DIESO COALESCERS

FOR GAS-TURBINE-PROPELLED SHIPS

BY

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Introduction

This article is intended to acquaint the Fleet with the detailed design and the testing effort that is necessary to provide the later classes of gas-turbine-propelled ships with components for the satisfactory cleaning up of fuel systems. The development of such systems and components entails the integration of knowledge from many branches of engineering and science, ranging from combustion, corrosion and fuel technology to bacteriology. Although each of these branches of science would provide the basis of a separate article, this article is concerned with equipment that is the responsibility of the Ship Department and discusses briefly the progress of work to date.

Ref. 1 gives a review of the fuel systems for these ships, i.e. the Types 21 and 22 frigates, the Type 42 destroyers and the CAH. That article shows that all these ships have different systems consisting of various combinations of non-displaced, displaced and water-ballasted fuel tanks, centrifuges, strainers, pre-filters and coalescers. All ships are common in that the final clean-up system (i.e. the boost system) employs a boost pump, pre-filter and filter/water separator (coalescer) before supplying fuel to a ring main and thence to the gas turbines. In fact, the Type 21 frigate has two boost lines working in parallel, the Type 22 frigates and the Type 42 destroyers each have three in parallel and the CAH has two × three boost lines in parallel.

The engine module specification requires fuel to be supplied to the gas turbines filtered with 98 per cent. efficiency to 5 microns and with a free (fresh) water content limited to 50 ppm by weight. The amount of sodium that may enter the engine with the fuel is to be limited to 0·28 ppm by weight made up from the following sources:

0·10 ppm by weight dissolved in the fuel
0·05 ppm by weight as particulate matter
0·13 ppm by weight in free sea-water

It should be noted that, as yet, there have been no proven instances in the Fleet of sodium being dissolved in the fuel or existing as particulate matter when it has been supplied to DEF STAN 91/4 for DIESO 47/20 (NATO F—76). However, fuels purchased abroad may be to a less stringent specification and contain sodium in these forms. Consequently, the aim of the development work reported here has been to enable fuel to be provided to the gas turbines with a maximum sodium content of 0·13 ppm introduced by sea-water contamination. This amount of sodium corresponds to a limit of 10 ppm of 'normal' free sea-water. Absorbed water contains no sodium. The maximum amount of sea-water at inlet to the coalescers from service tanks is specified as 5 per cent. Consequently the water removal efficiency of the coalescer is 99·98 per cent. This represents a safeguard since contamination levels of this order are extreme and are only likely to arise in the service tank through accident or operator error.

In general the solid contaminants that are foreign to the fuel, i.e. rust, sand, etc., can be satisfactorily removed by conventional pre-filters. However, the removal of solids derived from the fuel itself—namely fuel degradation products, waxes and asphaltenes, etc. and contaminants from heavier fuel oils such as FFO—is more difficult. Such contaminants, together with micro-biological growths, have proved to be the governing factors in developing and operating present coalescers.

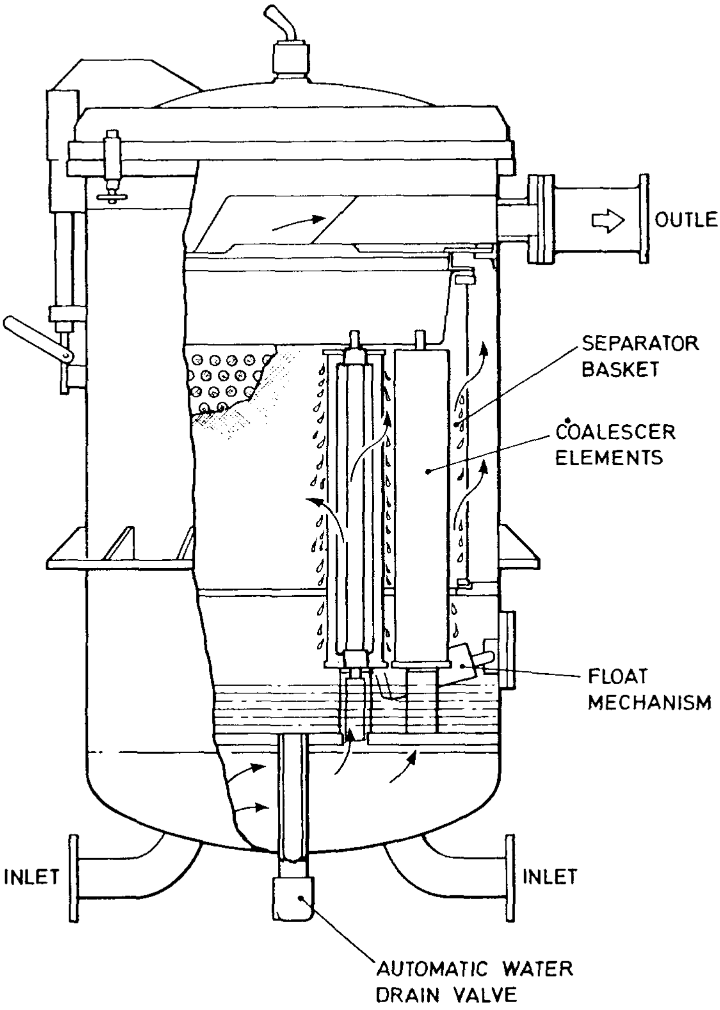

FIG. 1—CAH COALESCER

Principle of Coalescers

There are a number of kinds of coalescers ranging from electrical-precipitator types to the fibre-bed types employed in R.N. ships. However, as the name implies the object of each is to coalesce small drops of water to large ones that can separate out under gravity. From Stokes' Law, the settling is in proportion to the square of the diameter of the droplet. Consequently a typical droplet of 0·1 inches will settle out at some 60k times faster than a 10 micron droplet. Most present-day coalescers, for example that developed for the CAH shown in FIG. 1, are designed with a number of fibrous bed elements surrounded by a separator screen of hydrophobic material. The object of the separator screen is to retard the passage of fine droplets that do not settle out under gravity.

Most coalescer elements are constructed with a number of different materials to assist coalescence and filtration as the fuel-water mixture flows through them (Fig. 2). Briefly coalescing can be divided into four processes:

Interception of the water droplet.

Attachment of the droplet to the fibres.

Passage of droplets and coalescing through the bed.

Release after final growth 'ballooning' on exit from the bed.

The main physical properties that are important for the above four processes are:

Velocity.
Initial droplet size.
Fibre-bed construction.
Concentration of droplets.
Relative fuel/water density.
Interfacial tension.
Fuel viscosity.
Water viscosity.

Surfactants

The foregoing parameters are to different degrees important in each of the four processes; indeed, an increase in one parameter for a particular process may be detrimental in another. However, apart from the initial water droplet size, most of these parameters can be taken into account in designing a suitable coalescer and element. Unfortunately, a very important parameter is interfacial tension; this can be considerably affected by the introduction of very small amounts of surface active contaminants, i.e. surfactants. The effect of such contaminants is to change the shape of the emerging water droplets (Fig. 2) from the desired ballooning to water droplet chains breaking up to fine droplets that do not entirely settle out under gravity. Surfactants may also cause 'pointing' release, where 'fingers' of collected water channels taper to a point, vibrate and kick small droplets from the tip.

There are many surfactants that could contaminate DIESO. Those that are of interest here can be divided into two categories namely foreign

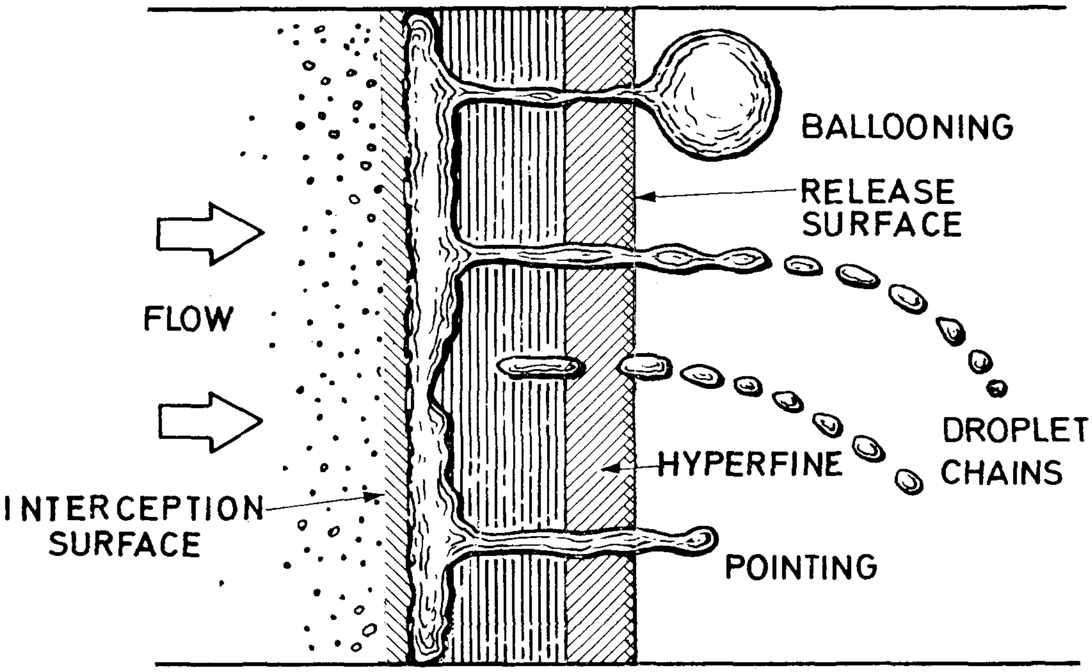

Fig. 2—Coalescing actions

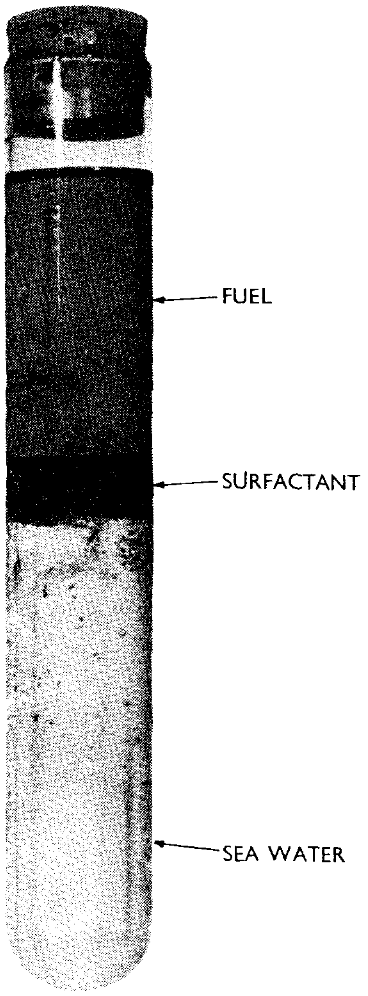

FIG. 3—CONCENTRATION OF SURFACTANTS FROM COALESCER SUMP

contaminants and those indigenous to the fuel. The most likely foreign contaminants are tank-cleaning fluids (Teepol, Gloquat, etc.) and heavy lubricating oils and FFO. The most likely indigenous contaminants will be fuel degradation products (asphaltenes, waxes, etc.) and also microbiological contaminants—which are originally foreign contaminants—and their excreted products, namely polysaccharide slimes.

Most of the foreign contaminants such as tank-cleaning fluids can be eliminated with good housekeeping. Contamination from FFO can be similarly eliminated, but this contamination will not take place onboard ships being most probably due to poorly cleaned supply tanks. Unfortunately contamination from FFO is not readily detected: recent trials at the AOL have shown that the satisfactory coalescing action of DIESO and sea-water is completely destroyed with the introduction of 0·1 per cent. of FFO.

Fuel degradation products are probably the most serious contaminants with which to deal. Such products are so fine that they cannot be detected by the human eye and are not filtered out by the pre-filters. FIG. 3 shows a high concentration of these surfactants collected from the sump of a coalescer during recent evaluation trials at the tank farm at Torpoint. It can be seen that the specific gravity of these surfactants is between that of the fuel and the sea-water; consequently it is doubtful

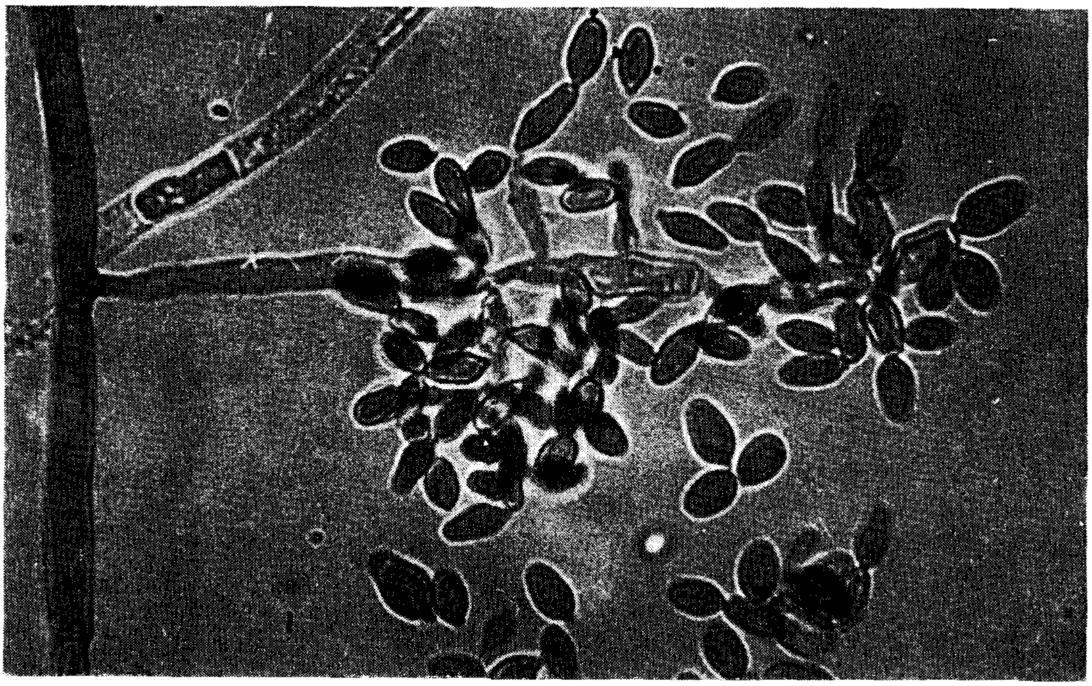

FIG. 4—CLADOSPORIUM RESINAE

if such contaminants can be removed by centrifuges.

Microbiological contamination of fuel systems and components was, until quite recently, considered to be peculiar to aviation types of fuel, i.e. kerosenes. Such contaminants in aircraft fuel not only block the systems but also the fungi produces metabolites that are capable of attacking aluminium. The most common and prolific contaminant is cladosporium resinae, the kerosene fungus (FIG. 4).

It was not until recently that the MOD became aware that this fungus could breed in DIESO. The breeding conditions needed are a source of water and hydrocarbons, an ideal environment being at the sea-water/fuel interface (FIG. 5). Such conditions are provided in water-displaced fuel systems! An unfortunate aspect of such contamination (unlike contamination from a small amount of FFO) is that once established the fungi will breed prolifically producing polysaccharide slime as a by-product. This slime is itself a surfactant.

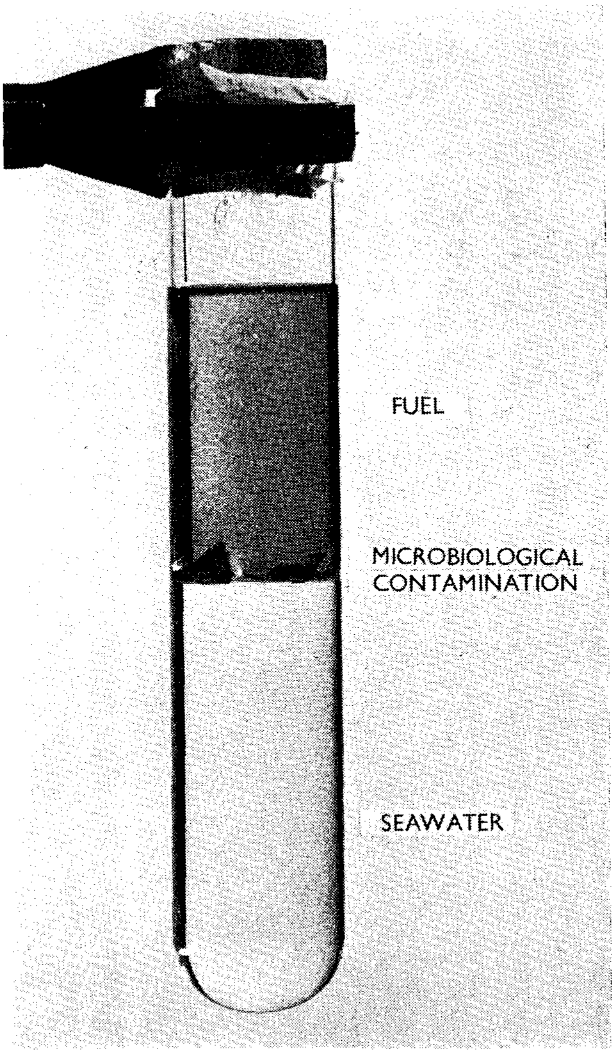

FIG. 5—SEA-WATER/FUEL INTERFACE SHOWING FUNGUS

At present there seem to be few good-housekeeping procedures that ships' staff can adopt to prevent such contamination. Preventive methods, such as the introduction of biocides into the fuel as used in aircraft practice, seemed the logical solution: however, such methods are very expensive and also such biocides are themselves surfactants to a certain extent. The introduction of routine tank and system cleaning procedures appears to be the only safe solution.

Early Development

Filter water coalescers have been used successfully for many years in the R.N. for removing both dirt and water (fresh or sea) from aviation fuels, initially gasolene for piston-engined aircraft and later from kerosene with the introduction of jet-propelled aircraft. The most important difference in aircraft application of coalescers is in the type of the fuel and the system in which it operates. Gasolene is a very clean fuel of relatively low distillation temperature, i.e. low fractions. Similarly kerosene (AVCAT) although with higher fractions than gasolene is a 'clean' fuel. Both these fuels are extremely low in surfactants and fuel degradation products. The requirement to remove water from aircraft fuels was not to protect the engine from high temperature corrosion but to stop ice forming when operating at high altitudes. The removal of sodium, although important, was not the prime consideration.

Another important factor is the difference in fuelling systems. Aircraft are not being fuelled continuously and consequently the fuel can be cleaned up in a recirculation system until the water content of the fuel in the tanks is below the limit. In some systems fuel is then transferred to the aircraft via a second coalescer and finally a streamline absorber. Ships' fuel systems, because of the requirement for continuous flow, have to operate on a once through basis.

It was with the knowledge of successful application of coalescers for aircraft fuel that D.G. Ships in the late 1960's and early 1970's embarked upon testing similar coalescers with DIESO. Unfortunately at this stage the only operating difference with which the manufacturers were aware was that the relative throughputs had to be reduced to one third to allow for the higher viscosity of DIESO over AVCAT.

The first efforts to remove fresh water from DIESO was on a recirculatory rig and using single elements. It soon became clear that the recirculation was not realistic, both foreign and indigenous dirt being filtered out in the first pass, i.e. only small amounts of 'raw' fuel had been through the elements. The rig was then modified to run on a once-through basis and better elements were developed.

The second set-back came after developing what appeared to be a successful type of element and using 'artificial' sea-water: coalescence failed almost completely. At this stage it was decided to transfer the development work from the manufacturer's inland testing station to a R.N. fuel tank depot (Torpoint) where large quantities of DIESO and sea-water were readily available. The results of these trials are given in Ref. 2.

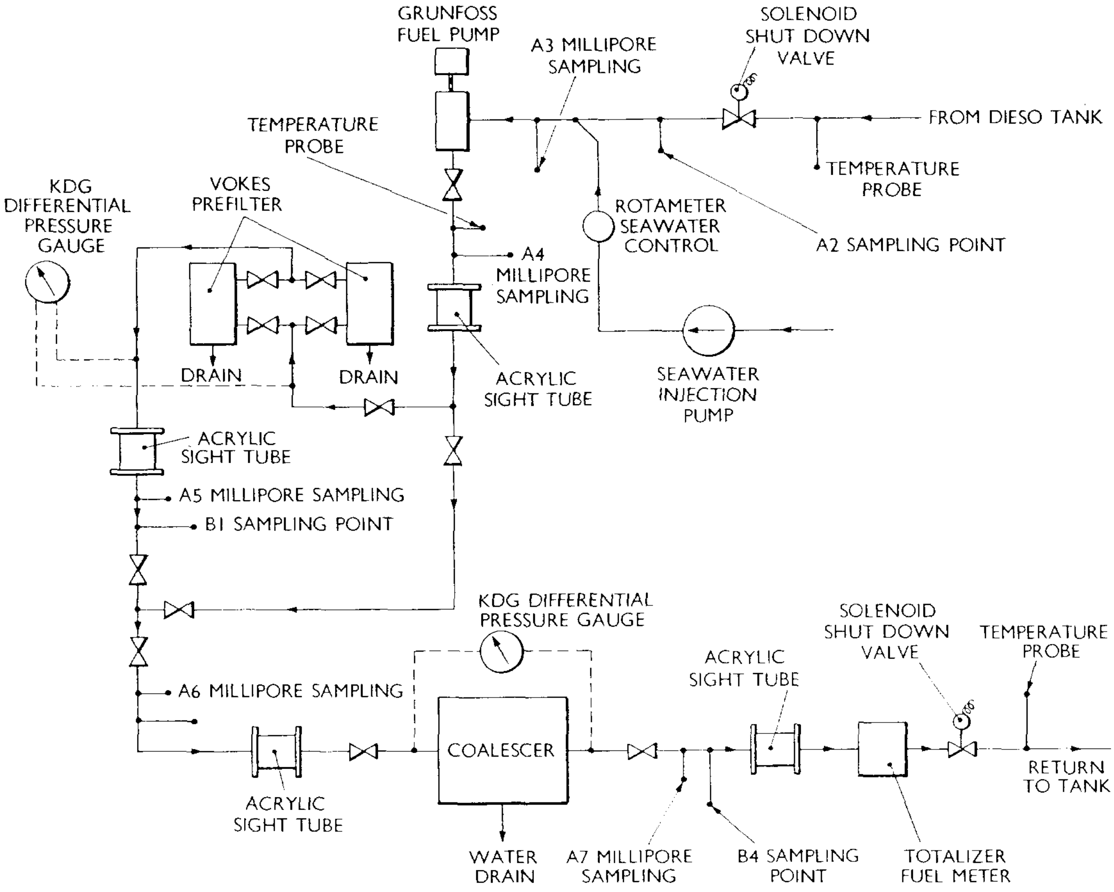

FIG. 6—DIAGRAMMATIC ARRANGEMENT OF COALESCER TEST RIG

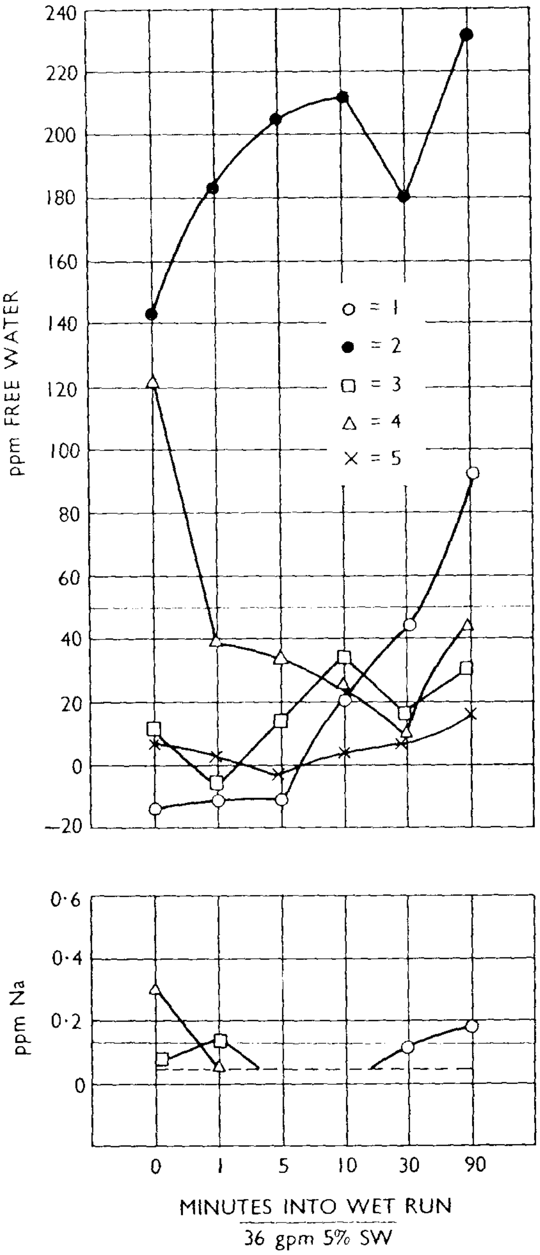

FIG. 7—FREE WATER AND SODIUM IN COALESCER EFFLUENT

Recent Developments

As a result of the Torpoint trials a new type of coalescer element and container (FIG. 1) was chosen for the latest gas-turbine ships, the Type 22 frigate and the CAH. However as these elements only had been tested, it was decided to type-test the whole equipment and in particular to carry out the 'performance' part of the type-testing at the Torpoint tank farm. As a mobile rig was available it was decided also to evaluate a number of different manufacturers' equipments for comparative purposes.

A diagrammatic arrangement of the rig (FIG. 6) shows that the raw fuel from one tank is pumped through the coalescer via a pre-filter. Sea-water is injected into the eye of the seven-stage centrifugal pump to present the coalescer with as fine a distribution of water droplets as possible. Fuel is then transferred to a separate tank. Fuel samples are taken at various points for analysis.

From the earlier work on single elements, Ref. 2, it had become evident that the most ardent operational duty of a pre-filter and coalescer combination was to run for the majority of the time on 'dry' fuel followed by slugs of water mixed with the fuel—the condition, for example, that would arise when changing over suction to a poorly drained service tank. Various combinations of dry/wet run periods and flow rates were used to simulate the emptying of the CAH tanks.

Typical results of free water and sodium in the coalescer effluent are shown in FIG. 7 for the three different types of coalescers (A, B and C) that were evaluated. The particular flow conditions were 36 igpm with dry and wet run periods of 7 hours and $1\frac{1}{2}$ hours respectively. Sea-water was injected at 5 per cent. of total flow rate.

Line 1 of FIG. 7 shows that coalescer (A) started to perform satisfactorily for the first five minutes; however, at this point coalescing appears to break down and the water content in the effluent started and continued to rise reaching unacceptable values towards the end of the water injection period. (The reason for the initial negative results is an experimental error and is explained later.)

Coalescer (B) gave unacceptably high values of water in the effluent throughout the whole of the wet run period (FIG. 7, line 2) and it would appear, like equipment (A), to give increasing amounts of water with time.

Also the initial value of water in the effluent was nearly three times the limit.

Coalescer (C) performed satisfactorily throughout (FIG. 7, line 3), though this coalescer also gave a slight increase in the amount of water in the effluent as the test proceeded.

During the present test programme and the earlier single element trials, Ref. 2, it was noticed that the pre-filter, on first being subjected to the initial slugs of water in the fuel, released most of its accumulated solids and surfactants. These in turn 'poisoned' the coalescer elements and are likely to cause failure or 'break through' of water. Consequently, it was considered that the use of a pre-filter may in fact be detrimental to the system; a trial was therefore carried out with coalescer (C) without a pre-filter. These results showed a relatively high initial concentration of water in the effluent (FIG. 7, line 4); however, as the test proceeded the coalescer elements 'recovered' to provide an effluent with acceptable quantities of water.

The final trial was conducted with elements from coalescer (C) fitted in coalescer (B). This combination gave satisfactory results throughout the whole of the wet run period (FIG. 7, line 5). The reason why elements from (C) performed more satisfactorily in coalescer (B) then in their own coalescer was the relatively light loading of the element, i.e. the surface area of the coalescer element in coalescer (C) is less than that in Coalescer (B). This more than compensated for the use of horizontal elements in coalescer (B), a configuration considered to be inferior to vertical ones (FIG. 1).

Apart from the initial 'break through' with equipment (C) operating without a pre-filter, the sodium in the effluent in these five trials is within limits. However, the most significant aspect of the sodium values was the lack of correlation to the corresponding amounts in free sea-water. If the water in the effluent had the same salinity as the inlet sea-water, sodium values of over 3·0 ppm should have been recorded. It appears that the coalescer elements are desalinating the sea-water as the concentration of sodium in the outlet free water is always less than that of the inlet free sea-water. However, other trials showed that if the quantity of water in the effluent continues to rise, there is a corresponding 'break through' of sodium, Ref. 3.

Accuracy of Results

Sodium, being a single element, is readily measured in the laboratory by flame spectroscopy, with a lower limit and reproducibility of 0·05 ppm being achieved.

The accurate measurement of water, down to the lower levels required in the present application, proved very difficult. As already stated, interest is only in free water because any absorbed water will not contain sodium. However, as there are no methods of accurately measuring free water down to the levels required, it has to be deduced from total water measurements minus the saturation value of the fuel, at the outlet from the coalescer, for that particular temperature. Ref. 4 has shown how a variety of DIESO oils can have widely different saturation levels, for example at 50°F the saturation levels can be between 53 ppm and 110 ppm. Also the saturation level of a particular fuel can alter by more than 10 ppm for a temperature change of 10°F. An added complication is that it is necessary to measure the free water in the coalescer effluent during the water injection period. Consequently it is necessary to determine the saturation values of the fuel at the coalescer effluent during the wet run period. However, it was discovered that the saturation properties of the particular fuel used in the trials varied little throughout the coalescing process.

The method of measuring the water concentrations was by the standard Karl Fischer technique but using a new automatic instrument with an accuracy of approximately 10 ppm both for determining the saturation levels and for determining the total water measurements. Consequently the overall accuracy of the free water measurements was approximately 20 ppm, i.e. twice the limit of free 'normal' sea-water. Also, a completely dry fuel could be indicated to have a negative concentration of free water of up to 20 ppm.

Another interesting result from this trials programme was the 'loss' of water from the polythene sampling bottles. Three samples were taken at each particular point in the trials programme for analysis for water and sodium. One sample was taken and analysed within an hour, one sample was taken for analysis by the AOL and the third sample was taken for independent analysis in the event of a disagreement between the first two samples. Unfortunately it was not until the trials were well under way that the results of the AOL's analysis became available. Their results indicated considerably less water than samples analysed on site. The third sample, analysed by the AMEE, indicated even less water. Typical results are:

Analysis	*Time Delay*	*Total Water*
Site	1-3 days	100 ppm
AOL	2-3 weeks	70 ppm
AMEE	7 weeks	40 ppm

Fortunately, recent investigations have shown that only water permeates through the polythene sample bottles; the sodium levels remain as originally taken.

Conclusions and Future Work

The main object of these trials was to produce and test coalescers that will provide the highly-rated gas turbines of the latest classes of R.N. ships with fuel to the required degree of purity. The fuel chosen for these trials had poor coalescing properties and was not particularly suitable for evaluating pre-filters where removal of solid contaminants is the objective. However, from these trials and earlier ones at Torpoint, Ref. 2, it was quite evident that the present pre-filters did not retain the very fine solids due to fuel degradation products and surfactants—the bulk of the filtration was achieved by the coalescer elements. A programme is being undertaken to develop suitable pre-filters that will present the coalescer with 'clean' fuel and hence prolong the life of elements. (Almost all the operational changes of coalescer elements have been due to blockage—not their inability to remove water. Coalescer element removal takes about eight times as long as a change of pre-filter elements.)

One of the most surprising results of the work reported here is the lack of correlation of sodium and free water in the coalescer effluent. At present ships have only detector kits for measuring free water. Instruments are being developed for onboard analysis of sodium, and hopefully these instruments will be suitable for on-line analysis.

At present the only knowledge of the effectiveness of coalescers is from shore-based testing. Such testing is easy to control and analysis of results is relatively easy to perform. However, there are certain drawbacks and limitations to shore-based testing, for example it does not simulate ships for motion, vibration, etc. Also, shore-based testing is restricted to a relatively small selection of fuels, all conforming to DEF STAN 91—4. Ships will, at some stage, have to take on fuel to an inferior standard from foreign sources. Therefore in order to gain knowledge of actual on-board operation of coalescers the trials in H.M. ships *Amazon, Sheffield,* and *Exmouth* should be extended to the later Type 21 frigates and Type 42 destroyers as they enter service.

The present coalescer elements, although successful, were developed on a trial-and-error basis without much knowledge of the fuel properties. With a better understanding of the chemical and physical properties of DIESO fuels that are relevant to the coalescing process, more successful elements could be developed.

References:

1. Trenary, Lt-Cdr. A. E., 'Fuel Systems in Gas Turbine Ships', *Journal of Naval Engineering,* Vol. 22, No. 2.
2. Stevens, M. A., 'The Arrangement of Some Types of Coalescer Filters for Use with Diesel Fuel', Admiralty Oil Laboratory Report No. 66, March 1973.
3. Admiralty Marine Engineering Establishment/Admiralty Oil Laboratory. Report to be published.
4. Ritchie, J., 'Diesel Fuel in the Royal Navy', *Journal of Naval Engineering,* Vol. 20, No. 1.