20) Trowbridge, M. E. O'K. 1960. "Centrifugal Purification of Oils for Marine Service". Trans.I.Mar.E., Vol. 72, p. 1.

21) Busby, T. S. 1963. "A Study of the Effect of Fuel Oil Ash on Glass Tank Refractories". Glass Technology, Vol. 4, p. 18.

22) Zimmerman, K. Unpublished work; M.A.N. Augsburg.

23) Brunner, A. 1958. "The Purification of Heavy Oil". Sulzer Technical Review, No. 4, p. 47.

24) Tipler, W. 1962. "Der Einfluss einiger Chemischer und physikalischer Kennzahlen auf die Ablagerung von Heizoelaschen". OE.G.E.W. Vienna. To be published in "Erdoelzeitschrift".

Appendix

Laboratory studies of the influence of sodium and vanadium in deposit formation

The part played by sodium and vanadium in the initial build-up of deposits is shown by deposition tests carried out in the author's company's laboratories using a range of fuels in which the ash content was constant, but the ash contained only these two metals. It was found, Fig. 9[24], that irrespective of

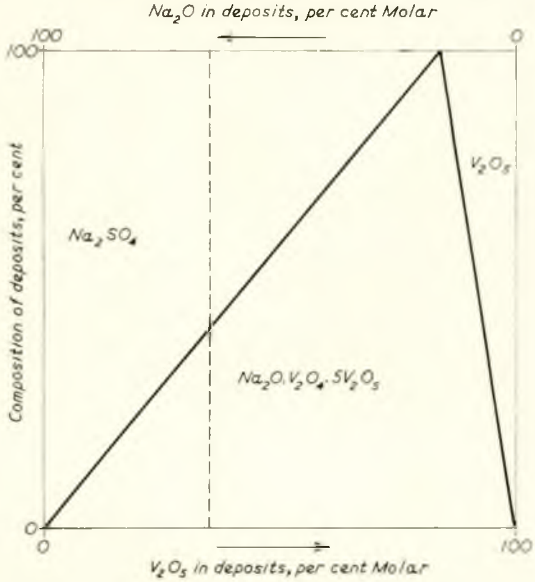

Fig. 9—*Compounds occurring in rig ash deposits*

the sodium/vanadium ratio of the fuel, the deposits contained only two compounds, namely sodium vanadyl vanadate, with either sodium sulphate or vanadium pentoxide according to whether the sodium/vanadium molar ratio was greater or less than 1 : 6, at which point the deposits consisted entirely of sodium vanadyl vanadate. With regard to the rate of build-up, this was greatest at the ratio of 1 : 6 mentioned above since the ash then had the lowest melting temperature but this result can be misleading in that the tests were only of relatively short duration (of the order of 50 hours). Had they been continued for much longer periods, comparable to boiler operating campaigns, it would probably have been found that at the critical ratio mentioned above the deposit layer would soon have reached an equilibrium level, while at other ratios thicker layers would have formed due to the wider ash melting range, as explained below.

Due to the low thermal conductivity of the ash deposits, the deposit surface temperature rises steadily, and the deposit thickness will reach equilibrium when the surface temperature attains a value at which all the ash in the gas stream is molten, so that the surface is merely washed by fluid without freezing and continued build-up. Thus the thickness of deposits formed during long-term boiler operation is greatly influenced by the range of melting temperatures of the ash components present in the gas stream. Therefore, not only is fouling reduced by raising the initial melting point of the ash but also by lowering its final melting point.

The application of these results to the water washing process is shown in Fig. 10, again assuming an ash composed of sodium and vanadium only. Consider fuel which yielded an initial deposit layer of composition corresponding to the dotted line in Fig. 9; this composition is transferred to the left-hand side of Fig. 10. If the fuel sodium content is now lowered, while the vanadium content remains constant, the first result is a reduction in the amount of sodium sulphate formed while the amount of sodium vanadyl vanadate remains constant.

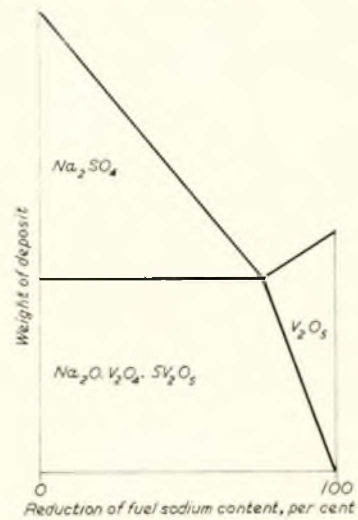

Fig. 10—*Effect of reduction of fuel sodium content on deposition*

Thus the initial rate of fouling due to the latter compound should remain constant but the equilibrium level of fouling is reduced by the narrowing of the ash melting range resulting from the lowering of the sodium sulphate content. It therefore follows that reduction of sodium content to the critical ratio of 1 : 6 should be advantageous. If further reductions in sodium level are possible, then no sodium sulphate will appear in the deposits, but instead, vanadium pentoxide. The amount of sodium vanadyl vanadate available will be lower, due to the sodium/vanadium molar ratio being below 1 : 6 so that the initial rate of fouling will be lower than before, but the final thickness of deposit will be somewhat increased above the value at the ratio of 1:6 due to the wider melting range of ash. Fortunately vanadium pentoxide melts at a much lower temperature than sodium sulphate (see Table I) so that the equilibrium deposit thickness should be much less.

A further finding in the laboratory trials mentioned above was that when the fuel ash composition approached the value corresponding to the formation of only sodium vanadyl vanadate the deposits became loose and easily removable from the test specimens.

Thus attempts to minimize fuel sodium contents would appear to be entirely justified.

Discussion

The Right Honourable Lord Geddes, C.B.E., D.L. said that it would be superfluous in company such as this for him to dilate on the contributions which Mr. Tipler had made to the knowledge of the use of petroleum as a prime mover in ships. Whenever he tackled a problem he did so with a fine combination of experience and curiosity, and the work he had described this evening was no exception.

Last Spring Mr. Tipler was one of the team which went to Ottawa on behalf of the Admiralty Fuels and Lubricants Advisory Committee to consult with the United States Navy and the Royal Canadian Navy about developments in the use of fuel and lubricants, and it was a source of pride that the British team included members such as Mr. Tipler who were able to speak with such authority on their subject.

Superheater fouling was one of the curses of the marine engineer. It was a difficult problem because it was so widely based. As Mr. Tipler had pointed out, there were at least three directions in which the solution must be sought. It was the shipowner who was bedevilled by it. If he asked his shipbuilder for help in the way of improved design he might readily be told that if only the fuel were better all would be well. The ship's engineer could so easily say that with better fuel and better designed plant there would be no trouble, and the bunker supplier could give an assurance that a better plant with better operation would solve the problem so long as his nearly perfect fuel was used.

When Mr. Tipler invited him to open the discussion he asked him why he should choose someone whose relatively slender technical experience was over 30 years ago. His reply was that he hoped to avoid the discussion developing into a contest of blaming the other chap, and that as the person he had invited had the advantage of some years in the oil industry before entering the shipping industry he would at least be able to see two sides of this problem.

This was one of the subjects on which co-operative research was urgently needed. Mr. Tipler and his company had gone a long way in the work which had been described this evening, but more needed to be done. Perhaps the next step would be an exchange of views between boiler manufacturers and fuel suppliers.

There were two points of detail with which the author had not dealt. As soon at it became recognized that sodium was one of the chief culprits in superheater fouling, the question arose as to the extent to which atmospheric moisture over the sea might carry entrained salt which would break down into its components in the furnace. Views on this had varied widely, and although Mr. Tipler's paper had not dealt specifically with this point he had at least shown that this was not the principal concern of sodium, even though it might go some way to account for the relatively high sodium content of the deposit after water washing.

Another point on which the author had made no comment was the metallurgy of the surface on which the deposit occurred. His approach to the problem had been purely in relation to the deposits arising from the fuel oil. He may have thought that the metallurgy of the tube would fall more within the province of the boiler maker than that of the fuel supplier, but the contact between the deposit and the tube was very intimate, and there was room for research into the adhesion of the one to the other.

He hoped that there would follow from Mr. Tipler's work a wider attack on the problem, and that none of the parties to it would approach it in the frame of mind that "I'm all right, Jack . . ."

Mr. T. W. Bunyan, B.Sc. (Member) said that on reading the first part of the paper one could not but feel that the difficulties resulting from sodium contamination could only be somewhat alleviated by introducing—except in the more extreme cases—even greater difficulties on board by the use of expensive and temperamental equipment. Anything which added to the responsibilities and anxieties of the engine room staff, who were already fully occupied in running a modern steam plant, was a very serious matter calling for a most careful assessment of the pros and cons.

The water washing and centrifuging plant described in the paper covered a throughput of some 30 tons/day, and to ensure its reasonable performance required informed and conscientious attention. To deal with something like twenty times this throughput, which was what would be necessary in a large passenger liner, the requirements of space, capital investment and complexity would be enormous. To have to "optimize the operation for each bunkering" sounded formidable, largely because he did not understand exactly what was meant by such optimization, but if it meant what he thought it meant, namely, a delicate laboratory investigation on a large number of representative fuel samples, carried out in the ship's chemical laboratory, then it was indeed formidable, and guaranteed beforehand to produce an end result far from optimum.

He regretted that the author had not given more space in his paper to the operation of a shore based installation which would, by virtue of bulk reduction, show vastly greater economies, and was in his view the really practical way to do this job. The author merely dismissed this matter with the comment on page 40 that "the risk of contamination of the fuel before its eventual use greatly reduces the value of any prior treatment ashore". This sounded very much like "passing the buck". He had no doubt that other speakers would take the author up on this point, so he would only say that were sodium-reduced fuels available at the major bunkering ports at prices competitive with Bunker C (and they certainly should be) such fuels would be purchased every time, risk or no risk.

Was it to be concluded that the water washing and centrifuging technique was the only practical method of reducing the sodium content in fuels? It would be useful to have a word on this from the author.

The reference to "considerable quantities of emulsion" being formed, and again "persistent accumulation of emulsion in the re-cycle tank", and also the author's remarks regarding the effectiveness of the demulsifying additive, struck a sinister note of warning. Emulsions of oil and water were the most unwanted things in an engine room; they were difficult to deal with and were an embarrassment to store until discharge overboard in mid-ocean or into a barge in port. Would the author therefore give further information as to the extent, if any, of the unusable emulsions which were generated during the trials on *Partula*?

The latter part of the paper he found much more reassuring and he read with relief the author's conclusions which effectively embraced the practical aspects of the problem. Amongst his remarks the author stated that "in these extreme cases it may be of interest to investigate the effects of fuel centrifuging". In other words, the author himself put forward this proposal as an extreme remedy for extreme conditions. The *Atlantic Seaman* at 1,020 deg. F. (549 deg. C.) superheat must be certainly one of these, and it was significant that Atlantic Refining had reverted to 850 deg. F. (454 deg. C.) in subsequent installations to make conditions less extreme.

There were two questions that he wished to put to the author. Firstly, what was the reduction in the heat transfer coefficient, the penalty which must be paid and appeared to be worth paying, for the very appreciable fouling improvement which the author stated was obtainable with superheater tubes in line rather than staggered? Secondly, was water washing every four months a bad thing? He had found that, in a banked superheater situated outside the furnace space, all deposits which had been produced during four months hard steaming at 950 deg. F. (510 deg. C.) superheat were washed down in twenty-four hours with a gentle spray of warm water, leaving the tubes clean and bright. The spalling damage to superheater refractories would, however, occur at a higher rate than would be the case with sodium-reduced fuel.

In conclusion, he repeated the plea for serious consideration by the oil companies for the production of sodium-reduced fuel for ship's bunkers.

Mr. M. E. O'Keefe Trowbridge, B.Sc., A.C.G.I. (Member) said that those who were concerned in that branch of applied technology known as marine engineering sometimes forgot the contribution which could be made by the scientist to that field of knowledge. The present paper was interesting and was to be commended as an example of the scientist's contribution to technology in the field of marine engineering.

Some of his colleagues, and others in the industry, had commented, and would be commenting, on the details of the experiments carried out and described in this paper. He wished to approach the paper from a rather different point of view, by considering the author's technique of applying the methods of the research laboratory to the hurly-burly of shipboard practice. In particular, he wanted to examine the results described as having been obtained by this method with those obtained using the more empirical, or possibly more practical method employed by the Atlantic Refining Company, in the work carried out on the *Atlantic Seaman*, described in reference 19 of the paper. As the author said in introducing his work, "These trials have been described in some detail in the hope of stimulating a full discussion of the fuel oil water washing process, since the results obtained appear to disagree with other published information on this subject." Since the results described in the present paper disagreed with such published information and also with other information with which they were familiar, he believed that as technologists they were entitled to ask themselves why the results described by the author disagreed with the other published work.

The author's stated intention in designing the series of experiments described was, firstly, to determine whether fuel oil water washing was effective in countering superheater fouling, and, secondly, to decide whether fuel oil water washing could be recommended to shipowners as an economic process capable of operation by the normal engine room staff, without disruption of their routine duties. To attempt to answer either of these questions definitively was, in itself, a formidable task. To attempt to answer both by a single series of experiments exhibited a degree of scientific courage which was wholly to be commended. The author pointed out that "the trial was essentially practical in its aims", and consequently it was decided that it must be carried out aboard ship and not in the calm of a research laboratory. The text following described in graphic detail how the excitement of the research laboratory was carried into the calm of the ship's engine room. In particular, Tables III, IV and V, by their very completeness demonstrated the degree to which the normal regimen of the engine room must be disturbed.

It was therefore suggested that the conditions needed to answer the second of the two questions above was not in fact met.

He wished now to consider the paper from the standpoint of designing an experiment. The author had described how, in an attempt to establish whether superheater fouling could be reduced by water washing using centrifugal equipment, the vessel was operated with one boiler using untreated fuel, whilst the other boiler was fed with fuel which had been water washed. This was, of course, entirely in accordance with the classical scientific method of the control experiment, varying only one parameter at a time. On the other hand, it was foreign to the normal method of operating boilers in marine practice, and hence tended to detract from the validity of the second part of the investigation, of determining whether the process was capable of operation by "the normal engine room staff".

It was a truism among scientists that the act of observation modified the observed. In the marine world, which dealt basically with human beings, this platitude became of even greater significance. He suggested that in a large measure the disagreement between the results described in this paper and those previously described by other workers in this field probably arose from this attempt to combine the measurements of the research laboratory with the normal operating regimen of the ship's boiler room. As everyone knew, the task of a ship's personnel was to operate the equipment under their care at its highest efficiency and this involved all the failings of human beings, as well as their virtues. As a consequence, in the selection of marine plant and equipment, account was taken not only of its technical merit but also its influence on the personnel. The equipment described in the paper, as he understood it, far from being that which would be normally selected for commercial practice, was designed to permit such measurement of variables as would give the maximum information applied to a research project. It was interesting to note, therefore, from the author's comments, how the research personnel themselves began to exhibit that degree of humanity which one did not generally ascribe to the scientist. "No further reference", wrote the author, "will be made to later failures of minor components of the gear, these being irrelevant to a discussion of the water washing process, although intensely irritating to the personnel concerned". Having experienced such things himself, the personnel concerned had his full sympathy in this.

Turning to some of the details, under the heading "Soot Blowing", and again under the heading "Additives", the author inferred that deposition took place when the surface temperature was higher than the melting point of the ash present in the flue gases. However, in the appendix it was stated that "The deposit thickness will reach equilibrium when the surface temperature attains a value at which the ash in the gas stream is molten, so that the surface is merely washed by fluid without freezing and continued build-up". These two statements appeared to him to be contradictory and, from his experience in considering the deposition of solids on surfaces, he favoured the second statement. Thus, he would have thought that, where the ash particles in the gas stream were molten, deposition on superheater surfaces would tend to take place under those conditions where the temperature of the surface was below the solidifying point of the ash, and he would therefore have expected deposition to depend both on the flame temperature being high enough to melt the ash particles and the surface temperature being sufficiently low to solidify the molten ash.

The author had argued in favour of low gas velocities in the superheater section. This was based on the theory of impingement of particles on a cylindrical surface at right angles to the gas flow. It did not, however, take account of the thickness of the boundary layer around such surfaces. In general, it could be said that the lower the gas velocity the thicker would be the quiescent boundary layer on the surface of the tubes. Before jumping to the conclusion, therefore, that low gas velocities represented the solution to their problems in boiler design, it behoved them to take into account the influence of gas velocity on boundary layer thickness. It was reasonable to assume that the thicker the boundary layer the higher the probability that once a molten particle had struck the surface it would, in fact, remain there to build up a deposit.

The author referred, in another part of his paper, to the surface it would, in fact, remain there to build up a deposit.

The first and obvious benefit from this lay in the reduction of down-time necessary for the cleaning of the superheater section. Subsidiary advantages of fuel washing were:

1) reduction in slagging of the refractories;
2) improved combustion characteristics of the fuel oil, possibly leading to higher thermal efficiencies;
3) reduction in pressure drop through the superheater section.

An important additional virtue to which attention had been drawn by the Atlantic Refining Company was the fact that the modest deposits formed by water-washed fuel could be more easily removed than those from unwashed fuel. This brought about the benefit of reduced damage to tubes and reduced replacement cost.

In conclusion, he said that the author had achieved the avowed intention, stated in his introduction, of "stimulating a full discussion of the fuel oil water washing process". The work published to date presented an overwhelming case in favour of water washing of heavy fuel oil for existing marine installations and for new buildings. It was only right, under such circumstances, that someone should devote the time and energy to calling a momentary halt to this trend, otherwise there was a danger of being carried along by a tide of enthusiasm. It was most useful to have this opportunity of pausing and considering its application.

Mr. E. H. Hubbard said that the paper contained some very stimulating thoughts. In Table I it was stated that sodium pyrosulphate was rarely found, and at the end of page 39 it said that "the layer of deposit nearer the tube (i.e. the initial bond of the deposit) is usually rich in either sodium vanadyl vanadate or sodium ferric sulphate". His own company's experience was different from this: in fact sodium pyrosulphate had sometimes been found, and often had been associated with sodium ferric sulphate. These two compounds were found underneath the vanadyl vanadate layer.

It was necessary to bear in mind that sodium pyrosulphate melted at 752 deg. F. (400 deg. C.) and decomposed at 842 deg. F. (450 deg. C.), giving off SO_3 and leaving sodium sulphate. This meant that if sodium pyrosulphate was found it was only in a narrow temperature region. The reason why his company found it and the author did not was, he believed due to the importance of the difference in temperature between the gases and the metal. If the deposit had a very low conductivity and the gas was very much hotter than the metal there would be a very large thermal gradient across the deposit. The rather small layer they were discussing, was at the most only perhaps 100 deg. C. across (it had to be described in terms of temperature). With a very high temperature gradient it would be very thin, so that one might not be able to find it to isolate it from the next layer. On the other hand, if the gas-metal temperature difference was small, as was often the case in the superheater banks of land boilers, the layer would be thicker, and this was where it had mostly been found.

His company had been doing some experiments recently on centrifuging. These were concerned with the second phase of Mr. Tipler's work where water washing was not employed. The *British Hussar*, a 50,000-ton tanker, started an experiment last July in which the fuel to one boiler was water washed and the fuel to the other boiler was not. The nominal steam temperature was 950 deg. F. (510 deg. C.) but it was actually run at 900 deg. F. (482 deg. C.) and the fuel rate to each boiler was 0·75 ton/hr. The experiment was not yet finished, so he could only give the results available to date; in fact, they had not yet inspected both boilers at the same time and were hoping to do so soon.

In answer to the last speaker he was able to say that they had tried as scientifically as was possible to measure the human element in this experiment and he did not think that the crew themselves knew that they were the subject of an experiment. Efforts had been made to determine the effect of the centrifuging. Did it, for example, take out anything more than normal filters within the system? There was, as in the author's case, a heat exchanger used to cool the treated fuel and to preheat the untreated fuel. Was there any cross-contamination? Was there, for example, any difference between one watch and the next? In this latter case one was found; it was only of the order of 10 per cent but it was a genuine effect and was being studied further.

To give the rather preliminary results obtained, the amount of sodium reduced by centrifuging only was roughly 25 per cent of that in the original fuel. This could be compared with Mr. Tipler's figure of 41 per cent when the fuel was water washed. The water used in the centrifuge was only for sealing and for cleaning the bowl out once every four hours. It amounted to 0·25 per cent of the fuel flow, and the amount of sludge, plus some oil which was removed from the centrifuge, was about 0·125 per cent of the fuel flow. Vanadium was not removed (as might be expected), some of the iron was removed and a small amount of the nickel.

There had been no serious mechanical difficulties in operating the centrifuge except in the initial stages when they were using potable water for the seal and for the bowl. This had deposited scale in the outlet ports. He did not know whether sailors knew what was in their potable water, but de-ionized water was now being used in the centrifuge and no trouble was being experienced at all.

They had tried to collect a sample of the sludge as it came out of the centrifuge and this had proved virtually impossible. It had finally been necessary to collect the whole of the sludge from representative cleanings and the laboratories had received a number of five-gallon drums full of sludge/water/oil mixture. This caused the analyst a certain amount of difficulty, because when he tried to ash it, it behaved like chips in a frying pan. He was able to state some of the things appearing in the sludge, and this was very relevant to the point mentioned by Mr. Tipler in the appendix, which interested him considerably. If the surface of the deposit was going to be molten, then it was a good idea to remove from the gas stream, all the things which had a very high melting point, since they would then stick more easily. If the things in the gas stream could also be kept molten, however, they might flow off. Mr. Hubbard stated that the centrifuge removed 17 per cent of the alumina, 65 per cent of the silica, 82 per cent of the zinc and 30 per cent of the calcium. The high melting point material which it did not remove, except in small proportions, was the nickel. This was disappointing, but was due to the fact that much of the nickel was present in the oil, like vanadium, as an organic compound.

Commander R. M. Inches, R.N. (Member) said that, in terms of general engineering experience, the fact that he had for the last four years been in Admiralty and responsible there for everything pertaining to the design, operation and maintenance of boilers for H.M. Ships barely counted, but observing that in that post he had been supported by a very powerful collection of expert advisers and advisory bodies, and observing again that the problems had come, by anybody's standards, very thick and fast, he hoped he would be forgiven for raising his voice in this expert company.

He wished first to comment on some of the preambles of the paper. Under the heading of "Thermodynamic Design" the author set out some fairly firm limits of safety, or perhaps, danger. He was very happy to endorse these, from the experience in modern naval boilers, in general terms, but felt he must sound a note of caution. Within the last few weeks it had been necessary to remove very high vanadium deposits from the superheaters of a design of boiler which was working on the very lowest boundary of the terms set out in the paper, and which, furthermore, in its other applications had not produced this problem, so that there appeared to be the possibility of exceptions.

Where the author talked about the interaction of thermodynamic and areodynamic factors, and later where he talked about soot blowing, Commander Inches had been interested in the author's statement that fouling was broadly proportional to gas velocity. Going on from that, he wondered whether, in the boiler with the higher gas velocity, the step was taken to keep the frequency of soot blowing level with this increased gas velocity, because this appeared to him possibly a relevant point.

What the author said about combustion conditions—and they were important—was now generally accepted so that it barely needed comment, but he certainly endorsed the author's statements in practical terms. There was the point, though, that from gas turbine experience such authorities as Bowden and Draper, Sulzer and McFarlane, had said that high temperature vanadium-rich deposits on gas turbine blades could be reduced by coarsening atomization and allowing incomplete combustion to the extent of about one per cent carbon loss. Possibly the explanation for this apparent contradiction lay in what people meant by coarse atomization. The gas turbine experts were talking about a deterioration from a mean droplet diameter of 43 microns to a mean droplet diameter of 69 microns. Perhaps the author could amplify a little on the terms in which he was talking. The author referred to a formula relating flame volume to fuel flow, which was again very interesting. A further important relationship was that of the effect on flame volume of varying air velocity, other things being kept equal. This variation in air velocity, at least in terms of air mixing velocity, was a very prevalent feature really in combustion equipment design, and if some more light could be shed on this it would be most useful for everybody.

When the author spoke of the load cycle effect, here again he agreed with him but would be very grateful for some additional evidence about the circumstances. H.M. Ships had a very interesting load cycle; it was so erratic as to be almost not worth calling a cycle and they would certainly benefit from any indications in detail of how this influenced the deposit situation.

A factor which was beneficial with regard to the operation of naval boilers, in the terms the author was discussing here, was that they were permitted to use a very much higher register draught loss, as it was called, in other words, the level of energy released purely for fuel-air mixing purposes, than was acceptable to other steam generator users.

He would be very interested in seeing the author's evidence for his statement that "there has not been any decline in the combustion characteristics of fuel oils". This could perhaps alter his own present opinion that blended fuels, which formed an ever-increasing proportion of the heavier fuels with which they were supplied, were more difficult to burn than straight run fuels, simply because the former contained components only from the two ends of the distilling range whereas, as he understood it, the whole of the range was represented in the straight run fuels.

Under the heading of "Ash Composition" the author pointed to a lot of problems that needed investigating. He was happy from his own point of view to be able to say that the Admiralty was backing the investigation of the majority of these problems, by sponsored work at various universities, so that when the work became available for publication it could be made available to everybody, which he hoped it would be. It was one of the objects of this work to remove some of the rather mystifying contradictions.

On additives, he merely wished to endorse the author's last paragraph referring to the disadvantage which their presence in the gas path could entail if they were not consumed.

The principle of reduction of the ash burden in the fuel was not only a logical alternative to additives but appeared to him to be logical in absolute terms. If a problem could be tackled before it ever really formed in its final and hard shape, then a very good start could be made. On those grounds and because the problem was a very live one in naval boilers, he was very interested in this whole business and had been ever since the paper by Walls and Proctor (author's reference 19). He had noted when reading that paper that one of the achievements was a substantial reduction in ash, by about two-thirds. The authors did not pay a great deal of attention to this but in his view it could only be beneficial, and it was particularly attractive to the R.N. because it appeared likely that, without the expenditure of the water, which in naval ships was traditionally not easily available, the ash could be removed by the centrifuging process. He was therefore very interested indeed to find that this line had been followed.

Again he was very interested now to find that there had been some pretty substantial success achieved in this work. As he was listening to the discussion this evening the degree of this success had been shown in various different lights but he still felt that this was something worth following up. The Admiralty were trying to get space for a trial in one of these ships principally affected, but on the fast frigates space was at the greatest premium ever. He hoped that the discussion this evening would encourage this enterprise; if it succeeded he had no doubt that it would be referred to at a later date.

In this context, he wondered whether, as a result of further work, the author would indicate the relative importance of various possible effects of centrifuging, for example, the removal of asphaltic material, the removing of silica and other insoluble solids, and even the removal of adventitious sea water, bearing in mind, in connexion with the last, that sodium was likely to enter into the combustion argument in the form of air-borne salt as well as fuel-borne salt.

When the author came to his conclusions, once more Commander Inches agreed with almost all he said, but there were a few points he wished to talk about. The author's suggestion that land experience concerning safe temperatures could be used as a criterion for marine boiler design underrated the importance of sodium and the extent to which it was liable to be present in the fuel, or the air, or both when a boiler was operating at sea. He felt, therefore, that even for new-designed plant it would be worth at least considering a centrifuging scheme in parallel with various others, based, he would certainly agree, on the arguments which the author had made here. The author also said, very fairly, that there was no need to halt the present upward trend in marine steam temperatures provided precautions were taken on the same lines as here indicated. Indeed, these precautions could well be taken, but he still felt that sometimes something could go wrong. He had some of the best authority for saying that "the best laid plans of mice and men gang aft agley". From his own experience, he would add that at sea this tended to happen even more often.

Mr. L. J. Culver, B.Sc. (Member) said that the author's applied chemistry seemed, to the boiler designer, to be more closely related to practical experience than some of the previous reports on this subject. But as a representative of the boiler manufacturers he joined battle with him on his comment (page 39) with regard to the "deterioration in the quality of fuel oils during recent years". They were prepared to be criticized on this point, but it would be interesting if the author could give some typical analysis of fuels burned, say, in 1963 compared to 1943. Increasing attention had to be given to the design of economizers and while increased steam temperatures and boiler ratings were both factors, there was reason to believe some fuels burnt were not quite as good as in the past. For example, had not sulphur and vanadium contents increased? The author's reference to low gas velocities had been appreciated, and there were obvious examples of land boiler philosophy in some marine boiler designs. Lest it be thought that all the problems could be solved by making boilers larger, a random comparison of oil fired boilers for naval, marine and land use would show both weight and volume ratios of approximately 1 : 2½ : 5. There was certainly a case for increasing the space allocated for marine boilers, but ship dimensions and economics were obviously limiting factors.

In the section on aerodynamics the author referred to the gas velocities in tube banks, but the marine boiler suffered from restricted spaces and lacked the comparatively generous gas ducts that were found in land practice and which enabled the land designer to produce a more uniform distribution of both gas weight and gas temperature across the tube banks such as superheaters.

In reviewing the question of water washing the author had made reference to the use of additives, but some work had also been done on the injection of slurry into furnaces upstream of superheaters, and it would be interesting to hear whether he had any comment to make with regard to this activity.

The effect of fouling in boilers compared with gas turbine equipment was influenced by the higher proportion of air used in turbine practice, but he understood that turbochargers also suffered from a certain amount of fouling and the author's comment here would again be of value.

Since the constituents varied appreciably the optimum use of washing or centrifuging must depend on the experience of the operating staff and a knowledge of the bunkers being used. If specific gravity were the only criteria available to them could the plant described be used to real advantage?

It was significant that in the conclusion the author only once referred to centrifuging, as worth investigating for extreme cases in existing installations. Mr. Culver agreed with the remaining conclusions for new construction except that with oil fuels it might not be possible to emulate the land boiler techniques to allow for four figure steam temperatures. While capital investment in centrifuging or washing plant would lead to extra duties for both operating and maintenance staff, the equivalent sum spent on larger boilers and superheaters would involve no more operating duties and yet would reduce the boiler maintenance costs.

Dr. D. J. A. Dear said that the author had pointed out in the appendix to his paper, that attempts to minimize the sodium content of heavy fuel oil were entirely justified. If this were accepted then they faced the dilemma of either preventing the sodium compounds getting into the fuel or removing them from the oil before it was used. Personally, he wished that a way could be found to keep the sodium out of the oil in the first place, and he thought that the author realized that a product with approximately 15 p.p.m. of sodium could easily be produced. However as things were, they were faced with the problem of getting it out, and here the author had successfully shown that with the ship's staff available to him this could not be done consistently with the plant described. For land based equipment it could be done, and at Leatherhead a water washing plant had been developed which was now at the British Coal Research Station. It was purely automatic and appeared to be running very successfully. With this water washing plant it had been shown that if an efficient transfer of the sodium compound to the water were achieved, the problem merely became one of removing the wash water from the oil. The data set out in the present paper were very similar to what had been obtained at Leatherhead. The paper showed that where the author had obtained a good transfer of sodium to the water, separation by the centrifuge was somewhat difficult. In the Leatherhead plant they used a chemical demulsifier and had tested a whole range of these to choose the most efficient. He was interested to know how the author chose his demulsifier, particularly with respect to world-wide operation.

The stability of these emulsions was also affected by temperature. At Leatherhead this was thought to be due to the surface viscosity of the film between the oil and the water droplets, and also to the solubility of the asphaltenes in the oil. In this connexion, with a centrifuge running at 248 deg. F. (120 deg. C.), it was easy to reduce the sodium content of a 6,500 sec. heavy residual fuel to less than 10 p.p.m. It appeared that in the author's plant the re-cycle temperature was somewhat low, and this would reduce the temperature sufficiently to prevent coalescence of the water drops and make the removal of the water difficult. Had the author carried out tests with higher re-cycle temperatures than 284 deg. F. (140 deg. C.) and had he any experience with pressurized plant where the treatment temperatures were above 212 deg. F. (100 deg. C.)?

Mr. R. E. Zoller, B.Sc. (Member) referred to Fig. 1 and stated there was a definite swing both here and in the United States towards lower steam temperatures in oil fired land boilers. Most new power plants limited the steam temperature to 1,000 deg. F. (538 deg. C.), while the marine were tending towards 950 deg. F. (510 deg. C.); the upper curve should fall after 1960 and the two curves should approach and not diverge as shown.

The statement on page 38 "that land combustion chambers are appreciably larger than necessary" might infer that this was a disadvantage, whereas the extra radiant surface that could be accommodated on land was a cheap and effective method of absorbing heat.

He agreed with the conclusions regarding oil atomization and reminded the author that one of the most effective methods incorporated steam atomizing with a water consumption less than that used in a fuel washing plant; also the most effective soot blowers in superheater zones had large traversing jets which were withdrawn right out of the casing.

He could not agree with the statement, on page 39, on recent rends. Whilst, on ships, superheat was rising, combustion chambers were not smaller and the superheater banks had much wider spacings. For example, the superheaters on the *Partula* were designed seven years ago with ⅝-in. clearance between tubes, whereas nowadays the same diameter tube would have a clearance of 1$\frac{3}{16}$in. Even ten years ago in-line tubes were used and the mean gas speed on the *Partula* was 41ft./sec.

The author gave criteria on widely varying aspects of boiler design but did not give a clear statement on superheater deposits and why superheater tubes shown in Fig. 8 became dirty before boiler tubes. An extra slide was shown indicating the preferred gas flow through a boiler and boiler makers were well aware of the advantages resulting from balanced gas flow and temperature, but, unfortunately, space was not always available in some confined boiler rooms. Reference was made to the advantages of in-line tubes which were now used more generally where space permitted.

The air speeds through oil registers had increased recently, especially in America where automation was now becoming popular and wider range oil firing was essential. It should be noted that the experiments reported in the paper employed oil with much less vanadium and sodium than was often bunkered.

In the discussion some engineers connected with centrifuging inferred that the Atlantic Refining Company were forced to employ a steam temperature of 850 deg. F. (454 deg. C.) on the insistence of the British boiler maker. The speaker attended the first discussion on the Atlantic *Rio* Class and the steam conditions for these Belgian-built ships had already been decided by the owners.

Mr. J. H. Milton (Member of Council) said that his reactions to the paper, some of which would be shared by others, were these. Firstly, the importance of removing sodium salts from boiler fuel had been admirably demonstrated by the author, particularly as these sodium layers, once deposited, presented an ideal temperature environment for the deposition of much more undesirable vanadium pentoxide. Secondly, at the present time, when many shipowners were seriously considering the economics of automation and possible reduction of engine room staff, to introduce any oil refining process, with its not insignificant running and capital cost, into already complicated engine rooms, was perhaps ill-timed. Surely prevention was better than cure and, if water washing of fuel could be effectively carried out on board ship, it must be a much more economical proposition to reduce the sodium content in bulk ashore. Thirdly, in these days of vicious competition from the large-bore Diesel engine, the process of the turbine installation, directly allied to boiler design and performance, was seriously penalized in cost, size and weight in endeavours to cope with fouling problems in the boiler gas circuit. This problem increased with the advanced steam conditions necessary to compete with the Diesel engine, operating on heavy fuel.

In conclusion, with reference to the point made by Mr. Bunyan concerning the ease of removing deposits on superheaters external to the boiler, this was a characteristic of this type of boiler which was specially designed to cope with the variety of fuel dealt with in the paper. The design was such that under normal conditions with 950 deg. F. (510 deg. C.) superheat there was much less chance of vanadium deposits forming on the superheater as the gas and metal temperatures were considerably lower than in the conventional "D" type boiler with its superheater within the main bank.

Dr. A. J. Hayter said that in view of the shortage of time, he intended to confine himself to one brief area of discussion.

The author mentioned the work carried out by the Atlantic Refining Company, reported in their paper* of 1960 before the Society of Naval Architects and Marine Engineers in America. He wished to draw some comparisons between that paper and the present work and also to add some more recent information which was available from the Atlantic Refining Company. It was quite interesting to note that both programmes commenced at roughly the same time in 1958. In comparing Mr. Tipler's with that of Mr. Walls, the Port Engineer of the Atlantic Refining Company, he thought he detected a difference in emphasis. Mr. Tipler's work, which seemed to be very thoughtful and logical, appeared to extend outwards from the fuel supplier until finally it reached the sea, and the experiments were put to a proving trial. This was fundamentally different from the Atlantic Refining programme. Here the project originated directly at sea. Both Atlantic Refining and Shell were suppliers of bunkers and also fleet operators. In the case of Atlantic the impetus for this work on an investigation of sodium reduction came not from the technical people on shore but from the fleet operators; in fact, Mr. Walls in his paper opened with the statement, "Beginning in the middle 1950's many of the ships in the Atlantic fleet began to experience more difficulties with superheater slagging. Three of the vessels operate with boiler steam temperatures of 1,020 deg. F. Four others operate at 910 deg. F. Troubles have also increased in the other ships operating at about 850 deg. F. Cleaning cycles were reduced to average intervals of 2/3 months with occasional cleanings required at shorter intervals. The magnitude of the fuel, labour, maintenance and additive costs arising from the deposit problem were considered large enough to justify a test programme to prove or disprove the advantages of sodium reduction in actual shipboard operation". The emphasis was obviously somewhat different. Here was a tanker fleet running into serious operating problems and the programme of action to correct this situation arose not from Atlantic Refining's technical section but from the tanker side of the business. They were faced with a problem and were concerned to find an effective answer to it in the shortest possible time.

The conclusions in the present paper could be divided into two main areas. There were those conclusions which were concerned with the effect of sodium removal, and he would have thought that Mr. Tipler and Mr. Walls of Atlantic Refining would find here a large measure of agreement. Mr. Tipler would agree that the following phenomena were observed: firstly, a reduction in deposits; secondly, the ease of removal of such deposits as were formed; thirdly, the very much shorter and cleaner flame pattern; and, fourthly, the improved condition of the brickwork. These points were made by Mr. Tipler and the same four by Mr. Walls, so here there was some agreement between them.

The area where there was the greatest divergence between the two papers concerned the mechanical viability of an installation such as this at sea. Mr. Tipler stated that the water washing plant was capable of removing more than 80 per cent of the sodium content when it was under the constant supervision of skilled operators, but that in the hands of ship's engineers the removal rate fell from between 30 per cent to 60 per cent. At the time of Mr. Walls' paper in 1960, the first water wash installation had become regarded as standard ship's equipment under the routine control of the ship's crew. Since that time the Atlantic Refining Company had embarked on a programme of steady conversion to fuel oil washing at sea, and at the present time six vessels were equipped.

Two weeks ago he was in the United States and talked with Mr. Walls, and had his permission to read the following letter as a contribution from him, provided the Chairman agreed. The letter read:

"It will probably be of interest for you to know that the installation of the 'fuel washing system' on the *Atlantic Heritage* is going along very well. As you are also aware, this ship will have steam conditions of 850lb. pressure and 850 deg. F. temperature. In other words, these conditions duplicate the *Atlantic Challenger* and *Atlantic Competitor*, the latter two being the systems which were installed in Antwerp, and I must say these units are running perfectly. I often think of the days in the past when Atlantic and Sharples approached this slag problem in marine boilers with a mutual and common interest to resolve it. Needless to say, our problems were many, but in the end we were rewarded for our endeavours. We both can remember the great controversy that took place in regard to corrosion on the fireside. In this particular aspect, as I am sure you remember, we ran many tests and by the same token had many discussions on this point. These steps were necessary because we both realized this grave problem. However, after four years of operating with a 'fuel washing system' on the *Atlantic Seaman* the problem of corrosion has not appeared to any degree. Superheater tube renewals are a thing of the past. To put it more plainly, corrosion does not exist in these boilers. During the past four years we have used various grades of Bunker C Fuel Oil from all parts of the world. Vanadium has ranged from 100 p.p.m. to 500 p.p.m. and sodium content has also been high; that is, in the 100-250 p.p.m. range. I mention this only to remind you that in the beginning we assumed that the fuels would be in this range and not to expect any improvement in quality. Also, and by far most important, our boiler operating cost on the *Seaman* Class has been reduced about $40,000.00 per year. We now operate these boilers about fifteen months continuously. In other words, the boilers are not taken off the line from drydocking to drydocking. Lately, our associations have again been drawn more closely together in regard to the automation of a fireroom aboard ship. With a 'fuel washing system' a reduction in engine room personnel becomes possible. For your information this procedure will take place here 1st September 1963. The 'washing system' will be controlled from a central console located at the turbine operating station. Due to the wide range of oils, in respect to gravity, that this machine can be handled by various temperature controls from a central station makes this automation possible. On the *Atlantic Navigator* the centrifuge ran continuously for three months, twenty-two days without a shut-down. Other systems in our fleet operate in this range. In closing and for your information, our superheater tube diameters have decreased about 0·003in. to 0·005in. in four years of operation. This loss is so insignificant it causes no concern. Our major problem is out of the way and was made possible by a realistic approach to a very perplexing problem. You will note that with the installation of this system on the *Atlantic Heritage* and *Atlantic Prestige* this will complete the programme on all our modern supertankers in the 850 deg. F. and 1,020 deg. F. range."

* Walls, W. A. and Proctor, W. S. 1960. "Reduction of Fireside Deposits in Marine Boilers". Philadelphia Section, S.N.A.M.E.

In Mr. Tipler's paper he mentioned 0·985 as the top specific gravity which could be handled without weighting the water. In fact, he had a note from the Chief Engineer of the *Atlantic Seaman,* who on one occasion with washing ran with fuel which was marginally over a gravity of 1 by keeping his re-cycle temperature low, and he was able to run effectively without the use of additives. He had spoken to Mr. Walls when he last saw him, and his statement was. "I have stopped worrying about superheater fouling and water washing some time ago. This is now a standard part of shipboard operation and I regard it as a problem which is solved. We are now turning to new problems."

Both papers had great value. Mr. Walls' paper was perhaps more practical and Mr. Tipler's paper was more concerned with the scientific parameters involved. In considering them it was well to consider the virtues of both, and in terms of the question of mechanical viability all one could say was, "Here is a fleet operator who has achieved considerable savings; who runs six ships on the system and who is not concerned with increasing engine room personnel but on 1st September 1963 is concerned to reduce it."

Mr. P. Saget said that he was very interested in Mr. Tipler's paper as his own organization had been conducting an investigation for eight years concerning fuel washing. He had read the paper very carefully and wished to give some complementary information about some of the data it contained. It was essentially technical, but he intended to quote some practical conclusions about it.

He saw on page 40 that fuel had to be washed, and Mr. Tipler pointed out that "washable" was a vague word. It was possible to give figures without going into detail and to measure, in a fuel, what would be called the efficiency of mixing, which was the quantity of sodium crystals in suspension in fuel which were extracted when water was mixed with oil. There was another coefficient, the separation efficiency, which was the quantity of water eliminated against the quantity used for washing. Of course, the better the mixing efficiency the worse the separation efficiency, and it was possible for a given fuel to draw the curve showing how the data were arrived at. For a very good fuel it was 1·005 and this figure went up to 1·08, for a very bad fuel. It was possible by using a computer to get a completely automated plant.

On page 45 of the paper at the top there was a curve which showed the variation of the water separation against the concentration of water, per cent vol. Making many tests, his organization had also produced a curve measuring the strength of the membrane between fuel and water, by using a distributor device and pushing a ring through the surface. The curve proved that this was essentially tied up with the strength of the membrane.

From page 47 of the paper it appeared that some factor other than sodium removal must have played a part in the results observed. It was true that the ash removal was excellent. It was also true that, with less than two per cent of water, each droplet of oil, when injected into the boiler, would explode. The droplets of water in the oil droplets would vapourize instantly, that was well known. It improved the combustion, but there was something else: instead of having one large ash particle there would be 20 small particles and, instead of these impinging on the tubes of the superheater, the flow of the gases would be followed more closely, and then they would escape. This had been done in some boilers in France.

These test results had been obtained on board two tankers, either for their Diesel engines or for their boilers. Fuel on board the two ships in question had been washed now for five years for one and 3½ years for the other. Some similar results were obtained on board cargo ships. Results were also obtained, but in a different way, from a gas turbine. The most important points were that, firstly, stable heating was absolutely necessary, otherwise the efficiency of washing could be reduced. Secondly, washing reduced the frequency of turbocharger turbine cleaning. They were cleaned every month, without washing, but with washing they were still clean after six months. Thirdly, for one year one of the ships had been washing fuel without an emulsifier and the results were still good. There was no mechanical mixer, only a cycle mixer, and water added into the fuel. Before the first heater there was more contact time between the oil and the water. The average efficiency on board these ships had been 75 per cent. An efficiency of 90 per cent was obtained in an Electricité de France power station, using very good fuels. Further tests in the same power plant, using inferior fuels, showed a lower efficiency, approximately 80 per cent in the worst cases. It was felt that the future of this type of operation was in the increase of temperature. The next steps taken in France would involve pressurized machines with temperatures as high as 130 deg. C. It was known already (because a complete investigation had been made) that each of the machines would be able to treat 25 metric tons/hr. of fuel, and the cost of such a process would be 1·2 per cent of the cost of the fuel, for one stage, and approximately 2 per cent for two stages of washing. Several speakers had mentioned ash removal. In some cases when washing fuel and when ash contained a lot of clay, it was impossible to obtain more than 20 per cent efficiency. When washing, never less than 90 per cent was achieved due to the fact that small ash particles were collected by water droplets which were much larger and were more easily eliminated.

The Atlantic Refining Company were well known to his organization who had equipped the last two ships, and they had reverted from a temperature of 1,050 deg. F. (566 deg. C.) to 850 deg. F. (454 deg. C.). From the information received from the shipowners it seemed that they had been influenced in this case by the fact that the prices of the Belgian shipyard (Cockerill's) were lower than American prices. Cockerill manufactured and usually installed Babcock and Wilcox boilers designed for 850 deg. F. (454 deg. C.). He could not assume that this was the only reason for so doing but was at least certainly one of the reasons. It was cheaper, apart from the fact that the shipyard used Babcock and Wilcox boilers.

Mr. D. J. Williams (Graduate) said that the paper was a very interesting and intelligible one and that he did not wish to detract in any way from the technical contents.

The facts concerning water washing were known to his company, and they respectfully suggested that this was the wrong approach to the problem. Figures had just been quoted of something like one per cent of fuel, and that was possibly high, giving problems with which they were familiar, high temperature oxidization corrosion, and it seemed that to treat 100 per cent of the fuel in order to obviate the problems of one per cent of the fuel was in itself incorrect.

He understood that the author had some knowledge of the efforts the speaker's company had been making for a number of years to combat this problem. He referred to additives. On page 40 of the paper there were just over 20 lines under the heading "Additives", in the course of an excellent 14-page paper, and it was his contention that in these lines lay the solution to the problem. The very first, and most eminent, speaker said that the paper failed to show that if a method could be obtained for breaking down the initial adhesion of corrosives the element vanadium pentoxide among others, a solution would have been found. Taking that one stage further, the solution would have been found because as yet no one had asked why this corrosion could not be removed by soot blowers. Very quickly, the answer was that no known soot blower could remove corrosion, resulting from high residual fuel, over 1,450 deg. F. (788 deg. C.) which was the operating gas temperature of superheaters on many high output boilers. It followed, therefore (and the paper brought it out), that the raising of the ash melting temperature and the surface temperature would go some way towards obviating the problem. Unfortunately (this was the only point he wished to contest), it went on to say that only limited success had been achieved from the use of additives. This might be true, and the reason, he contended, was that the additives had been put in in the wrong way and into the wrong place.

There were three ways in which additives could combat corrosion. One was mixed with the fuel, which was the basic error of 100 per cent treatment of one per cent of the trouble. The second method was entraining an additive with the combustion air. Random results had been recorded from that method. The third one was through retractable soot blowers, and the term "soot blowers" was used in its familiar form. He was not thinking of the old fashioned things with random results; he was thinking of the long retractable soot blowers, as dealt with in a paper* presented by Mr. Hutchings in February's edition of the TRANSACTIONS. This brought up, possibly for the first time in the TRANSACTIONS, the enormous scope of the correct placing of retractable soot blowers. His company agreed with this, but if the additive was introduced through a long retractable soot blower directly on to the tubes which had been seen to be affected, it was able to do what it was going to do in the right place. This fine film was the start of the build-up of the vanadium pentoxide slagging. Once this was established a semi-molten tenacious slagging could then occur. This in all probability, over a certain thickness, could be removed by soot blowers, but the bonded deposit could not be removed by any soot blower; it followed, therefore, that if this adhesion could be broken down they were well on the way to obviating this problem. It was done by first hoping to start off with a clean boiler, and that soot blowers would maintain reasonably clean surfaces. Immediately the operation was done with soot blowing the additive was put in purely automatically, which would be appreciated in this day and age when shipowners' were tearing their hair through lack of personnel and any automation was to be welcomed. Water washing as such was out of the question for shipboard use, and it was debatable whether centrifuging was not also out of the question, for reasons brought up by other contributors. The maintenance cost could also be quite high. There existed equipment on board ship which had to be there, so that if it was possible to use the equipment which was already there and did not have to be attended to by ship's personnel that was again a point for additives, administered through soot blowers. The equipment was available and existing soot blowers could be converted. There were no major capital problems involved in this method. It would appear novel to many people present; the reason was that it was primarily an American development, and had only been available in Britain in the last two years.

He did not wish to contest the paper for what it was intended to present—it had done that very well—but he asked the author to think again whether this was in fact the answer, to have water washing of 100 per cent of fuel when it had been proved that there were many steam generators existing where slurries blown in through long retractable soot blowers had maintained clean superheaters. Some figures had been quoted for this water washing which would infer that if the sodium content was over 300 p.p.m. three-quarters removal of that would leave a content that was still too high and would give rise to vanadium pentoxide slagging. Any fuel washing system on land was vulnerable to the entrainment of sodium chloride later, as was pointed out, and he would be grateful to have the benefit of the author's knowledge of the slurry method and his opinions on it.

MR. D. BRADLEY said that he would like to comment on Mr. Tipler's most interesting paper from the point of view of the man on the touch-line—able to wave a flag but not able to blow the whistle. From this position comment could be objective and therefore all the more valuable. He wished to take a number of the statements made and to analyse their basis. By so doing it might be found that alternative conclusions could and should be drawn.

The first statement to consider was that "results disagree with published information". In general conclusion this was so; in detail it was not so. Even with the differences in specification between the *Partula* and the vessels of the Atlantic Refining Company there was an astonishing measure of agreement. The *Atlantic Seaman* averaged 67 per cent sodium removal, the theoretical average appeared to be 73 per cent, and the *Partula* averaged 69 per cent for the 715 r.p.m. mixer condition of Table IV. The degrees of cleanliness of the refractory lining and superheater tubes resulting from the operation of the water wash plant were also similar.

It was stated that the results of Table IV were obtained only in the presence of two or three supervisory grade engineers and could not be reproduced by normal engine room staff. The reason for the presence of these engineers was to carry out optimization trials (as evidenced by the variation in figures for r.p.m. and demulsifier addition in Table IV). It was not to maintain good performance. If there were disagreements with published data they were only in this area and it was worth remembering that it was stated in the paper on the *Atlantic Seaman* that "no extra manpower was required".

It was understood that the water supply was a source of difficulty through inconstant head conditions. It would have been interesting in these circumstances to be given the moisture contents in the cases listed in Table V, which really were used as the hub of the argument. Low sodium removal would result if mal-operation gave high moisture.

General statements were given on the economics of water washing which again did not disagree with published information except in detail. The penalty of design to avoid fouling was primarily one of increased space required by the boiler and superheater. Space was money, and it would have been interesting to see this aspect developed rather than to see consideration of the cost of demulsifier and of water. This was particularly so when in a correctly running installation these costs were significantly lower, due, for example, to a five per cent water treat instead of a 10 per cent treat. He understood that five per cent was never seriously tried on the *Partula*, though he would appreciate correction if this were not so.

Turning to the question of plant operation, it was not made clear in the paper that the early difficulties of emulsion formation and ineffectiveness of the injection mixer were found to be attributable to one cause—the demulsifier pump. Change of the plunger to give operation in the range over which control was sensitive removed all of the difficulties, from which it followed that the trouble had been inconsistent supply of demulsifier. The injection type mixer was therefore not to be ruled out and it should be noted that it was in frequent and successful use in other installations.

He wished before concluding to say a few words on the state of the boiler surfaces both with and without fuel washing. Differences were striking, as shown by the photographs in Mr. Tipler's paper and also Mr. Wall's paper (*Atlantic Seaman*). Carbon on the floor, as stated by Mr. Tipler, was much less in the washed boiler. In fact, the figures were an average of 2-3in. with peaks of 8in. in the unwashed case, as compared with an average of 1in. in the washed case. Deposits on the port tubes averaged 0·05in. as compared with 0·15 to 0·2in. on the starboard tubes. Deposits on the port tubes, as well as being less in quantity, were also easily removed by a brush and hot water. One could therefore add cheaper cleaning and less damage on cleaning, to the stated advantages of improved refractory life, decreased nozzle wear, and less frequent cleaning.

Finally, he wished to return to the statement that results differed from those previously published. He contended that this was not so. Results were identical; conclusions differed. As stated, sodium was the root cause of fouling, and washing to remove sodium was demonstrably useful. Again it should be remembered that the Atlantic Refining trials commenced by proving this by using a batch of specially prepared low sodium fuel. Benefits undoubtedly could be obtained by straight centrifuging with no washing but, as noted in the paper, the difference in boiler condition was less striking. A conclusion that could not possibly be disputed was therefore that the centrifuge reduced boiler operational costs, whether it was used in conjunction with water washing equipment or not, whilst maximum effect would result from washing.

* Hutchings, E. G. 1963. "The Design and Development of Two-drum Marine Boilers". Trans.I.Mar.E., Vol. 75, p. 37.

MR. T. D. BROWN said that Mr. Tipler was the first person to have formulated any qualitative approach to the problem of the possible thickness of deposits and his suggestion that not only the initial melting point of the ash but also the final melting point governed deposit thickness was very attractive.

If his theory was applied to a mixture of MgO (a common additive) and Na_2O, V_2O_4, $5V_2O_5$ then it could be seen in Fig. 11* that a small change in the percentage *MgO* might lead to a wide variation in deposit character. This diagram explained the existence of the heavy deposits which were easily removed so often reported in the literature†‡ when magnesium had been used as an additive. The wide melting range occurring with a 15-20 per cent magnesium mixture would allow the heavy build-up to take place and it was probable that the deposit would break off before its surface temperature reached the final melting point of about 1,800 deg. F. (982 deg. C.) thus pre-

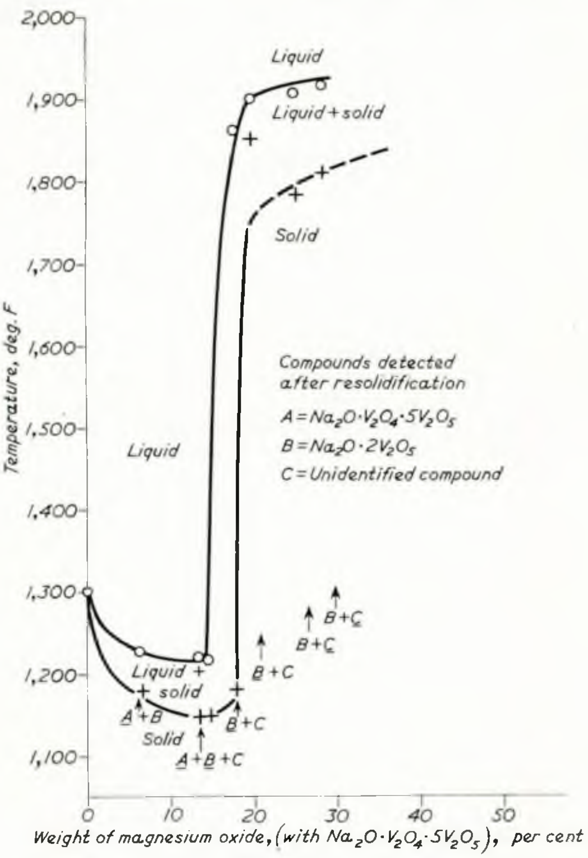

FIG. 11—*Liquid-solid regions in the pseudobinary system MgO—Na_2 O.V_2 O_4. $5V_2O_5$*

venting the formation of a hard glassy surface. However, in the mixtures with a magnesia content lower than 15 per cent one could expect to find a thin glassy deposit. So many magnesia concentrations had been used in additive trials he was surprised that this type of deposit had never been observed. Could Mr. Tipler comment on this?

The effect of gas velocity on the rate of fouling was often neglected in studies of deposition and it was worth noting in this context that the gas flow through a superheater was far from uniform. His department had recently completed a study of flow patterns in naval boilers (types Y101, Y102 and Y111), using a water modelling technique. The accompanying illustration, Fig. 12§ showed the gas flow patterns in a Y102 or Y111 steaming at full power.

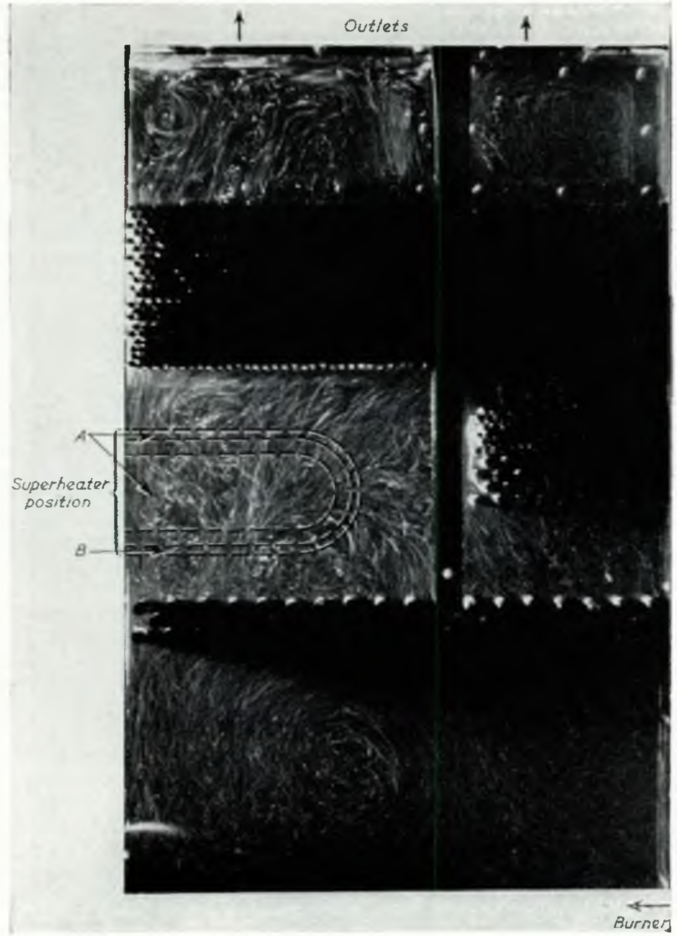

FIG. 12—*Flow patterns in Y102 boiler*

It could be seen that the flow was far from uniform and that there were regions of high velocity, high mass flow along the wall of the boiler (A) and also across the centre of the superheater (B). This uneven distribution of flow would accentuate the fouling in certain areas of the superheater and a more even distribution of velocity should remove any areas of high deposition and also improve the heat transfer to the superheater. These flow patterns also showed that it might be possible for deposits to accumulate by impaction on the nominally downstream faces of superheaters.

At Sheffield work was being carried out on the problem of deposits and corrosion by studying the effect of excess air on the rate and nature of deposition. Using a controlled mixing history furnace fired with kerosene (0·25 per cent vanadium) attempts were being made to reduce the amount of deposit collected on simulated superheater tubes at 1,238 deg. F. (670 deg. C.) by stoichiometric or near stoichiometric combustion.

Preliminary experiments showed that the deposit accumulated, measured solely as the increase in weight of the sample tubes decreased when the excess oxygen in the combustion gas decreased from 7½ per cent to 0·5 per cent. It was intended to repeat this work using a platinum coated tube in order to differentiate between deposit and corrosion product since both could lead to an increase in weight of the sample.

* Pollard, A. J. "Reactions of Boron Oxide, Magnesium Oxide and Zinc Oxide with the Sodium Vanadium Oxides of Oil Ash". N.R.L. Memorandum Report 1386, January 1963.

† Buckland, B. O. and Saunders, D. G. "Modified Residual Fuel for Gas Turbines. 1955. T.A.S.M.E. 77, 1199.

‡ Niles, D. and Sanders, M. R. "Reaction of Magnesium with Inorganic Constituents of Heavy Fuel Oil". A.S.M.E. Paper No. 60-WA-278, September 1960.

§ This photograph does not show the flow patterns in the boiler section behind the burner. This was omitted for simplicity in illuminating the model.

Correspondence

Dr. P. Chambadal wrote that, as Mr. Tipler had pointed out, fuel oil water washing was sometimes used not only in stationary or marine steam plants, but also in high temperature gas turbines. Thus some experience with heavy fuel washing had been obtained at the St. Dizier power plant which consisted of a Brown Boveri 6,000 kW gas turbine operating at 1,382 deg. F. (750 deg. C.). The purpose of washing was to reduce the ash content as well as the sodium content of the fuel: the amount of ash before washing sometimes reached 400 p.p.m., and that of sodium was about 100 p.p.m. As, on the other hand, the vanadium content was negligible, the use of any additives was not necessary and the treatment of the fuel consisted only in reheating, mixing with water and with demulsifying agent, and centrifuging. A diagram of the fuel treatment system was given in the writer's paper presented at the 1962 Conference of the International Congress on Combustion Engines (C.I.M.A.C., pp. 1,011-1,040).

The results of the tests carried out up to date could be, broadly speaking, summarized as follows. It seemed that single-stage washing was sufficient to prevent the fouling of the turbine, but not to avoid corrosion of the blades; but double-stage washing would allow a satisfactory operation without fouling or rapid corrosion. Of course, these conclusions applied only to the particular fuel tested at St. Dizier, and also to the particular conditions of the tests; it was well known how difficult was any generalization in this field.

It was worth noting that neither washing nor additives were necessary when the gas turbine was combined with free-piston gasifiers. In this case the only treatment required by heavy fuel was heating and centrifuging, as well as a change-over to light fuel during starting and shut-down. The previously mentioned C.I.M.A.C. paper also gave a diagram of the heavy and light fuel circuits at the 6,000 kW Cherbourg plant (reproduced in *The Oil Engine and Gas Turbine,* January 1963). The same fuel treatment was also used in other free-piston plants; for instance, it would be applied in the new 26,000/28,000 kW plant which was now in erection at Chartres and was scheduled for completion in 1964.

Dr. H. E. Crossley wrote that he had read the paper by Mr. Tipler with considerable interest, and was pleased to know that there had been so much effort towards a better understanding of the part played by sodium in fuel oil.

For some years he had felt that the removal of sodium from fuel oil was worth careful study with the hope of providing a process which would be fairly simple and cheap, and practicable for use in various circumstances. No doubt Mr. Tipler had in mind simplicity and cheapness in putting forward a process of washing and centrifuging, but Dr. Crossley did not share the optimism he must have had. Sodium salts occurring in fuel oils were mostly in a watery phase dispersed in the oil. The removal of this watery phase must involve a process of demulsification and, as Mr. Tipler knew, the demulsification of oils was frequently unsatisfactory when it was confined to simple washing and centrifuging. It seemed likely that if a successful process was ever to be developed it would involve the practice of specialized techniques arising from colloid chemistry.

Dr. Crossley suggested that the really important issue at present was to decide whether it was worth the cost and trouble of removing sodium from oil to prevent the fouling and corrosion of superheaters. Closely related to this matter was the present lack of knowledge on the extent to which sodium removal would have to be carried out to gain maximum benefit. It could logically be expected that reduction in the amount of sodium would progressively retard the rate of fouling of superheaters, but it was not known whether the removal of sodium down to, say, less than 5 p.p.m. would be completely effective or only partially effective in providing a complete answer to the problem of fouling and corrosion.

It still remained to be decided whether vanadium pentoxide, as such, in the presence of oil ash free from sodium would melt on superheater tubes at temperatures representative of present plant, and if not, what increase in temperature could take place before melting occurred. Many believed that the presence of a liquid phase on superheater tubes was essential for corrosion to take place, and certainly the presence of a liquid phase could be expected to accelerate fouling.

Mr. Tipler's experience that centrifuging alone had material benefits was surprising. Although a possible explanation was suggested it might be wise to defer conclusions about this simple pretreatment until further experience had been obtained.

Mr. J. J. MacFarlane, B.Sc., F.R.I.C., was of the opinion that there could be no doubt that fuel oil for marine boilers was exposed to more contamination by extraneous solids than such a fuel would be in a land installation. It was evident that the efficient removal of this material by a well established device such as the centrifuge could be expected to have beneficial effects on the performance of fuel handling and combustion equipment and on the amount of ash reaching the heat exchange surfaces of this boiler.

The position regarding sodium contamination of the fuel oil was not so obvious. Mr. Tipler's company had established that sodium could occur in fuel oil in a form which could not readily be removed by ordinary physical separation, even under controlled laboratory conditions. The amount of such sodium present in a given bunker might vary between 0 and 50 p.p.m. (as Na_2O) and might represent up to 70 per cent of the total sodium present.

What the author's test results did not show was the comparison between this unavoidable sodium burden and the amount of sodium entering the boiler as removable fuel contaminant and as airborne salt.

It was unfortunate that tests of this kind should be influenced by imponderable factors such as the availability of labour to run a hand-controlled plant. The alternative of a fully automated washing plant such as that described by Atlantic Refining Corporation or by Dr. Dear of the Central Electricity Research Laboratory would seem to be the logical approach here.

The author had made a praiseworthy attempt to describe the chemistry and physics of fuel oil ash deposition in terms which appealed to an engineering audience.

There was a danger of over-simplification however in that he nowhere mentioned the fact that under furnace conditions in the presence of excess air, the sodium and vanadium compounds present in fuel oil were volatile and that these elements were probably deposited by condensation from the vapour state. Deposition by this mechanism would occur all round the tube circumference, the rate of deposition being mainly controlled by the temperature difference between the combustion gases and the receiving surface. It was the non-volatile components of the ash which were most influenced by aerodynamic forces and which deposited on upstream facing surfaces, surfaces which could be seen by the approaching gases. It was this kind of impacted deposit which would be affected by changes in tube arrangement such as those described by the author. A corollary of the author's suggestion of the building-up of an equilibrium deposit was that the composition of material deposited by condensation could be expected to change as deposit thickness and, with it, temperature difference between gas and the deposit surface was reduced.

It would be useful in this connexion to have the author's data comparing sodium/vanadium ratio in the deposit with that in the original fuel oil. Temperature differences between gas and metal surface were usually much smaller in gas turbines than they were in boilers. Experience showed that under gas turbine conditions, considerable fractionation of the depositing material occurred, the deposit being much richer in vanadium and containing much less sodium than the parent fuel ash.

The author's work on the usefulness of the addition of aluminium to magnesium in combustion additives, in combatting deposition by sodium-bearing fuel oil ash, was most interesting. The successful use of granular metallic magnesium, introduced with the combustion air in quite small concentrations, had been described by the Central Electricity Generating Board. This prompted the thought that this idea might be extended to the use of a readily available 50 per cent magnesium/aluminium alloy. This material was brittle and could therefore be obtained in a finely milled condition. The alloy burned quite effectively when injected with the combustion air and gave the sort of very finely divided, high surface area, oxide smoke which C.E.G.B. had already shown to be so effective when using magnesium alone. Such an additive would readily lend itself to automatic dosing.

Mr. H. F. Jones wrote that Lord Geddes in opening the discussion had strongly advocated much closer co-operation between the boiler makers and the fuel suppliers.

However, he had said little about the co-operation of the shipowner, who was both the customer and the user. Further, it was possible that even closer co-operation between the directors of shipping companies, who were concerned with fuel costs, and their superintendent engineers along with the engine room staff, would benefit all concerned and possibly facilitate more reliable information on end results becoming available to equipment manufacturers and fuel suppliers.

Lord Geddes mentioned the bunker supplier and "his nearly perfect fuel", presumably with his tongue in his cheek, because he should know from experience that residual fuel of the Bunker C type was offered by the major suppliers not as the perfect fuel but as the *cheapest* fuel distributed and stocked on a global basis. Moreover quality (including its ash content) varied and would continue to vary because of the widely different crude oils used and the manufacturing processes to which such crudes had been subjected in order to meet the requirements for products that fetched a higher price than bunker fuels, and which were justifiably controlled to meet tighter specifications.

The shipowner, in order to be fully competitive, purchased the cheapest fuel he could, and on this basis he should insist that the boilers and ancillary equipment were designed to give satisfactory results on the lowest of the fluctuating qualities inherent in fuel oil.

Mr. Bunyan was to be commended for giving a forthright warning about the troubles that could arise from land based experts advocating the use of temperamental and delicate equipment aboard ship. Nevertheless, it was hoped he would realize, as the author obviously did, without any intention to "pass the buck", that reducing the sodium content of the fuel during handling and storage ashore was not a sound proposition. It would be analogous to dumping distilled water, or water boiled for drinking purposes, *back* into the cistern before consumption. The most advantageous place to remove undesirable impurities from a fuel was as near to the oil burner or injector as was practical, otherwise much work would be done for little advantage.

Those who happened to hold the same opinion as Mr. Bunyan on this aspect should bear in mind that the practical trials of centrifuging and purification of fuels aboard ship had been initiated and done aboard the tankers of major oil companies. Obviously, if the reduction of sodium content ashore were a reliable practice the oil companies involved in such research would have found this easier to put into effect than anyone else.

It was not impossible that at sometime in the future "de-ashed" (almost ash free) residual fuels might become available at a limited number of supply points. Whether shipowners would be prepared to contract for such improved quality at a premium "guestimated" at about half the difference in price between Bunker C and marine Diesel fuel remained to be seen.

Meantime the author had given the user sound food for thought on a possible way of at least partially overcoming the troubles caused by the impurities contained in the cheapest liquid fuels, especially when aggravated by a little sea water.

Author's Reply

In reply, the author said that he was deeply indebted to all those who gave up their time to make so many valuable contributions to the discussion of this paper.

That the paper should provoke such a volume of constructive discussion was a source of great satisfaction to all who were associated with the work described. It was sad therefore that the reply to this discussion must be prefaced by recording the sudden death a few days ago of Mr. J. Harle, a member of the Institute, whose guidance, based on long experience of marine engineering, was a constant source of encouragement to all associated with the project. The author in particular benefited greatly from his advice in this and other investigations.

Lord Geddes and others had complimented the author on the paper, but it must be pointed out that this credit should not be given to one man but to the Management who made available the facilities for the investigation and allocated a considerable volume of manpower for its conduct both aboard ship and in the laboratory; the efforts of the many men involved should also be acknowledged. The author did little more than observe and record the results achieved by their exertions.

Lord Geddes was entirely correct in advocating co-operative research on superheater fouling in view of the complex interaction of several groups of variables which resulted in this phenomenon. The author himself had several times suggested such co-operation (e.g. reference 25) and the Central Electricity Generating Board had now taken up this proposal and were actively organizing joint action between boiler manufacturers, oil companies and themselves concerning high temperature corrosion in oil fired power station boilers. In the marine field similar co-operation should be possible, but the author suggested that technical studies should be prefaced by consideration of the economic aspect of the problem. He had no doubt that marine boilers could now be built, capable of producing steam at temperatures up to 950 deg. F. (510 deg. C.) using present day marine fuel oils and yet avoiding significant fouling and corrosion. However such boilers would probably be more expensive in first cost than current boiler designs. Similarly the oil companies could supply fuels which would not seriously foul present day boilers, but such fuels would inevitably be dearer than those now supplied due to the additional processing involved. Thus, on technical grounds, two solutions to the problem of fouling were already available, but neither was acceptable on economic grounds. If major shipowners could collate information on the severity of superheater fouling, and on its overall cost to them, then the boiler manufacturers and oil companies could see the economic limits within which a final solution to the problem must lie. An estimate of these cost limits might well stimulate increased activity by both chemists and engineers who had been somewhat disheartened by years of chasing an "economic phantom".

With regard to the contribution of airborne salt to deposit formation, the author's company had not studied this facet, and it had been hoped that one of the contributors to the discussion might speak of investigations being made by his organization. Unfortunately such data were not forthcoming. The author would refer to published figures on salt concentrations in marine atmospheres (reference 26), and express the hope that this study would be continued and expanded.

Concerning the effect of metallurgy on the adherence of deposit layers, again little was at present known, but an exploratory investigation sponsored by the author's company (reference 27) had shown it to be a complex and intriguing study. Some systematic work on the influence of ash composition on deposit adhesion was also available (reference 28).

The author agreed with Mr. Bunyan that the prospect of operating a water washing plant of capacity twenty times that used aboard *Partula* was not attractive at the present stage of development of this class of equipment. With regard to the alternative of shore treatment, the author considered that the statement made in the paper was reasonable, an opinion which was supported by Mr. Jones in a written contribution to the discussion.

Mr. Bunyan had also asked whether the water washing technique was the only practical method of reducing the sodium contents of fuel oils. So far as the author was aware it was the only method in regular use by power plant operators, and it could be successfully applied to fuel oils of restricted characteristics available in certain areas. This limitation was of course unacceptable when the installation was aboard ship. In some refineries de-salting techniques for reducing the sodium contents of fuels were already in use, and most oil companies were expending considerable efforts (e.g. reference 29) to evolve methods of de-ashing fuels at lower costs than that quoted by Mr. Jones.

The author regretted that he could give no precise figures for the rate of emulsion formation in the *Partula* installation; once operation of the plant had been stabilized this factor caused no problems.

Mr. Bunyan's question concerning the effect on heat transfer coefficient of changing from staggered to in-line tube layouts could not be answered in a few words in view of the numerous factors involved. However a comprehensive discussion of the effect of this change was available in reference 4 of the paper itself. This pioneer study warranted close examination.

Lastly Mr. Bunyan asked whether tube washing every four months was a bad thing. Certainly if the operator could always remove deposits as easily as Mr. Bunyan indicated there would be no problem, and this paper would not have been presented. The unfortunate fact was, however, that in numerous ships two months' steaming was sufficient to produce deposits of such thickness and tenacity that measures much more violent than Mr. Bunyan's "gentle spray of warm water" were needed, and clean bright tubes were rarely seen.

Mr. Trowbridge was closely associated with the project throughout, and his observations were therefore of great interest, and his contribution to the work should be fully acknowledged. Mr. Trowbridge suggested that "the excitement of the research laboratory was carried into the calm of the ship's engine room". This was not quite the case, since all the personnel directly concerned with the investigation were marine engineers (with the exception of the author who became a research worker only after completion of the project). The basic concept of the trials was that they should be as practical as those made aboard the *Atlantic Seaman*. The only major difference (and the author considered it an improvement) was that aboard the *Partula* one boiler was used as a standard against which to judge the performance of the other. This introduced no new problems of boiler operation since the fuel system was so arranged that the boiler controls were completely unaltered so far as the operator was concerned.

Mr. Trowbridge was entirely correct in pointing out the difficulties of planning a rigorous trial using operational plant as the test instrument, but the author could see no alternative to this approach if truly practical data were being sought. Certainly mistakes were made, the most serious and elementary being to instal the gear aboard ship without the period of shop trials which had been envisaged. In retrospect it would obviously have been preferable to have accepted the delay of several months incurred by awaiting the docking of a similar vessel to the *Partula,* and to have used that period for a thorough examination of the potential of the equipment.

Mr. Trowbridge's comments concerning the influence of ash melting temperatures and tube surface temperatures on the formation of deposits indicated that the paper lacked clarity on this point. Fuel oil ash was usually a complex mixture of a number of components. Consequently it did not have a single sharp melting point, but gradually softened and liquified over a broad range of temperatures (e.g. reference 30). Bonded deposits would form if the tube surface temperature exceeded the initial melting point of the ash (i.e. the lowest temperature at which any of the compounds in the gas stream melted). Deposition would reach equilibrium when the surface temperature of the deposit layer reached a level at which *all* the ash in the gas stream was molten. The word "all" was included in the Appendix to which Mr. Trowbridge referred, and was of considerable importance. This latter temperature was the true final melting temperature of the ash.

Mr. Trowbridge was correct in pointing out the influence of boundary layer thickness on deposit formation, and it was true that in the region of extremely low velocities, say below 1ft./sec., reduction of velocity could increase the "catch efficiency" of a tube bundle. However this region was not of practical interest, and there was ample evidence that when considering velocities above 10ft./sec., reduction of velocity would yield a reduction of fouling rates (e.g. references 3, 4 and 10 of the paper).

Mr. Hubbard was correct in pointing out that sodium pyrosulphate could be found in deposits formed at temperatures below 842 deg. F. (450 deg. C.) and the author's colleagues had made similar observations (reference 28). This point was not mentioned in the paper since the major preoccupation was with zones where the surface temperatures were above 842 deg. F. (450 deg. C.) and the fouling problem was correspondingly more severe. It was interesting to note that Mr. Hubbard did not appear to support the claim of Dr. Wickert (reference 30) that sodium pyrosulphate could exist at temperatures up to 1,058 deg. F. (570 deg. C.).

Mr. Hubbard's account of preliminary results obtained aboard the *British Hussar* were of great interest, and the author looked forward to fuller publication of Mr. Hubbard's findings in due course. A completely independent investigation of the effects of fuel centrifuging would be an invaluable addition to the work described in the present paper.

The ash removal rates quoted were of interest, but the author felt confident that Mr. Hubbard would agree that too much emphasis should not be placed on the figures he had quoted. The proportion of each metal removed from the fuel depended on the form in which it was present in the fuel. In the case of nickel and vanadium which were present in organic forms, the removal rates were almost certain to be very low. Silicon on the other hand was usually present as solid particles and was therefore relatively easy to eliminate. In a number of other cases, calcium, magnesium and sodium for example, either organic or inorganic forms might be present, and the efficiency of removal was heavily dependent upon the relative concentrations of the two forms. Nevertheless, in spite of these unknowns, it did appear that centrifuging of fuel oil could do nothing but good. Whether the benefits obtained were economically sound could only be judged when data were available from a larger number of trials.

The contribution made by Commander Inches was of particular interest since it was based on his wide experience of naval boilers; on the other hand, as Commander Inches himself had pointed out, naval requirements placed peculiar burdens on the boiler designer, since the plant was required to be the ultimate in compactness combined with the ability to operate over an extremely wide and irregular load cycle. It was encouraging, therefore, to observe the broad agreement between the findings in the naval and merchant marine fields.

Commander Inches' general endorsement of the safety and danger limits, outlined under the heading "Thermodynamic Design" in the paper, was greatly appreciated, but it must be pointed out that these limits were never envisaged as firm figures to which there could be no exception. The figures quoted were merely a rough guide for making a first assessment of the problem and exceptional results such as that quoted must be expected.

The possibility of combating fouling by increasing the frequency of soot blowing in boilers using high gas velocities was an interesting one. The author had no data on the relative frequency of soot blowing in the boilers from which he quoted results. Perhaps Commander Inches himself could initiate sea trials on this particular facet of the problem. The author did not feel over-optimistic concerning the outcome of such a trial since the superheater tubes of most marine boilers were very closely packed. This implied that it was very difficult to achieve a good coverage of the tube surfaces by the soot blowers.

As Commander Inches had said, it was generally accepted that combustion conditions were an important factor in deposit formation. However, the layout of current marine boilers suggested that this factor was still largely overlooked. In any design in which flames were formed at right-angles to the superheater banks, so that gases were bled off from the sides of the flames to enter the tube banks, it was difficult to envisage combustion being completed in the furnace (see Fig. 13).

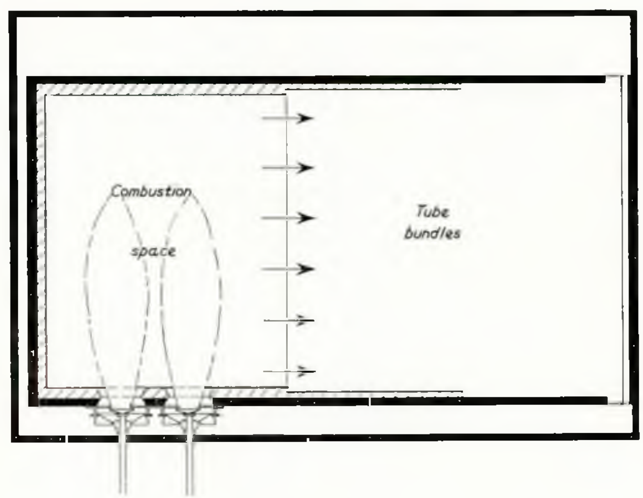

Fig. 13

While this situation held, one must continue to advocate attention to combustion conditions.

The idea of controlling ash deposition in gas turbines by variation of fuel spray particle size was pioneered by the author's company (reference 13 of the paper). Outstanding results were obtained on an experimental gas turbine and on test rigs, but practical difficulties (e.g. reference 12 of the paper) made it impossible to exploit this discovery in the field. There was certainly nothing of particular significance in the mean droplet diameters of 43 and 69 microns used in the earliest investigations of this facet. Observation of fouled superheater banks had shown that impact deposits on the upstream sides of the tubes were the major contributors to the fouling. This in turn suggested that either the gas velocity should be reduced, or the ash particles made smaller. The latter was most readily achieved by attention to obtaining complete combustion *in the furnace* and by reducing fuel spray particle size. In a practical plant, burning large quantities of fuel, it was considered unlikely that mean particle size would ever be so fine as to aggravate the problem. A controlled amount of carbon in the gas stream in the form of cenospheres (not smoke particles) might be advantageous but, in the author's opinion, the difficulties encountered in gas turbines eliminated this approach on boiler plant.

With regard to the influence of air velocity on flame volume, the formula quoted in the paper relating flame volume and fuel flow rate could be extended as:

$$V \propto F^{\frac{3}{2}} v^{-\frac{3}{2}} \propto F^{\frac{3}{2}} \triangle p^{-\frac{3}{4}}$$

where V = Flame volume
F = Fuel flow rate
v = Air velocity through air register
$\triangle p$ = Pressure loss across air register

Concerning the effect of load cycle, the author was unable to add anything to the statement made in the paper which would be of any significance under the particular (and extreme) circumstances of a naval boiler.

Commander Inches' remarks concerning the make-up of fuel oils required some comment. Fuel oils sold for boiler applications were almost without exception blended fuels, i.e. they consisted of residual components cut back with a distillate to obtain the required viscosity level. The range of distillation temperatures covered by the distillate fraction might vary considerably. Only in exceptional circumstances would the fuel oil meet Commander Inches' definition of a straight run fuel. Some years before the author had been responsible for a series of trials in which fuels to a fixed specification were made from a given crude oil, using as wide a variety of refinery techniques as possible. No significant difference in the combustion characteristics of these fuels was detected when they were burned using a pressure jet type burner.

The contribution which the Admiralty were making to the study of fouling by supporting investigations at universities should be greatly appreciated by all concerned with this problem, and publication of the results of these detailed experiments was keenly awaited.

Fuel centrifuging trials aboard a frigate would be of great interest due to the wide differences in condition in such a ship compared with the *British Hussar* and *Partula*. However, having had the privilege of visiting such a ship with Commander Inches, the author fully appreciated the space problem involved.

It was difficult to comment on Commander Inches' enquiry concerning the relative importance of removing asphaltic material, silica and other solids, or sea water from the fuel. All occurred simultaneously, to extents dependent upon the previous history of the fuel, and the removal of each type of component was beneficial. Their relative importance must vary from case to case. The presence of airborne salt was a further complicating factor, particularly in naval installations having air inlets much nearer sea level than in most merchant vessels. The Admiralty's own studies should elucidate this latter point.

Following the work described in the paper, the author would agree wholeheartedly with Commander Inches that things certainly did "gang aft agley", particularly at sea. The Commander might well be correct in stating that experience with land based boilers might cause trouble if applied to marine boilers, but they were evidently agreed that at least some valid lessons could be learned ashore.

Although he had written at some length in reply to Commander Inches' comments, the author was conscious that he had not dealt adequately with the many valuable observations made.

Mr. Culver had asked for comparative analyses for bunkers supplied in 1963 and 1943. The choice of 1943 was unfortunate since under the conditions then prevailing, fuel quality was extremely variable, and the author could see little point in comparing these two years. Comments concerning the hydrocarbon content of the fuel oils were made in reply to Commander Inches. With regard to ash content, the statement contained in the paper stood. Mr. Culver referred to deterioration of heat recovery equipment. In this case the ash content of the fuel was of little significance, since this deterioration resulted from the formation and condensation of sulphuric acid in low temperature regions of the plant. Discussion of this type of attack was beyond the scope of the present paper.

The author agreed with Mr. Culver that marine boiler design could not follow land practice too closely due to the penalties of weight and space which were involved; nevertheless some exchanges of ideas and experience might be beneficial to both.

With regard to the use of additives injected in slurry form, the author had discussed this approach in the United States and was convinced that it was worthy of trial ashore. He was dubious of its practicability at sea due to the difficulty of obtaining a reasonably even deposit layer of the additive over a closely packed superheater bundle. In addition the production of the slurry itself was not a particularly simple proposition.

In view of the volume of discussion, the author asked Mr. Culver to excuse him from dealing with deposition in turbochargers, particularly as this was beyond the scope of the paper. He would be pleased to meet Mr. Culver on this subject.

Dr. Dear's experience with an automatic washing plant was of great interest, but unfortunately he had omitted to mention the throughput of which it was capable, or the demulsifier used. The author could not agree with Dr. Dear's statement that "a product with approximately 15 p.p.m. of sodium could easily be produced" in view of the laboratory trials quoted in the paper under "Discussion of Results". Dr. Dear must realize that he was faced with a very favourable situation in that his power plants were static and supplied with fuels from a limited number of sources. Shipboard operation involved a range of variables which could be ignored in land practice.

Some trials were carried out at a recycle temperature greater than 140 deg. F. (60 deg. C.) but circumstances did not permit a thorough investigation of this variable; the temperature quoted was used on the advice of the equipment manufacturers. The author had no experience of a pressurized plant, and would follow Dr. Dear's experiments with keen interest.

Mr. Zoller was entirely correct in commenting on the downward trend of steam temperatures in the United States. In the original version of Fig. 1 this had been shown by a break in the upper curve, but an error had crept into a later version; this would be corrected.

Mr. Zoller's comments concerning recent trends in marine boiler design would be re-assuring to boiler operators.

He had also asked why surface temperature influenced the rate of deposit build-up. This subject was discussed in reply to Mr. Trowbridge—it was believed that the rate of build-up was markedly influenced by the stickiness of the ash particles when they contacted the surface, i.e. by whether the surface temperature lay within the melting range of the ash. Concerning the mechanism of deposit build-up, he would again refer to references 3, 4 and 10 of the paper.

Mr. Milton's comments concerning the severe competition which steam was experiencing from the Diesel engine at sea were of definite significance, but called for no comment from the author. The author also noted that Mr. Milton's experience supported the claim that fouling could be minimized by attention to boiler design.

Dr. Hayter had again touched on the differences in the approach to trials aboard the *Atlantic Seaman* and *Partula*, this point being first raised by Mr. Trowbridge. The author would refer Dr. Hayter to the reply already given on this point. The further data concerning the experience of the Atlantic fleet was of considerable interest, but he still wondered why Atlantic had reverted from 1,020 deg. F. (549 deg. C.) superheat to 850 deg. F. (454 deg. C.) for more recent building. Mr. Saget in his contribution had suggested one reason for this change. The author had discussed water washing with Mr. Walls, on a number of occasions, and was delighted that his efforts were evidently being crowned with success.

Mr. Saget's contribution concerning experience with fuel oil water washing in France supported that described by Dr. Hayter with regard to the Atlantic Refining Company. However neither advanced a satisfactory explanation for the comparatively poor results obtained aboard the *Partula*.

In reply to Mr. Williams, the author would refer to his comments on slurry injection made in reply to Mr. Culver. He would hesitate to recommend this technique for use at sea.

Mr. Bradley's interpretation of the results obtained aboard the *Partula* was rather more optimistic than the author's. Certainly fuel oil water washing did produce improvements in boiler condition, but experience aboard the *Partula* did not suggest that this process could be recommended as economic and suitable for general shipboard use. Although straightforward centrifuging gave less striking results, it was cheaper in both first cost and running costs, and on balance more economic.

Mr. Brown had made some extremely interesting remarks concerning the influence of magnesium oxide upon the melting range of sodium vanadyl vanadate. Unfortunately fuel oil ash was usually a complex mixture so that the clear cut results shown in Mr. Brown's figure were unlikely to be reproduced in practice. With regard to magnesia contents as low as 15 per cent, the author could not recall any case of additive concentrations of this low level being used. In general, much higher concentrations were employed with the aim of forming magnesium ortho-vanadate ($3MgO.V_2O_5$). However if tests were run using lower concentrations, the results obtained would probably be complicated by the presence of other elements in the ash; it might nevertheless be of value for Mr. Brown to examine this region in his investigation.

The studies of air flow in naval boilers which Mr. Brown had illustrated were a good indication of the valuable information which could be obtained by the use of the water model technique. Much wider use of this approach should result in the evolution of boiler designs combining the several features mentioned by earlier speakers.

The first results of Mr. Brown's studies of the influence of excess air on deposition rates were encouraging and further results would be eagerly awaited by boiler designers and operators alike.

Dr. Chambadal had written concerning the beneficial effects of fuel oil water washing in a high temperature gas turbine, but, as Dr. Chambadal himself had pointed out, the fuel oil was of a particular type having a negligible vanadium content.

Dr. Crossley's written contribution appeared to be less optimistic concerning the practicability of sodium removal from fuel oil than were the verbal comments of his colleague Dr. Dear. On the basis of the appendix to the paper, the author would agree with Dr. Crossley that reduction of the fuel sodium content should progressively lower that rate of fouling. On the other hand, economic factors would determine the extent to which it was worth trying to reduce sodium contents.

With regard to the effect of vanadium in the absence of sodium, trials made on a gas turbine (reference 31) showed that bonded deposits formed at a turbine inlet temperature of 1,202 deg. F. (650 deg. C.) but unfortunately data were not available for lower temperatures corresponding to present day steam plant. However it would appear reasonable to expect very low fouling rates in this hypothetical case of the complete absence of sodium.

Mr. MacFarlane had written pointing out the dangers of oversimplifying the mechanism of deposition by omitting to mention the possibility of deposit formation by condensation. Mr. MacFarlane was probably correct in pointing out that under *idealized* furnace conditions the sodium and vanadium might be entirely in the vapour phase. However it was not true in practice that these elements deposited mainly from the vapour phase. Observation of marine boilers showed the dominant importance of impact deposits, and such deposits would be formed by relatively large ash particles present in the solid or liquid phases. Analyses of such deposits, as shown in Table VI of the paper, indicated that they consisted mainly of sodium and vanadium oxides. Had these metals been mainly in the vapour phase, they would presumably not have formed the marked impact deposits which were observed. All the analyses quoted in Table VI inevitably referred to impact deposits since only the upstream sides of the superheater tubes were accessible for the removal of samples.

Certainly some fine deposit layers formed on the downstream sides of tubes, and condensation might well be the mechanism behind such deposition. However at the present time such deposits were of no operational significance in marine boilers. The author had therefore felt entitled to omit discussion of the condensation mechanism in the interest of clarity.

Mr. Jones' written contribution called for no comment from the author, apart from thanks for his support in a line of argument which was not widely accepted, although soundly based on a considerable volume of investigation and experience.

In conclusion, the author would state that while he was most appreciative of the volume of discussion which the paper stimulated, he did not feel equal to the task of drawing conclusions from the mass of information presented. In such a matter where deductions must inevitably be based on economic as well as technical factors, conclusions must vary according to the set of economic factors selected. It would therefore appear advisable to leave the reader to draw his own conclusions, against the economical background relevant to his case. Certainly the contributors to the discussion had presented him with a wealth of data.

REFERENCES IN REPLY

25) Tipler, W. 1963. "The Mechanism of Corrosion by Fuel Impurities"—Butterworths. First edition. Contribution to discussion, p. 526.
26) MacNair, E. J. 1963. *Ibid.* Contribution to discussion.
27) Steel, J. S. and Brandes, E. A. 1963. *Ibid.* "Growth and Adhesion of Oxides in Furnace Deposits", p. 374.
28) Small, N. J. H. *et al.* 1963. *Ibid.* "Recent Advances in the Chemistry of Fuel Oil Ash", p. 238.
29) Voorhies, A. *et al.* 1963. *Ibid.* "Demetallization of Residual Fuels", p. 312.
30) Wickert, K. 1961. "Das Oelfeuer Jahrbuch 1961". Verlag Gustav Kopf and Co. KG., p. 153.
31) Brown, T. W. F. 1954. "High Temperature Turbine Machinery for Marine Propulsion"—Proc.I.Mech.E., Vol. 168, p. 125.

INSTITUTE ACTIVITIES

Minutes of Proceedings of the Ordinary Meeting Held at the Memorial Building on Tuesday, 10th December 1963

An Ordinary Meeting was held by the Institute on Tuesday, 10th December 1963, when a paper entitled "Some Results Obtained from a Fuel Oil Water Washing Plant in Studies of the Fouling of Marine Superheaters" by W. Tipler, M.A., was presented by the author and discussed.

Commander F. M. Paskins, O.B.E., R.D., R.N.R. (Chairman of Council) was in the Chair and ninety members and guests were present.

Fourteen speakers took part in the discussion which followed.

The Chairman thanked the author for his paper and his reply which had received enthusiastic response.

The meeting ended at 8.5 p.m.

Section Meetings

Northern Ireland Panel

A senior meeting was held on Tuesday, 21st January 1964, at 7.00 p.m., in the Millfield Building of the College of Technology, Belfast. D. H. Alexander, O.B.E., F.C.G.I., M.Sc., Wh.Sc. (Local Vice-President) was in the Chair and about forty-five members and visitors were present.

The speakers at the meeting were Mr. C. W. Herbert (Member) and Mr. G. F. Milne, B.Sc. (Associate Member), who presented a paper entitled "The Application of Free-piston Gas Turbine Machinery to Marine Propulsion".

Dr. F. Wallace, Reader in Thermodynamics at The Queen's University of Belfast, proposed a vote of thanks, which was seconded by E. C. Sides (Member).

Scottish

The Tenth Annual Dinner was held on Friday, 21st February 1964, at the Central Hotel, Glasgow, at 7.15 p.m.

Mr. L. D. Trenchard (Chairman of the Section) presided and 434 members and guests were present.

Commander F. M. Paskins, O.B.E., R.D., R.N.R. (Chairman of Council) and the Chairman, Mr. L. D. Trenchard, received the guests at a reception prior to the Dinner.

Sir Charles Connell, D.L., M.A., proposed the toast to

At the Annual Dinner of the Scottish Section, held on Friday, 21st February 1964, at the Central Hotel, Glasgow. From left to right: Sir Charles Connell, D.L., M.A., Commander F. M. Paskins, O.B.E., R.D., R.N.R. (Chairman of Council) and Mr. W. Nicholson

Mr. L. D. Trenchard (extreme right) (Chairman and Honorary Secretary of the Scottish Section) with guests at the Annual Dinner of the Section. From left to right: The Reverend J. R. Gray, Captain R. G. Black, U.S.N., commander of the Hunley, *and Sir Charles Connell, D.L., M.A.*

"The Institute of Marine Engineers in Scotland", to which Commander F. M. Paskins, O.B.E., R.D., R.N.R., replied.

The toast "Our Guests" was proposed by the Chairman and the reply was made by Mr. Iain V. R. Harrison.

The top table party consisted of representatives of local shipowners, shipbuilders, survey societies, sister institutions and office bearers of the Section. The United States Navy was represented by Captain R. G. Black, U.S.N., commander of the Polaris depot ship *Hunley*. London Headquarters was represented by Mr. W. Young, C.B.E. (Vice-Chairman of Council) and Mr. J. Stuart Robinson, M.A. (Secretary of the Institute). The Reverend J. R. Gray was the officiating chaplain.

The Dinner was followed by a conversazione until about midnight.

South Wales

Junior Meeting

A junior meeting was held on Monday, 20th January 1964, at 6.00 p.m., at the Welsh College of Advanced Technology, Cardiff. Dr. A. Harvey, B.Sc., F.Inst.P., Principal of the College, presided for the evening, and sixty students and members were present.

Dr. A. J. Johnson, B.Sc. (Eng.) and Mr. W. McClimont, B.Sc. (Member) gave a lecture on "Vibration" to the appreciative audience.

General Meeting

A general meeting was held on Monday, 3rd February 1964, at 6.00 p.m., at the South Wales Institute of Engineers, Park Place, Cardiff. Mr. T. C. Bishop (Chairman of the Section) was in the Chair and sixty-eight members were present.

A paper entitled "Unusual Damage to Hull and Machinery" was presented by Mr. J. Wormald, B.Sc. (Member). The lecture was well illustrated by drawings.

The vote of thanks to Mr. Wormald was proposed by Mr. F. R. Dale, B.Sc. (Associate Member) and that to the Chairman, by Mr. R. H. Rees, O.B.E. (Member).

West Midlands

A general meeting was held at 7.00 p.m., on Thursday, 20th February 1964, at the Engineering and Building Centre, Broad Street, Birmingham. Mr. R. R. Gilchrist, M.A. (Chairman of the Section) was in the Chair and thirty-one members and visitors were present.

Mr. J. H. Milton (Member of Council) presented a paper entitled "Interesting Investigations" and, with the aid of slides, described in great detail the work entailed in carrying out investigations into main and auxiliary equipment in the marine field. He also described the problems which were encountered in overcoming and trying to establish the reasons for certain of the failures, and the work involved in trying to achieve this without interfering with the running of the machinery.

Unfortunately, the discussion was limited, due to the time running out, but all questions which were asked were ably dealt with by the author.

On behalf of the members and visitors present, the Chairman thanked Mr. Milton for a most interesting and stimulating paper.

The meeting closed at approximately 9.00 p.m.

West of England

A general meeting was held on Monday, 10th February 1964, at 7.00 p.m., at Smith's Assembly Rooms, Westgate Buildings, Bath. Captain A. C. W. Wilson, R.N. (Chairman

NIGERIAN SECTION

Members of the Committee of the recently formed Nigerian Section, with the guest of honour, the Honourable R. A. Njoku (seated in centre), Federal Minister of Transport, Nigeria, at the inaugural Dinner of the Section, held on Saturday, 11th January 1964, at the Bristol Hotel, Lagos. Also seated are: Captain J. E. A. Wey, Royal Nigerian Navy (left) (Chairman of the Section), and Mr. G. H. Bassey (Vice-Chairman of the Section). Standing, from left to right: Mr. A. C. Bose (Honorary Secretary), Mr. M. A. Lawal, Mr. R. V. Rajan (Honorary Treasurer), Mr. O. E. Asuquo, Lieutenant L. V. Reddy, I.N., and Mr. E. F. Quirk

A group of members of the Nigerian Section at the inaugural dinner which proved a great success. The Federal Minister of Transport, the Honourable R. A. Njoku, made an excellent speech in which he wished the new Section a great future of the Section) was in the Chair and Mr. F. C. Tottle, M.B.E. (Local Vice-President, Bristol) was also present. Thirty-two members and visitors attended the meeting.

After a speech of welcome by the Chairman, a paper entitled "The Application of Free-piston Gas Turbine Machinery to Marine Propulsion" was presented by the authors, Mr. C. W. Herbert (Member) and Mr. G. F. Milne, B.Sc. (Associate Member).

The authors gave an account of their experience in this field and described the evolution and performance of this type of machinery, from 1957 to the present day. A description was given of the two different installations in g.t.v. *Goodwood* and g.t.v. *Rembrandt*, showing that the system was simple and reliable. This type of machinery had tremendous scope, because of the relatively few working parts, and was ideal for c.p. propellers and bridge control. Much thought had also been given to machinery arrangements for different classes of vessels.

The authors realized, however, that at present, the efficiency of this plant could not compare with that of the Diesel engine, particularly the 2-S.C.S.A. turboblown type. Nevertheless, great strides were being made in this direction with free-piston machinery. Piston ring and liner wear could compete more than favourably with that of the Diesel engine and the gas turbine gave trouble free running at all times.

One point of interest, made by Mr. Herbert, regarding the increase in efficiency of this plant, concerned the introduction of wet compression. He felt that this feature would give tremendous improvement in efficiency, although a great deal of research had still to be done.

During the ensuing discussion, it was pointed out that, from an efficiency point of view, free-piston machinery was competing against the gas turbine and the Diesel engine, which were being perfected all the time, and it would be a long time before the free-piston machinery could catch up with them. The authors agreed with this, but remarked that a time would come when these competitors would reach their optimum efficiency and, by that time, the free-piston gas turbine installation would also have reached its maximum efficiency, which, coupled with the many other advantages offered, would make it a really worthwhile proposition.

In closing the proceedings, the Chairman expressed his gratitude to the authors for their very interesting paper and for answering the questions put to them by the members.

The meeting closed at 9.15 p.m.

Election of Members

Elected on 10th February 1964

MEMBERS

Philip Sayer Armstrong
George Samuel Boffey
Nigel Caffyn
Richard Ellis
Giovanni Giuliana, Dott. Ing., Lt. Col. Engineer, Italian Navy
Theodore Iatropoulos
Vladimir J. Lebedev, Capt., U.S.S.R.N.
Donald MacInnes
Ronald Ewen Mackinnon
David Anderson Nicol Martin
Earl Matthews
Donald Stephen Townend, B.Sc. (Eng.), London
Prof. Dr. Ir. W. P. A. Van Lammeren
Ronald Watson

ASSOCIATE MEMBERS

Leonard Murray Short Bell
Charles Kenneth Bragg
Raymond Neil Callaby
John William Carlisle
Peter Davies-Carr
Michael Ferryman
James Henry Gerrard
Charles Belli
James Henry Emmerson
Md. Abdus Samad
Peter Ash Vie

GRADUATES

Geoffrey Francis Dart
Derek Clement Davies
David Emerson
George Douglas Hornsby
Gulab Rijhwani
Hira Lal Sharma
William Alan Stewart

STUDENTS

Howard Barnes
Alan Nicholas Campion
Bruce Michael Faulder
Edward Bruce Gibson
Brian John Hall
Michael Anthony Jackson
Brian Thomas Kevin
Michael Constantine Lainas
David George Malton
Sarosh Homi Marker
Michael Hugh Mateer
Brendon Michael Pickthall
Francis Edward Pleavin
Peter Priestnall
Martin John Reeves
John Stephen Riley
Peter Derek Stanworth
Brian Norman Stonely
Roger John Timms
Norman Travis
Robert Hubert Vart

PROBATIONER STUDENTS

Roland Aylwin Bainbridge
Thomas Joseph Bampton
Peter Ross Noel Barrar
Michael Anthony Brown
Anthony Victor Chivers
John Robert Clark
Terence William Davies
Edwin Stuart Garrett
Kenneth Graham
Nicholas John Harris
Anthony George Hines
Jeremy Victor Hockin
G. Hopkins
Ian Melvin Horrocks
Meirion Hughes
Anthony Jackson
Paul Jessey
Colin Charles Knill
Ross Richard Larsen
Alan Curtis Littlewood
Irvine Oswald Long
John Maling
Christopher John Matlock
Peter Thomas Mitchell
Christopher John Morton
Douglas Mackenzie Nettleton
George Edward Nicholson
Ian Clarence Pickering
Nicholas Michael Pope
David Warwick Preston
Simon Mellersh Rendall
Anthony Reid Russell
Stephen John Sherring
Anthony Charles Smith
Dennis Richard Michael Smith
James William Smith

Joseph Gillan, B.Sc. (Belfast)
Andrew Alexander Hope
William Lamb
James Lyness
William James McAnally
Allan Wilson McAra, Lt. Cdr., R.N.
Stanley John Marchant
James Brian Mason
Donald Alexander Matheson
Daniel Fairbairn Matthews
Peter William Benjamin Stoodley
Robert Laslett Thomas

ASSOCIATES
Reginald Sydney Abbott
John Probyn Sproat
Barry Patrick Sullivan
Christopher Paul Tamblin
John Tomlinson
Brian William Wright Taylor
Daniel Turner
Terry Grant Wise

TRANSFERRED FROM ASSOCIATE MEMBER TO MEMBER
Robert William Anderson
Derek Charles Patrick Crowe
William Francis Dowie
Frank Hipson

TRANSFERRED FROM ASSOCIATE TO MEMBER
Douglas Royston Matthews

TRANSFERRED FROM GRADUATE TO ASSOCIATE MEMBER
John Gabriel Creen
Robert Howe
Desmond William John Phillimore
Davinder Nath Sabharwal, Lieut. (E), I.N.

TRANSFERRED FROM STUDENT TO GRADUATE
Michael Douglas Spear
Alan Frank Wilde

TRANSFERRED FROM PROBATIONER STUDENT TO STUDENT
Sunday U. Akpan
John Brian Gray
Christopher Guy Scott Wilson

OBITUARY

RICHARD JOSEPH BLACKMAN, O.B.E. (Member 8399), a Member of the Institute since 5th April 1937, died suddenly on 19th September 1963, following a heart attack. He was in his sixty-third year.

Mr. Blackman, who had served an apprenticeship with Associated Portland Cement Manufacturers, joined the sea staff of Houlder Brothers and Co. Ltd., in May 1924, as junior engineer in s.s. *La Rosarina* and served continuously at sea in a number of vessels until January 1935, when he was appointed chief engineer in m.v. *Imperial Transport*. In December 1937 he was transferred to m.v. *Beacon Grange*, then the latest vessel of the Houlder Line. Mr. Blackman continued his service in the *Beacon Grange* and, on 22nd August 1940, the vessel was bombed, badly damaged and set on fire. By virtue of strenuous efforts by the officers and crew for sixteen days, the fire was extinguished and repairs executed, and the vessel was able to proceed to Dundee. For exceptionally good work at this time, several officers were decorated, Mr. Blackman being awarded the O.B.E. He was still serving in the same vessel when she was torpedoed and sunk on 27th April 1941. Mr. Blackman then remained ashore and, for the remainder of the war period, was retained by the Ministry of Supply. He returned to Houlder Brothers as engineer superintendent in 1948.

For the past few years he had not enjoyed the best of health and had intended to retire from active service with the company towards the end of 1963.

HENRY DAVID BUTTERWORTH, B.Sc. (Member 12362) died suddenly in October 1963 at the age of 56 years.

He gained his Bachelor of Science Degree in engineering from Leeds University in 1927 and, from 1928, was articled for four years to William Shepherd, chartered civil engineer and consultant. From 1940-1945 he served, with the rank of Commander, R.N.V.R., as Admiralty Civil Engineer (India), being responsible for all Indian-based dredging craft and, for the following four years, held a similar appointment at H.M. Dockyard, Portsmouth. He left the Admiralty in 1949 and, for the remaining fourteen years of his life, was engaged on engineering contracts by a number of companies in various parts of the world. He was, at different times, employed on projects in Lagos, Singapore, Hong Kong, British Guiana and Haifa. In September 1962, Mr. Butterworth accepted an appointment in West Bengal with I.C.C. Ltd., consulting engineers, but a year later was compelled to make a sudden return to the United Kingdom by ill-health due to a heart condition. His death occurred shortly afterwards before any steps could be taken to alleviate this.

Mr. Butterworth was elected a Member of the Institute on 4th April 1949; he was also a Member of the Institution of Professional Civil Servants, of the Institute of Navigation and a Fellow of the Royal Geographical Society.

ALFRED HAROLD CHARLTON (Member 21662), who died on 9th November 1963, served his apprenticeship with John Lynn and Co. Ltd., engineers. He began his seagoing career in 1931 as fifth engineer with Sir W. R. Smith and Co. Ltd. and served with that company through various grades up to second engineer. From 1936 to the outbreak of the Second World War he was at sea with several companies as either third or second engineer. In 1939 he joined the Royal Navy as an engine room articifer, rising to the rank of Lieutenant (E). Demobilized in 1946, he joined the Palm Line Ltd. as second engineer, later transferring to F. C. Strick and Co. Ltd. in the same grade. He returned to the service of Sir W. R. Smith and Co. Ltd. as a chief engineer, in 1949, and held that appointment until, in 1959, he joined Wm. Doxford and Sons Ltd., as Guarantee Chief Engineer. He remained in this employment until the time of his death.

Mr. Charlton was elected a Member of this Institute on 14th December 1959.

FREDERICK JOHN CHENERY (Member 7959) was born on 12th March 1904. From 1921 to 1926 he was apprenticed to the Shell Mex Co. Ltd., after which he joined the Anglo-Saxon Petroleum Co. Ltd. as a seagoing engineer. He remained with Anglo-Saxon for the next thirteen years, until in 1933 he secured an appointment as a construction engineer in the Trans-Jordan. He resigned this appointment in 1949 to join the Shell Refining and Marketing Co. Ltd. as a project engineer. Later he became engineer in charge of construction of major oil and chemical plants and, having been employed in various capacities, became assistant chief engineer in 1959. He was due to retire in March of this year.

Mr. Chenery was elected a Member of the Institute on 7th October 1935.

ENGINEER LIEUTENANT JOHN CORDINGLEY, R.N. (Member 3977) died in a Harrogate nursing home on 23rd October 1961.

Born on 15th March 1879, he was educated at Bradford Grammar School and served an engineering apprenticeship with the Campbell Gas Engine Co. Ltd. Lieutenant Cordingley saw many years' sea service, both with the Royal Navy and the Merchant Service, and held a First Class Board of Trade Certificate. He retired from the Navy in 1936 and accepted an appointment as Engineer Manager at the Victoria Dyeworks of Buckle Crossley and Co. Ltd. He retired from this position three years later at the age of 59 years. He was very interested in ship modelling and was an accomplished artist. He was a staunch supporter of the Church and was Vicar's Warden at St. Peter's Church, Allerton, Bradford, for twelve years.

Lieutenant Cordingley was elected a Member of the Institute on 20th July 1920.

GEORGE ELLIS GLOVER (Member 8889) was born on 24th October 1906. He served his apprenticeship with John Lysoght Ltd., from 1922 to 1927, after which he spent nine years as a seagoing engineer, first with the Prince Line Ltd., and later with the Anglo-Saxon Petroleum Co. Ltd. During his sea service he gained a First Class Motor Certificate. In 1936 he joined the United British Oilfields of Trinidad as a maintenance engineer and remained with that company until 1946. During this time he held posts as Senior Refinery Engineer and Office Engineer. In 1947 he became Resident Field Engineer with the Caribbean Shell Venezuela Co. Ltd and, in that capacity, held various posts in the different oil fields in Venezuela. Later he was transferred to the office staff, as Senior Engineer of C.S.V. Ltd., in Maracaibo, where he remained until 1959. He was due for retirement from foreign service and had been appointed to a senior post in the London Offices of the Shell International Petroleum Co. Ltd. However, he was unable to take up that appointment, due to a breakdown in health following coronary thrombosis. He died on 28th March 1963, after a long illness.

Mr. Glover was elected a Member of the Institute on 1st May 1939.

CRAWFORD WILLIAM HUME (Member 11023), formerly chairman of James Howden and Co. Ltd., died in London on 23rd November 1963.

Born in Glasgow on 30th April 1895, Mr. Hume was educated at Glasgow Academy and Glasgow University, being awarded the Muir Bursary in Engineering in 1915. He also served an apprenticeship with Howden's. For two years from 1918, he was in the United States, there being responsible for the management of James Howden and Co. of America (Inc.). He joined the board of directors of the parent company in 1921 and became chairman of the board in 1939. He resigned from the chairmanship in June 1963, due to ill health.

Mr. Hume was elected a Member of this Institute on 5th November 1946 and, in addition, had been elected to membership of a number of other professional institutions, including the Royal Institution of Naval architects, the Institution of Engineers and Shipbuilders in Scotland and the North East Coast Institution of Engineers and Shipbuilders.

He is survived by his wife and a daughter.

JAMES WHEELER LAWSON (Honorary Life Member 2097) died on 17th November 1963, in his seventy-third year. He was elected a Graduate of the Institute on 30th July 1908, transferred to Associate in 1913 and was made an Honorary Life Member in 1959. He had, thus, had fifty-five years of continuous membership.

Mr. Lawson was born in Maryborough, Queensland, and was educated at a private school in London. In 1907, he was apprenticed to G. and J. Weir Ltd., of Cathcart, Glasgow, and in this period attended the Glasgow Technical College.

In 1913, he joined the London and Pacific Petroleum Co., as junior engineer in s.s. *Mina Brea* and, two years later, became junior engineer with the Indo-China S.N. Co., remaining with that company until his retirement in 1946. He became successively, second engineer in 1917, chief engineer in 1925, Assistant Superintendent, Hong Kong, in 1930, and finally Superintendent Engineer, Hong Kong, in 1935.

On the surrender of Hong Kong in 1941, Mr. Lawson was interned by the Japanese, at Stanley Camp, until released in 1946. Owing to ill health, he retired from the service of the company and joined his family in Hobart, Tasmania.

Mr. Lawson was always very proud of his association with the Institute and in his retirement, still took a keen interest in its proceedings.

RALPH BERNAL PARKE PADBURY (Member 3516), Governing Director of Dudgeon and Gray Ltd., died on 8th January 1964. He was in his seventy-eighth year.

Mr. Padbury was educated at Emmanuel School, Wandsworth Common, and studied engineering at the Polytechnic, Battersea, and at the Colchester School of Science and Art. From 1902 to 1907, he was apprenticed to A. G. Mumford Ltd., of Colchester.

On completion of his apprenticeship, he joined the Orient Steam Navigation Co. Ltd. (Orient Line) as a seagoing engineer and served the company in that capacity for the following six years. During this time, he gained a First Class Board of Trade Certificate of Competency and was finally serving as an engineer in charge of a watch. In 1913 he accepted a shore appointment with the Orient Line and was engaged as a draughtsman for two years until, in 1915, he joined the Department of the Engineer-in-Chief of the Fleet, at the Admiralty. In this appointment, he acted as Assistant to the Engineer Officer dealing with machinery of merchant vessels requisitioned for Admiralty service.

Mr. Padbury joined Dudgeon and Gray Ltd., as a consulting engineer, naval architect and marine surveyor, in 1919 and, two years later, was appointed by the company to be in sole charge during the reconditioning and reconstruction of s.s. *Podesta,* a vessel which, having been sunk during the First World War, had lain submerged for four years. At this time, he also acted as Port Superintending Officer, Port Said, for the United States Shipping Board, and as non-exclusive surveyor for the American Bureau of Shipping, in Port Said and all ports on the Red Sea.

He became a director of Messrs. Dudgeon and Gray in 1930 and Governing Director in 1939.

Mr. Padbury was elected a Member of this Institute on 14th January 1919 and was, in addition, a Member of the Royal Institution of Naval Architects and a Fellow of the Society of Consulting Marine Engineers and Ship Surveyors.

CLEMENT JOHN RIDYARD (Member 8892), who had been a Member of the Institute since 1st May 1939, died on 28th December 1963, at the age of sixty-four.

He was apprenticed to Day Summers and Co. Ltd. from 1916 to 1921 and, on completing his indentures, commenced a seagoing career with Alfred Holt and Co. Ltd. He remained with that company until 1949, gaining a First Class Board of Trade Certificate and attaining the grade of second engineer; he left Holt's to become superintendent engineer to Chr. Salvesen and Co. Ltd. Returning to the sea in 1954, he served with various companies until September 1962. From then up to the time of his death he held no appointment, owing to the shipping depression.

DAVID STEPHEN (Member 17819) who was born on 2nd April 1909, served his apprenticeship, from 1927 to 1932, with Richard Irving and Sons Ltd. of Peterhead. During this period he studied engineering at evening classes at Peterhead Academy.

In 1934 he commenced sea service as a junior engineer with the British India Steam Navigation Co. Ltd. and, remaining with that company for the next fifteen years, gained successive promotion to fourth, third and second engineer. He obtained his First Class Certificate in 1945. After leaving the service of the B.I.S.N. Co., Mr. Stephen obtained, through the Agents for the Crown Colonies, a post as Marine Engineer Grade I with the Port Directorate, Basrah, serving as chief engineer in a dredger. He returned to the United Kingdom in 1959, after the political upheavals in Iraq.

From 1959 onwards his health was such as to prevent him from continuing in his career and he was compelled to retire prematurely. He died suddenly at Woodford Hospital, Aberdeen on 2nd September 1963.

Mr. Stephen was elected a Member of the Institute on 25th September 1956.

CYRIL WILEMAN (Member 17826) died suddenly at his home in Tarleton, Lancashire, on 7th September 1963.

Mr. Wileman was born on 29th August 1902. He served his apprenticeship with the Cunard Steamship Co. Ltd., at their Engine Works in Liverpool, from 1918-1922, and with Charles Howson and Co. Ltd., from 1923-1924. He also studied engineering at Liverpool Central Technical School and Liverpool College of Engineering.

He went to sea, in 1924, as a junior engineer with the Ellerman Hall Line, was promoted to second engineer in 1930 and sailed continuously, in that grade, until December 1938, when he left the company to seek shore employment. He had held a First Class Certificate since October 1929. After retiring from the sea, Mr. Wileman accepted an appointment with the Inspectorate of Fighting Vehicles and Mechanical Equipment, War Office Inspection Organization, as Inspecting Officer and, at the time of his death, was Inspector-in-Charge at Leyland Motors Ltd.

Mr. Wileman was elected a Member of this Institute on 25th September 1956.