FUEL SYSTEMS IN GAS TURBINE SHIPS

BY

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The fuel in a ship's storage tanks will contain sodium. The gas turbine engines used to power our new ships require fuel with a very low sodium content if they are to achieve an acceptable life. The design philosophy which is being developed for their ship fuel systems is quite different from that used for earlier ships. This article is intended as an introduction to the subject.

Introduction

Sodium may effect a gas turbine in two ways. It may cause corrosion in the engine control system (which uses fuel as its process fluid) resulting in system failure. It may also have a marked effect on turbine blade corrosion.

The mechanism of turbine blade corrosion is discussed at length in Ref. 1. FIG. 2 (reproduced from Ref. 1) illustrates the variation of hot corrosion with temperature.

The G6 engines in the County and Tribal Class ships run with turbine blade metal temperatures in the range 670-710°C; the downrated Olympus engine in H.M.S. *Exmouth* runs with turbine blade metal temperatures in the range 700-750°C; and the Tyne and Olympus engines in the Type 21 and 42 Classes (and intended for the Type 22 and CAH) run with blade metal temperatures in the range 750-800°C.

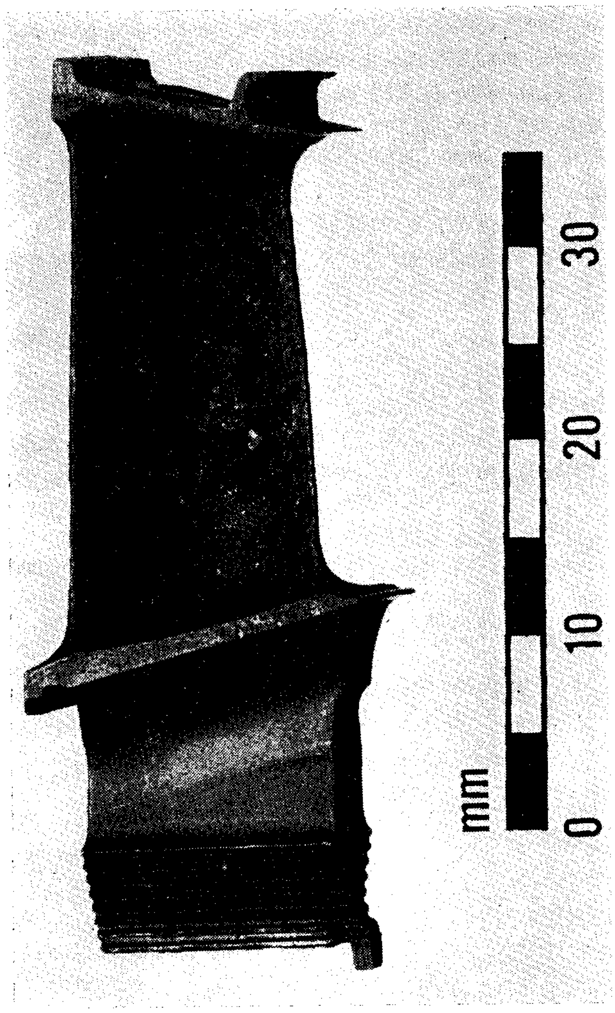

FIG. 1—TYNE H.P. TURBINE BLADE SHOWING CORROSION DAMAGE DUE TO SODIUM

FIG. 2 shows that the G6 engines are not liable to hot corrosion and that the Olympus in H.M.S. *Exmouth* is subject to a rate of hot corrosion where other factors are more likely to limit engine life, but that the Olympus and Tyne engines in the new ships run in the band where hot corrosion is potentially most severe. Reducing the sodium content of the fuel supplied to the engines in these new ships is therefore of great importance to engine life.

The Gas Turbine Fuel Cleanliness Requirements

There is as yet limited experience of gas turbine engines with blade metal temperatures in the range 750-870°C running with significant quantities of sodium in the fuel or combustion air; results from tests of a Tyne engine at the Naval Marine Wing of the NGTE and experience from coastal power stations run by the CEGB have, however, led MOD(PE) to formulate requirements for fuel at delivery to the gas turbines limiting the sodium content to 0·28 ppm by weight, sub-divided as follows:

0·1 ppm by weight dissolved in the fuel
0·05 ppm by weight as particulate matter
0·13 ppm by weight in free sea-water.

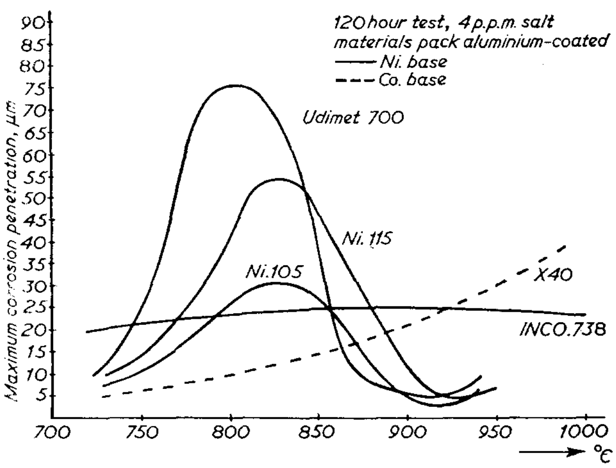

FIG. 2—HOT CORROSION—TEMPERATURE EFFECT

If this sea-water is assumed to be of standard composition, 0·13 ppm by weight of sodium is equivalent to 10 ppm of sea-water or 1 pint of sea water in 50 tons of fuel.

Whilst these requirements include allowances for sodium dissolved in the fuel and for sodium present with the fuel as particulate matter, there have so far been no proven instances of significant quantities of sodium reaching gas turbines from either of these sources. No actions are currently being taken specifically to reduce the quantity of sodium reaching engines from these sources.

The engine module specifications for the Tyne and Olympus engines require the fresh water content of the fuel to be limited to 50 ppm to avoid problems with atomization and combustion, and the fuel to be filtered with 98 per cent. efficiency to 5 microns to avoid problems of blocking of the fine orifices of the engine control system. These requirements are met by the actions taken to reduce the sodium content of the fuel.

The design aim for the ship's fuel system in the new gas turbine ships is therefore the continuous provision of fuel containing less than 0·28 ppm of sodium and less than 10 ppm of free sea-water.

Description of Ship Fuel Systems

The County and Tribal Class ships have conventional steam ship fuel systems with service tanks between the ships' storage tanks and the gas turbines. These ships also have stripping systems to remove water from the bottom of tanks.

H.M.S. *Exmouth* has a ship fuel system which is the fore-runner of current designs where fuel is settled and stripped, and then passed to the engine via pre-filters and a coalescer.

The ship fuel system in the new gas turbine ships can be divided up as follows:

(*a*) Fuel supply system between the service tank and the engine.

(*b*) Fuel transfer system between storage tanks and service tanks.

(*c*) Refuelling system from deck filling connections to storage tanks.

The Fuel Supply System

This is essentially the same in all ships, involving a number of boost lines each comprising a boost pump, one or more pre-filters, and a coalescer. Each boost line feeds the fuel supply ringmain, which can also be fed from small header tanks should insufficient fuel be available from the boost pumps during an electrical failure.

The Fuel Transfer Systems

FIG. 3 illustrates diagrammatically these systems in the new gas turbine ships. The Type 21 has no equipment in this system except a transfer pump, and the Type 42 is similar except that fuel from the water-displaced storage tanks is pumped to the undisplaced storage tanks via a manual-cleaning centrifuge.

The CAH has a 50-micron duplex back-flushing strainer in the transfer pump discharge for the removal of solid contaminant. It also has large self-cleaning centrifuges which can take suction from the service tanks or from four selected wing tanks. These wing tanks will be used as settling tanks, and all fuel will be centrifuged into the service tanks except when operating continuously at very high powers.

The Type 22 has buffer tanks between storage and service tanks, and all fuel is passed to the buffer tanks from the storage tanks via self-cleaning centrifuges. There is also a 50-micron duplex back-flushing strainer in the transfer pump discharge line.

As fuel tanks containing DIESO are more prone to corrosion than FFO tanks, the tanks in some ships are treated with a three-coat epoxy paint to combat this corrosion and extend the tank life. This treatment will have the added benefit of reducing the amount of corrosion products put into the fuel whilst it is in the tanks, thus making a small reduction in the clean-up duty of the fuel system.

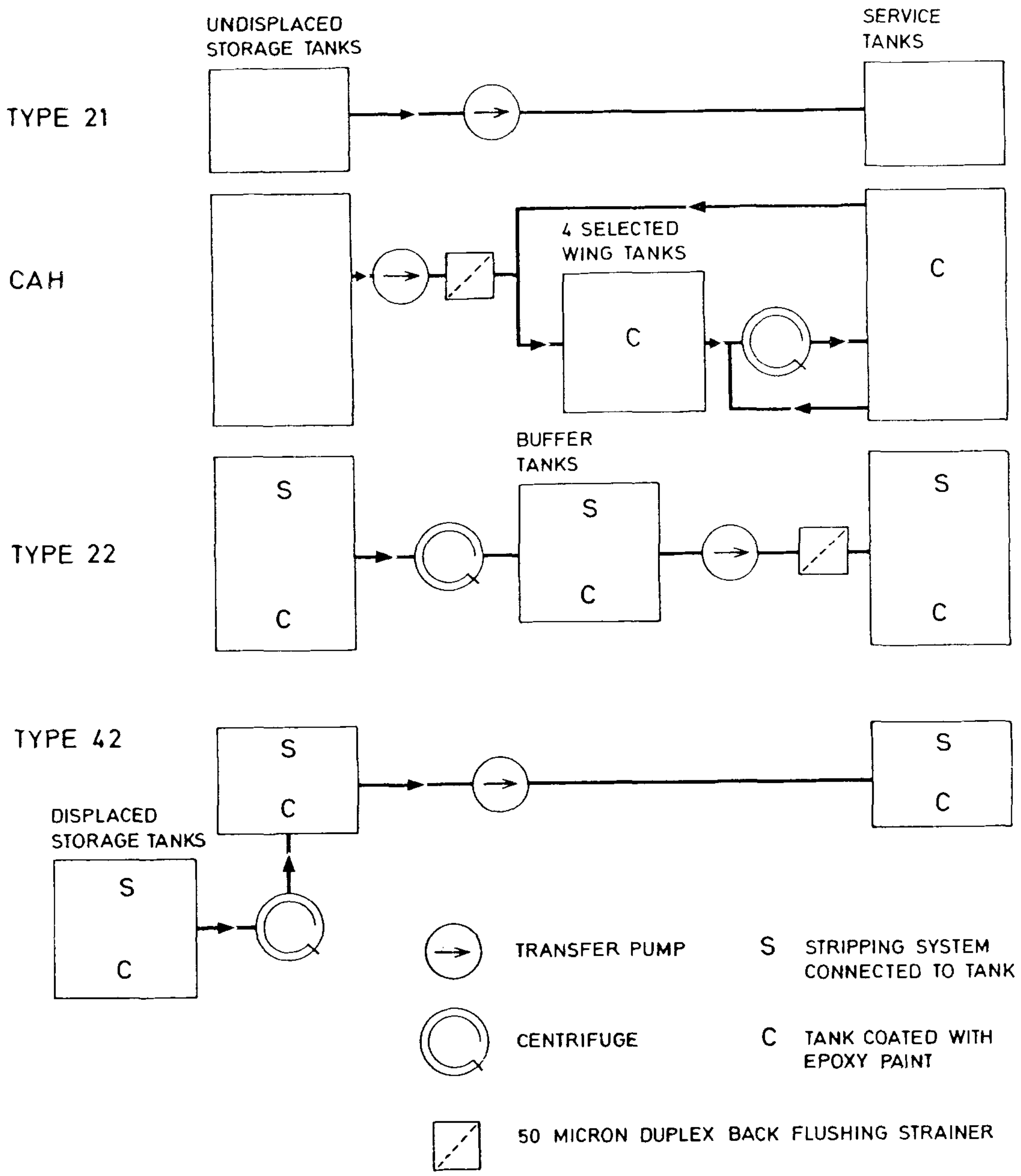

FIG. 3—DIAGRAMMATIC ILLUSTRATION OF FUEL TRANSFER SYSTEMS

Stripping systems for the removal of settled water and dirt from the bottoms of tanks are fitted in two of the classes of ships as indicated in FIG. 3.

The Refuelling System

This system is similar to that in the latest steam ships, involving one or more fuelling trunks, and has no effect on fuel quality.

The Nature of DIESO

Much information on the physical properties of DIESO is contained in Ref. 2 and Ref. 3. It is now the standard fuel for most of our ships and will be used for all the new gas turbine ships. As explained in Ref. 2, the cost and availability of cleaner fuels make them unattractive as alternatives to DIESO.

DIESO is the Joint Services designation for a particular range of distillate fuels and not the definition of the constituents of a specific material. DIESO for supply to gas turbine ships is normally purchased to the requirements of

DEF STAN 91-4 for DIESO 47/20 (NATO F-76) fuel and these specifications include clauses limiting the free water content of the fuel to 500 ppm. However, the DIESO in a ships storage tanks may have become contaminated with extra water on its way to, or within, those tanks.

It is necessary to enlarge a little on the way in which DIESO and sea-water behave when mixed together to understand one important implication of the gas turbine fuel requirements. FIG. 1 of Ref 3 shows how water may be absorbed by DIESO in quantities which vary with temperature. Water which is absorbed in this way (normally referred to as dissolved water) does not contain sodium and its existence presents no problem to main engine gas turbines. The remaining water in the fuel (known as free water) is available for separation and can contain sodium. This explains the use of the term 'free water' in the gas turbine fuel requirements.

Coalescers

Coalescers, sometimes referred to as filter/water separators, have been used for many years in ships aviation fuel systems for the removal of free water from clean distillate fuel, and they have a long life in this application. In the absence of any evidence to suggest that the removal of free water from DIESO would prove more difficult, coalescers were selected in the mid 60's as the prime means of water removal in gas turbine ship fuel systems. Their specification included the requirements to reduce the free water content of DIESO from 5 per cent. (50 000 ppm) at inlet to 10 ppm at outlet in a single pass.

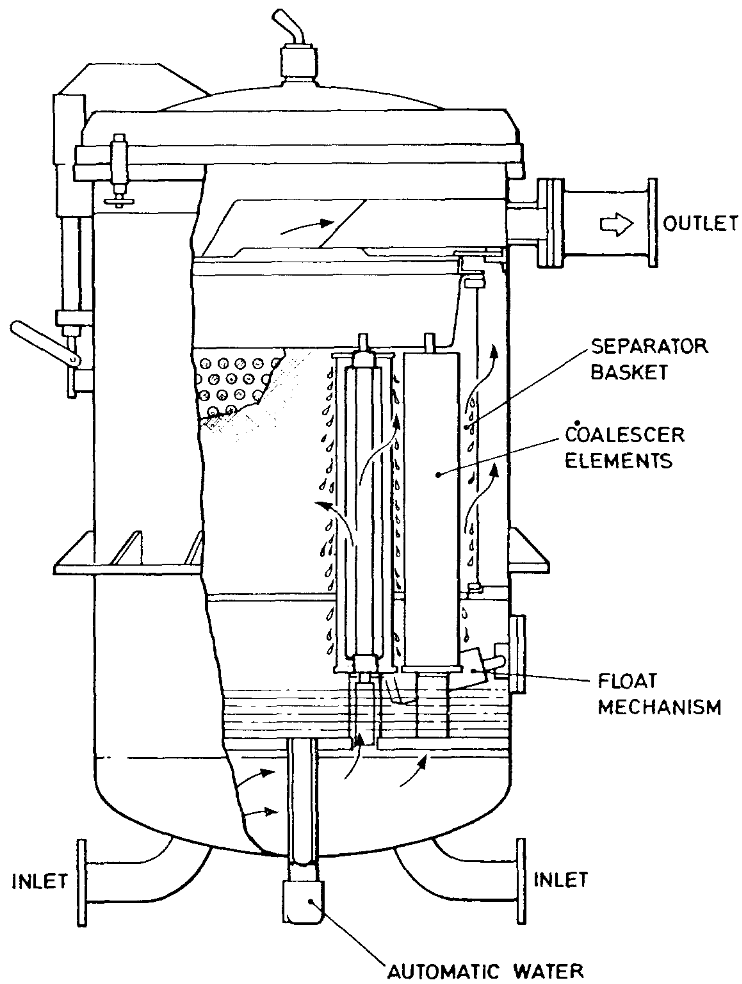

FIG. 4—SKETCH OF TYPICAL COALESCER UNIT

Principle of Operation of Coalescers

A general view of a typical coalescer unit is shown at FIG. 4. The fuel is fed to the inside of a number of coalescer elements. The element consists primarily of glass fibre, chosen because it is preferentially wetted by water in the presence of fuel, and as the fuel passes through the element water droplets are intercepted by, and become attached to, the fibres. These droplets remain attached to the fibres, growing by coalescence with other droplets, until they are large enough to be detached from the fibres by the viscous drag of the fuel flow over them. They then pass through the element for release from its outer surface in drops which are large enough to settle out of the fuel stream under gravity against the direction of the fuel flow. This process is shown diagrammatically in FIG. 5.

Fuel leaving the coalescer element is then passed through a stripper made of hydrophobic material which prevents the passage of the larger droplets of water remaining in the fuel, collecting them for removal from the fuel by settling.

The coalescer elements generally have a pore size of the order of 1 micron, so that the fuel has to be very finely filtered before reaching the coalescer to prevent it from being quickly blocked by solids. Elements are changed when they reach their maximum pressure drop and, since a set typically comprises 16 elements each 20 in. long and $3\frac{3}{4}$ in. diameter, frequent changing would involve a major support, storage and disposal problem.

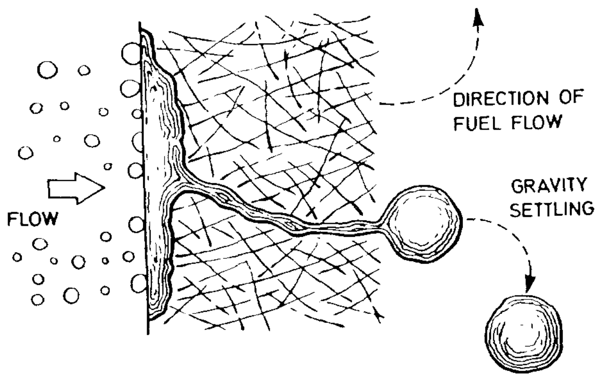

FIG. 5—NORMAL PASSAGE OF WATER THROUGH A COALESCER ELEMENT

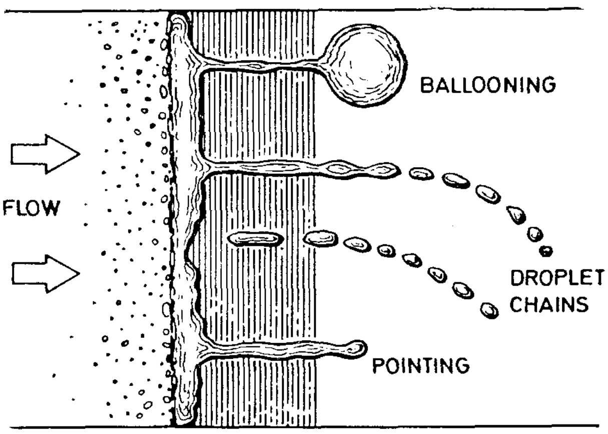

FIG. 6—EFFECT OF SURFACTANTS ON RELEASE OF WATER FROM COALESCER ELEMENT

Effect of Surfactants on Coalescer Operation

All the stages by which a coalescer separates water from fuel rely to some extent on the relative surface tensions of water and DIESO. Surface active agents, or surfactants, are a group of substances which, when added to a mixture of DIESO and water even in concentrations as low as 1 ppm, have a marked effect on their surface tensions. Their presence results in interference with the attachment process, the prevention of coalescence, and the removal of smaller drops of water from the fibres by the passing flow. The effect on the release process is illustrated in FIG. 6 which shows small drops of water leaving the element and a phenomenon known as pointing (also caused by surfactants) in which a column of water vibrates and kicks off small drops. Ballooning is the normal method of release in surfactant-free fuel.

Surfactants may occur in the fuel as naphthenates, they may be introduced in the refining process as sulphonates, or during transportation as the result of micro-biological growth, or they may be introduced in tank cleaning fluids.

Fluids containing surfactants that may be present onboard are listed in the last part of the article.

Differences between AVCAT and DIESO Affecting Coalescer Operation

DIESO has both a higher density and a higher viscosity than AVCAT, so that water separates more slowly from DIESO under the influence of gravity. This means that the water content of DIESO reaching a coalescer tends to be higher than is the case with AVCAT, and also that the flow rate through a DIESO coalescer needs to be lower to permit adequate settling within the coalescer unit. The lower surface tension of DIESO has an adverse effect on the attachment process.

The combination of these effects with the effects of the appreciable quantity of solid contaminants which are present in DIESO (but not in AVCAT) and the effects of surfactants make the duty of a DIESO coalescer much more formidable than the duty of an AVCAT coalescer.

Outline of Completed Development Work on Coalescers

Coalescer development work began slowly since manufacturers believed that AVCAT coalescers could be used successfully with DIESO at reduced flow rates. However, initial testing of single elements showed that this was not the case because of the various factors already discussed, and a great deal of work has been done in recent years at the Admiralty Marine Engineering Establishment, at fuel depots and at manufacturers works, with the assistance of the Admiralty Oil Laboratory and the Admiralty Engineering Laboratory. Test requirements were complicated by the discovery of the effects of surfactants. As most of the surfactant present is removed on the first pass through a coalescer, re-circulation testing was abandoned in favour of once-through testing, which had to be done at fuel depots because of the large quantities of DIESO required.

This work has now progressed to the point where current coalescers are capable of achieving the arduous duty specified when operating on the most heavily contaminated fuel available at Thanckes Tank Farm, Devonport. Work is also proceeding to identify the best of pre-filter for use upstream of the coalescer to protect it from solid contaminants and to achieve the optimum life for the two components.

The Admiralty Engineering Laboratory has done some work on electro-static coalescers which suggests that they are unlikely to be suitable for the duty.

Centrifuges

Centrifuges are used in some fuel systems to assist in the fuel clean-up process. The units are large, 30-gallon per minute, self-cleaning machines, tests of which have given very encouraging results, showing them to be capable of reducing the water content of fuel to within the gas turbine fuel requirements from 500 ppm at inlet. The machines incorporate a hydraulic mechanism which opens the bowl for sludge removal whilst it is rotating, thus obviating the need for time consuming manual cleaning (see FIG. 7). Centrifuges do not compete directly with coalescers as there are no units available which will meet the full shock requirements, but they have the advantage of being able to deal with solid contaminants without the maintenance and spares problems of changing coalescer elements, and their efficiency is less susceptible to the harmful effects of surfactants.

Recent Ship Experience

The coalescers in H.M.S. *Exmouth* frequently blocked with solid contaminants in early days after her conversion to gas turbine propulsion. This

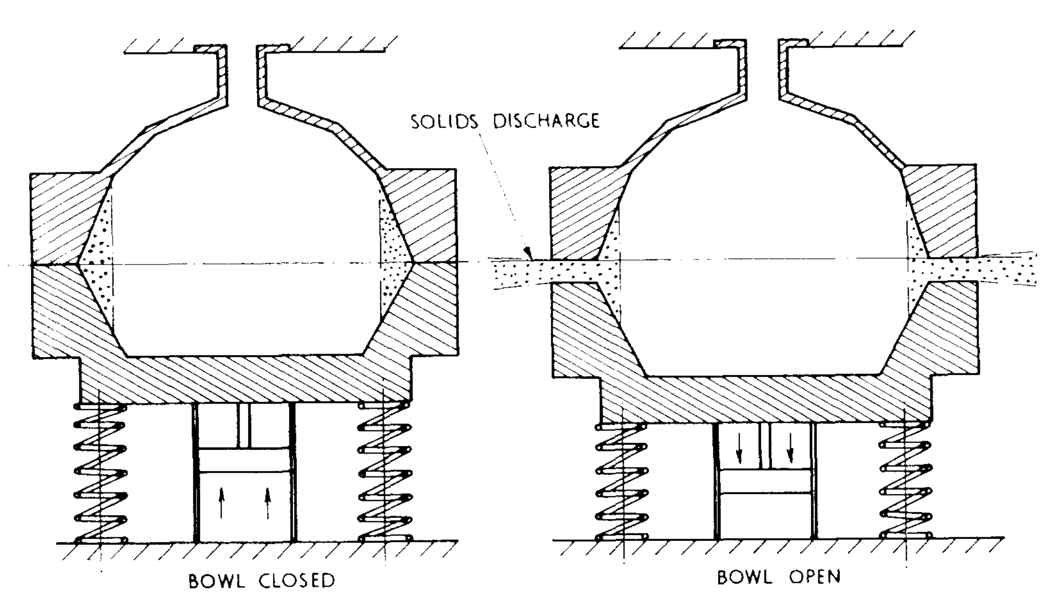

FIG. 7—ILLUSTRATION OF SELF-CLEANING MECHANISM OF CENTRIFUGE

problem was particularly serious in rough weather when accumulated solids in the bottom of the tanks was stirred up by ship motion. This problem was also thought to have been aggravated by FFO residues remaining in the tanks after conversion.

During the past year, coalescer life has been much improved, the latest set of elements still being in use after 8 months of running. The condition of the tanks, which are not coated, is reported to be good.

Samples of the fuel received in the ship have been taken on several occasions during the year, including samples of fuel received from commercial sources. None of these samples has contained more than 0·1 ppm of sodium.

Samples were taken from the fuel system of H.M.S. *Amazon* during her recent visit to the West Indies. Although some of the fuels received contained large quantities of solids and one fuel had a high sodium content, all the coalescer discharge samples contained less than 0·1 ppm of sodium.

During the first few days of H.M.S. *Sheffield*'s CSTs, one service tank became contaminated with a large quantity of sea-water from a leaking sea-tube. Before this was discovered, fuel containing up to 500 ppm of free water reached the fuel supply system, and was brought within the gas turbine fuel requirements by the pre-filter/coalescer combination. The contaminated tank was then isolated and stripped at intervals, and after 24 hours its water content had been reduced to less than 0·1 per cent. (1000 ppm). This illustrates the value of a stripping system for cleaning up fuel contaminated by water.

What is the Problem?

Coalescers have shown themselves capable of achieving their arduous specification on the dirtiest fuel available in one fuel depot, and early reports from the new gas turbine ships are encouraging. Any MEO who allows fuel containing 5 per cent. water to reach his fuel supply system has only himself to blame. So what is the problem?

Traditionally, the main check on the acceptability of the water content of fuel has been whether or not it will burn correctly, and a water content of 0·1 per cent. (or 1000 ppm) would not be likely to interfere with combustion in a boiler or a diesel engine. Fuel systems involving storage tanks, stripping systems, and service tanks have consistently provided fuel to this standard and, once the pre-transfer checks have been carried out, there has been no need to establish the quality of fuel at any stage within these systems. So the first problem is a lack of information about the quality of fuel likely to be present in a ship's tanks and systems.

Whilst the fuel received from RFAs and from our own fuel depots generally contains less than 200 ppm of free water, the fuel systems of these ships must be designed for fuels they are likely to receive world-wide. Since we have a very limited experience of gas turbine ships operating outside Home Waters, the second problem is to assess the risk of these ships receiving contaminated fuels, to establish the nature and amounts of these contaminants, and to find out if the fuel systems can deal with them successfully.

Fuel can only be analysed to the necessary accuracy using laboratory equipment, so that a MEO does not know whether his fuel system is meeting the requirements. The third problem is to develop instruments which can be used on board to give him this information.

The Shell Detector Kit (Syringe and capsules supplied under NS. Cat. Nos. 0253/253005 and 0473/473157 respectively) and Esso Hydrokits (Supplied under NS. Cat. No. 0463/224-0327) are used with aviation fuel to indicate a free-water content of 30 ppm. They can also be used with surfactant-free DIESO to indicate the same water content; they must, however, be used with caution since, if the fuel contains surfactants, the Shell Detector Kit will change colour whatever the water content and the Esso Hydrokit will not change colour until the water content is well in excess of 30 ppm.

Coalescers are achieving their specified duty on the dirtiest fuel available ashore, but this fuel is probably much cleaner than they will see in a ship in rough weather several years after the tanks were last cleaned. Centrifuges have been tested ashore using fuel containing jewellers' rouge to assess their solid-removing efficiency; this may not however, be relevant to what they will do with dirty DIESO. As it is not possible to make-up a standard 'dirty DIESO' for component testing since fuel constituents are so varied, the fourth problem is to monitor the performance of these components in ships' fuel systems to establish their performance more precisely than can be done ashore.

A micro-biological growth, whose existence is encouraged by sea-water and by high storage temperatures, can occur in DIESO. This growth, which has recently appeared for the first time in an RFA's tanks, produces large quantities of minute particles containing a surfactant, and may cause sudden coalescer failure. The fifth problem is to find means of ensuring that this growth never reaches the fuel tanks of a gas turbine ship, and to find a method of cleaning the system should contamination occur.

It appears that the R.N. has equipment which will bring normal surfactant-free DIESO to within the gas turbine fuel cleanliness requirements; however, before it can be decided which of the fuel transfer systems previously discussed is the best design, it is necessary to have the answers to the following questions:

(*a*) Does the value of a stripping system repay the increased complexity it involves?

(*b*) Will centrifuges be able continuously to produce fuel within the gas turbine fuel cleanliness requirements?

(*c*) Does heavy ship-motion in rough weather stir up contaminant from the bottom of storage tanks to impose an unacceptable load on the fuel system?

(*d*) Are current tank-cleaning intervals acceptable?

(*e*) Are the present criteria for changing pre-filter and coalescer elements correct?

(*f*) Does the length of time for which fuel is allowed to settle before being used have a significant effect on its quality?

(*g*) Is there a significant variation in the quality of fuel available from coated and uncoated tanks?

(*h*) Can fuel systems be designed that will produce acceptable fuel from water-displaced storage tanks?

(*j*) Are ships liable to receive fuels from any sources which cannot be cleaned up to the acceptable standards by any of these systems?

What is being done about it?

The magnitude of the task facing the MOD of co-ordinating the efforts of specialist sections, the Admiralty Marine Engineering Establishment, the Admiralty Oil Laboratory, manufacturers and universities in developing pre-filters and coalescers, centrifuges and instruments, in carrying out research into fuel properties, and in mounting a data collection programme to gather knowledge on the behaviour of ships' systems led to the setting up of the Fuel Systems Steering Committee under the chairmanship of an assistant director of the Ship Department in December 1973. This committee administers four working groups, each tackling different aspects of the problem.

An instrument suitable for the continuous monitoring of the sodium content of fuel is undergoing a feasibility study.

Coalescer development work is going on to determine the best type of pre-filter to use to minimize system maintenance. Research work is also being done on the basic properties of fuel that affect coalescer operation.

A MEAP 1 is currently employed full time collecting samples of fuel and a large amount of supporting data from H.M. ships *Amazon, Sheffield,* and *Exmouth.* Data and samples of the fuel supplied to these ships is being obtained with the assistance of DGST(N).

Implications for the Operator

As previously stated, the fuel received from our own fuel depots and RFAs is generally of good quality. However, strict attention must always be given to the quality of fuel received, particularly from commercial sources. The fuel itself and its specification should be examined carefully, and enquiries should be made as to how long the fuel has been in the source tank and whether the tank or system have previously contained other fuels. A fuel sample taken from a running system will show definite signs of cloudiness with a free-water content of 100 ppm or more.

Materials that are commonly available in ships and which contain surfactants include:

FFO
Soap
Teepol
Tank cleaning fluids
Gloquat (C)
OMD 113, OX 38, other detergent oils
Paint.

Since as little as 1 ppm of surfactant may destroy coalescer operation, great care must be exercised to keep these materials away from the ship's fuel system and tanks.

The message to the operator is implicit in the first part of the article. The task of reducing the water content of fuel to less than 1 pint in 50 tons cannot be achieved by any system without scrupulous attention to detail. It is suggested that the care and attention accorded to feed-water systems in steam ships should now be applied to looking after the fuel systems in gas turbine ships.

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