FUEL SYSTEM PROBLEMS IN GAS TURBINE SHIPS —AN UPDATE

BY

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Introduction

An article[1] in this *Journal* in 1983 described the problems then being experienced with the fuel clean-up systems in supplying fuel of the required quality to the aero-derived gas turbines of R.N. ships. It went on to outline remedial measures for the future and this present article reviews the progress made since then.

The Problem

The gas turbine manufacturer's specification for limits of impurities in fuel are given in TABLE I. The R.N. is still working to the higher standard 1983 figures, because it is the coalescers (see below) which determine the quality of the fuel received by the gas turbines and in achieving the 0.3 ppm sodium requirement they easily achieve the 1983 dirt and water requirements.

TABLE I—*Specified allowable limits of impurities in fuel received by gas turbines*

	applying in 1983	*applying in 1987*
Dirt (mg/l based on 5 micron filtration standard)	1·0	3.0
Free water (ppm by volume)	50	500
Sodium (ppm by weight)	0.30	0.30

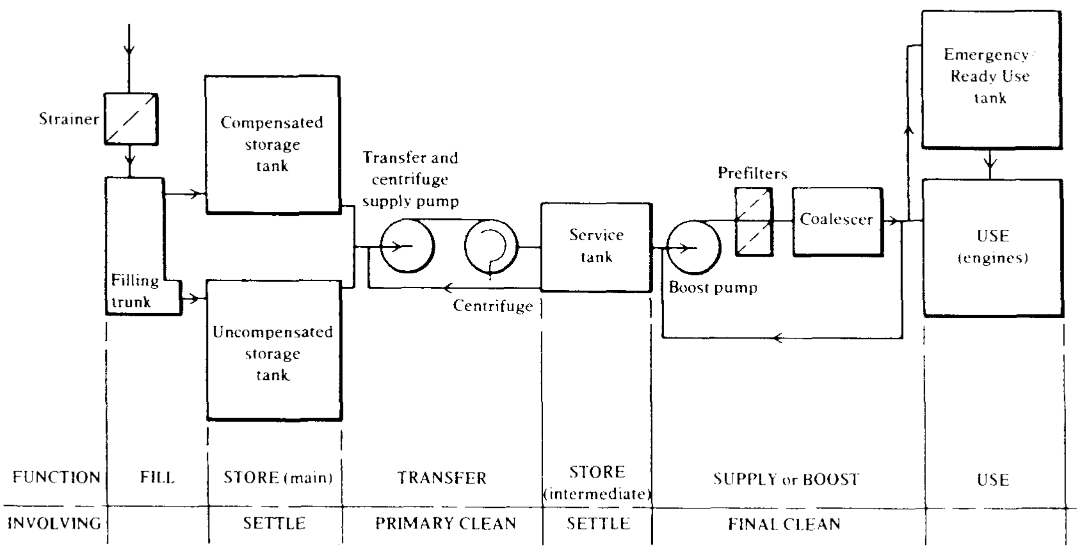

FIG. 1—SIMPLIFIED DIAGRAM OF A TYPICAL GAS TURBINE WARSHIP FUEL SYSTEM

A typical fuel system for gas turbine ships is shown diagramatically in FIG. 1. The principal components of the clean-up equipment are:

(*a*) Centrifuges (not fitted in Type 21s) to remove the bulk of the water and dirt. These are also effective in removing microbiological contamination.

(*b*) Pre-filters, whose purpose is to protect the coalescers from dirt. The pre-filter contains relatively few elements and these are designed to be changed easily and quickly. A typical unit is shown in Fig. 2.

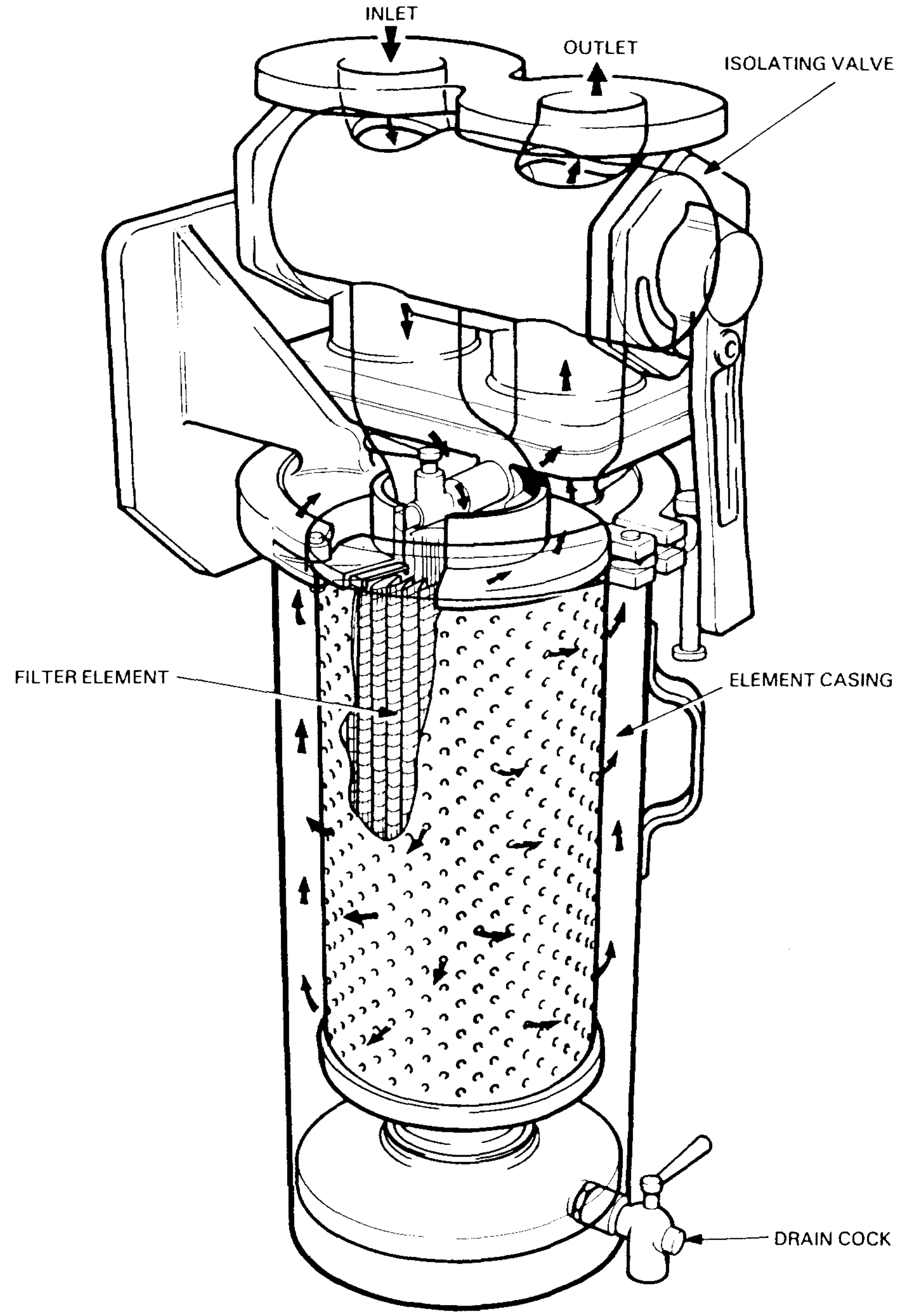

Fig. 2—Typical pre-filter unit

(*c*) Filter/water separators (also known as coalescers). Their main task is to remove water and, even more importantly, the sodium which may be dissolved in it. To achieve this the coalescer elements must have a very fine filtration standard, and consequently they can rapidly become clogged by fine dirt if the pre-filters malfunction. The coalescer unit used in the majority of R.N. gas turbine ships is shown in Fig. 3; it contains 16 coalescer elements, so that changing elements requires more effort and is costlier than for pre-filters which normally contain only two elements.

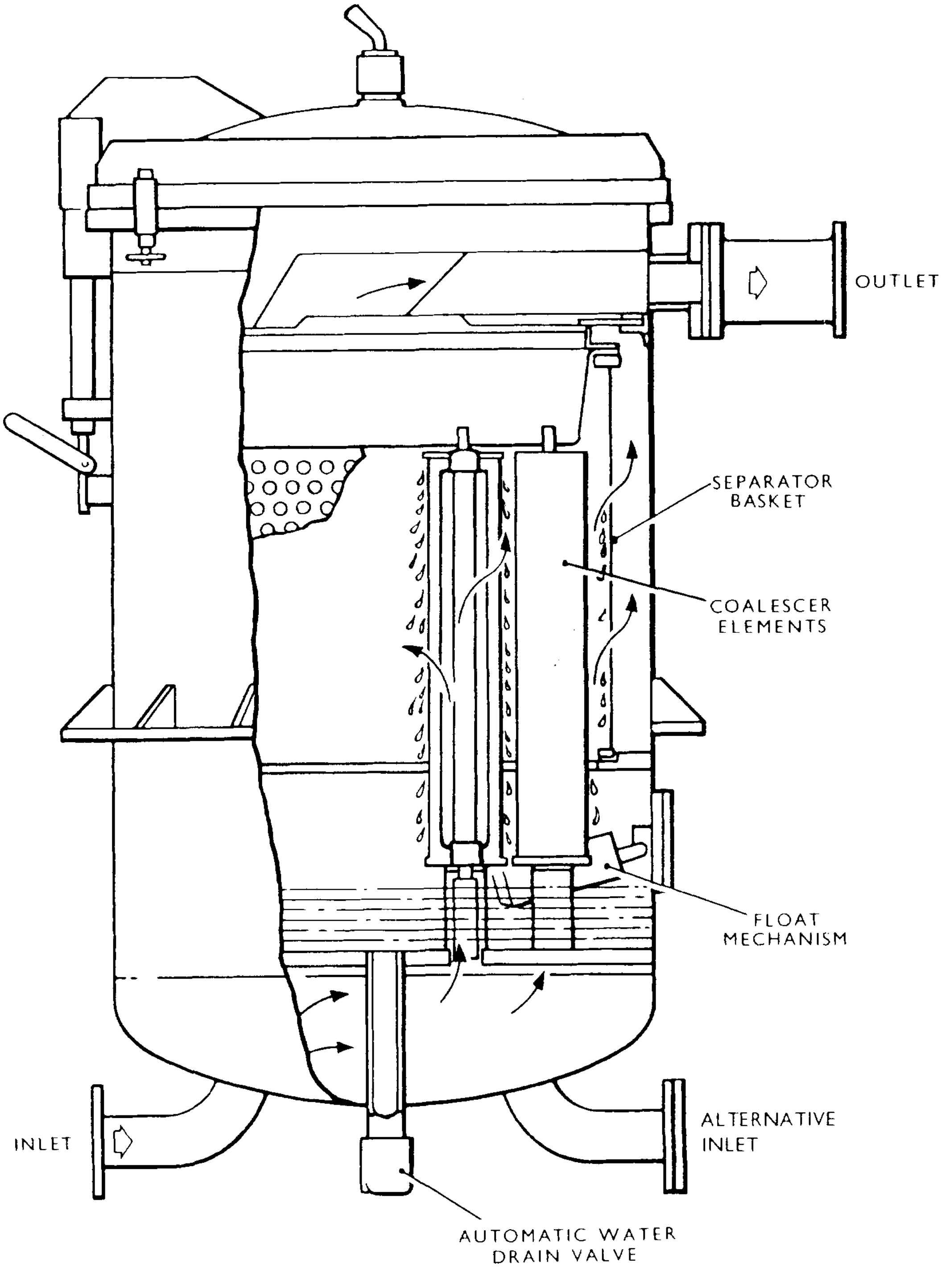

FIG. 3—TYPICAL COALESCER UNIT

The earlier article dealt with the main problems under four headings and for ease of comparison a similar approach is used here:

(*a*) Quality of fuel received on board.
(*b*) Effectiveness of on-board clean up systems.
(*c*) Usage rate of coalescer elements.
(*d*) Microbiological contamination (MBC).

Quality of Fuel Received on Board

The previous article mentioned the world-wide trend for the storage stability of F-76 Dieso to become poorer, resulting in the formation of fuel-derived organic solids of small particle size. Work then in hand to counter the problem was listed as:

(*a*) Studies by RAE Cobham on the effectiveness of stability additives.

(*b*) In conjunction with (*a*) above, consideration of a modified or additional test in the F-76 specification to control storage stability.

(*c*) Consideration of reducing the storage turn-round time of fuel.

(*d*) Consideration of filtration and/or centrifuging in RFAs.

(*e*) Consideration of filtration and/or centrifuging in shore oil fuel depots (OFDs).

The studies on storage stability (including (*a*) and (*b*) above) are now well advanced at RAE Cobham. In outline, the tests using samples stored for up to two years have shown that the known commercially available additives have little effect in improving storage stability of unstable fuels. Some additives contain dispersants designed to keep the organic dirt in fine suspension which allows it to pass freely through the coarser filters of say motor transport fuel systems. Such additives would be disastrous in warships, for the fine filters used in gas turbine fuel systems would clog very quickly. The tests also confirmed that the present standard method used in the F-76 specification for measuring storage stability can frequently indicate that this is satisfactory even when it is not, particularly when additives have been used.

In conjunction with this work, the staff of RAE Cobham are carrying out fundamental chemical research on storage instability with the object of developing a clear understanding of the complex mechanisms involved. This is of great importance both in developing a successful additive and in devising a suitable storage stability control test to replace the one currently used in the F-76 specification. This work has made excellent progress.

A further control on the quality of fuel received on board has been provided by incorporating a filtration test, using the Diesel Fuel Filtration Test Kit described later, in the latest issue of the F-76 specification[2]. Because this directly determines the filter blocking tendency of fuel, it is much more relevant than the test previously used which measured the suspended particulate contamination.

The scope for reducing the storage turn-round time of fuel has been found to be very limited. One further possibility being considered is to purchase two categories of fuel, one for long-term storage and one to be used within say nine months. The balance to be struck here lies between the saving on purchasing the short-life fuel and the increased logistical cost of storing two categories.

Studies of the application of fine filters, water coalescers and centrifuges in RFAs and OFDs have been carried out. The scope for application of centrifuges is limited because their relatively small unit size militates against them being used except for recirculating tanks over a long period. However, future designs of RFAs are likely to include pre-filters and coalescers to clean and dry fuel to a high degree before delivery to warships.

Effectiveness of On-board Clean-Up Systems

The effectiveness of the ship clean-up systems is monitored by the Fuel Sampling Rating, who aims to sample each ship every six months. The results are summarized in TABLE II which shows the percentage of samples that met the 1983 criteria of TABLE I. The figures are for the period of almost four years from March 1983 to December 1986. For comparison, the figures in parenthesis are for the preceeding period of just over two years and, taken overall, there is little difference between the two. The sodium results are the most important since these directly effect gas turbine hot end corrosion and consequently gas turbine life. Although the more recent figures appear slightly worse, this is caused by only four samples. Of these , one was 0.31 ppm and two were 0.35 ppm (i.e. not too seriously over the limit), and one of the 0.35 ppm readings was suspect because the associated dirt and water levels were very low. The fourth sample contained 0.5 ppm, but this was in a Batch I Type 42 before she had received modifications to cure a recognized weakness in her coalescer. This modification, which includes larger diameter coalescer support rods and improved knife edge seals on the end plates and elements, has now been fitted in all Batch I Type 42s. Thus the clean-up systems are seen generally to be performing well.

TABLE II—*Percentage of samples satisfying Table I (1983 figures) in period 1 March 1983 to 1 December 1986 (corresponding figures for 1 January 1981 to 28 February 1983 in parentheses)*

Ship Class	*Dirt*	*Water*	*Sodium*
Type 21	97(93)	100(100)	97(100)
Type 42 Batch I	99(100)	100(95)	99(100)
Type 42 Batch II	94(100)	99(98)	100(100)
Type 22	97(100)	100(100)	99(100)
CVS	100(93)	97(95)	100(100)

Usage Rate of Coalescer Elements

In 1983 the life of coalescer elements was unacceptably short. There was little problem given clean fuel, but with fuel having poor storage stability and containing fine organic dirt, coalescer life on occasion was as low as 12 hours. In contrast the pre-filters, designed to protect the coalescers from fine dirt and to have their elements quickly and easily changed, showed no sign of blockage and did not need changing. The solution, to make the pre-filters finer and the coalescers coarser, appeared obvious enough.

In practice, this was not quite so easy. Pre-filter manufacturers co-operated in designing finer pre-filters and offered them for assessment. Initially they were tested on water-free fuel by RAE Cobham using a portable test rig which could be set up at an oil fuel depot alongside a tank of reference 'dirty' fuel. Preparing such a fuel was a problem in itself. The use of artificial contaminant was investigated and found unsatisfactory because none could be found which adequately reproduced the filter-blocking behaviour of the natural fine dirt. A tank of fuel which had undergone storage degradation was located and used, although by the very fact that it was unstable its characteristics changed with time and limited the period for which it could be used for pre-filter testing. Many configurations of pre-filter were tested. The difficulty lay in designing a composite filter material that gave a good compromise between protecting the coalescer almost perfectly but having a very short life, and having a long life but giving inadequate protection. After initial development using the portable rig, samples were assessed on a rig at ARE (NAMD) Haslar using fuel that was not water-free. After a large amount of testing, a suitable design was identified having a nominal filtration standard in the region of 3 microns, and this went into service with the Fleet early in 1986. Because of the very variable nature of both fuel quality and dirt particle size distribution, it is very difficult to put figures on the expected life of the coalescers and the new pre-filters. Based on the shore trials (which it must be stressed were for a batch of fuel having particular dirt characteristics), the coalescer life is expected to be improved by a factor of at least three times, and the new pre-filter life is expected to be of the order of twice the life given by the coalescer when protected by the old pre-filter. Although the pre-filter elements need to be changed more frequently than formerly, this is preferable to frequent changing of the coalescer elements, particularly because the coalescer contains sixteen or more elements (depending on type) compared to two in the pre-filter. Reports from the Fleet generally support these figures although the very variable quality of the fuel makes it difficult to accumulate any precise data rapidly. It is worth emphasizing that fine pre-filters behave to some extent as coalescers and consequently the separated water must be frequently drained from the pre-filter casing. This precaution is still more important with the new pre-filters since they remove considerably more water. Neglect of this can lead to overloading of the coalescer due to slugs of water passing from the pre-filter, and to growth of MBC in the pre-filter.

Turning to the coalescer elements themselves, a modified element with a nominal filtration standard of 4 microns instead of 1 micron was developed in 1983. Trials at ARE Haslar showed that water and dirt removal efficiency was satisfactory and trials at RAE Cobham showed an improvement in life by a factor of up to two, based on two different samples of 'dirty' fuel. The modification was authorised in 1985, although the newer elements do not reach the Fleet until supplies of the original element are exhausted.

The fine organic dirt produced by fuel instability cannot normally be removed by centrifuging, due to the very small size of the dirt particles and their density being quite close to that of the fuel. There has been some evidence, as yet not proven, that if the fuel is heated to a moderate temperature in the range 20 to 40°C this dirt can be removed by centrifuging. Preliminary experiments appeared very encouraging and more rigorous trials are now taking place at ARE Haslar. If successful, this could be a very valuable way of reducing pre-filter and coalescer usage.

The difficulty of assessing the filter blocking tendency of a fuel has in the past been a major hindrance to development of suitable filters and indeed to all work on the fuel instability and performance of fuel clean-up systems. Particle analysis counts and measurements of volume or mass of dirt are laborious and slow and in any case do not necessarily reflect the true filter blocking capacity. The absence of a rapid and simple method also made it difficult for the fuel specification to define the fuel cleanliness and for the warship or RFA to check the filter blocking capacity of any fuel being transferred or to check the satisfactory functioning of the fuel clean-up equipment. The presence of a white lace-like formation in the water reaction test (the primary purpose of which is to check that the fuel will allow satisfactory separation of water in a coalescer) did give a rough indication but its use as a routine check had to be discontinued because it was too unreliable and subjective. To meet this need a Diesel Fuel Filtration Test Kit (DFTK) has been designed and developed at RAE Cobham. It is portable, simple and reliable, and gives a rapid, direct indication of the filter blocking tendency of fuel by pumping a sample through a standard filter paper at a standard rate and measuring either the pressure drop after the passage of 250 ml, or, if it should occur first, the volume of fuel passed when the pressure drop across the filter reaches 1 bar. A number of prototypes were produced including five which were supplied to warships for trial periods ranging from four to six months for monitoring fuel cleanliness through the fuel clean-up system. The trials were successful and it was decided that all gas turbine warships, RFAs, OFDs and STUFT should be equipped with the production version shown in FIG. 4. The kits were issued at the end of 1986.

In warships the DFTK is intended to be used to check the quality of fuel from commercial or other non-R.N. sources and as a diagnostic tool to check the correct functioning of the fuel clean-up system. OFDs, RFAs and STUFT will use the DFTK to check the quality of fuel stocks on a regular basis and before delivery to the customer. As already mentioned, the test has now been written into the F-76 specification[2]. It is also being considered for use by the U.S. Navy and some Commonwealth navies and as a standard test by the Institute of Petroleum.

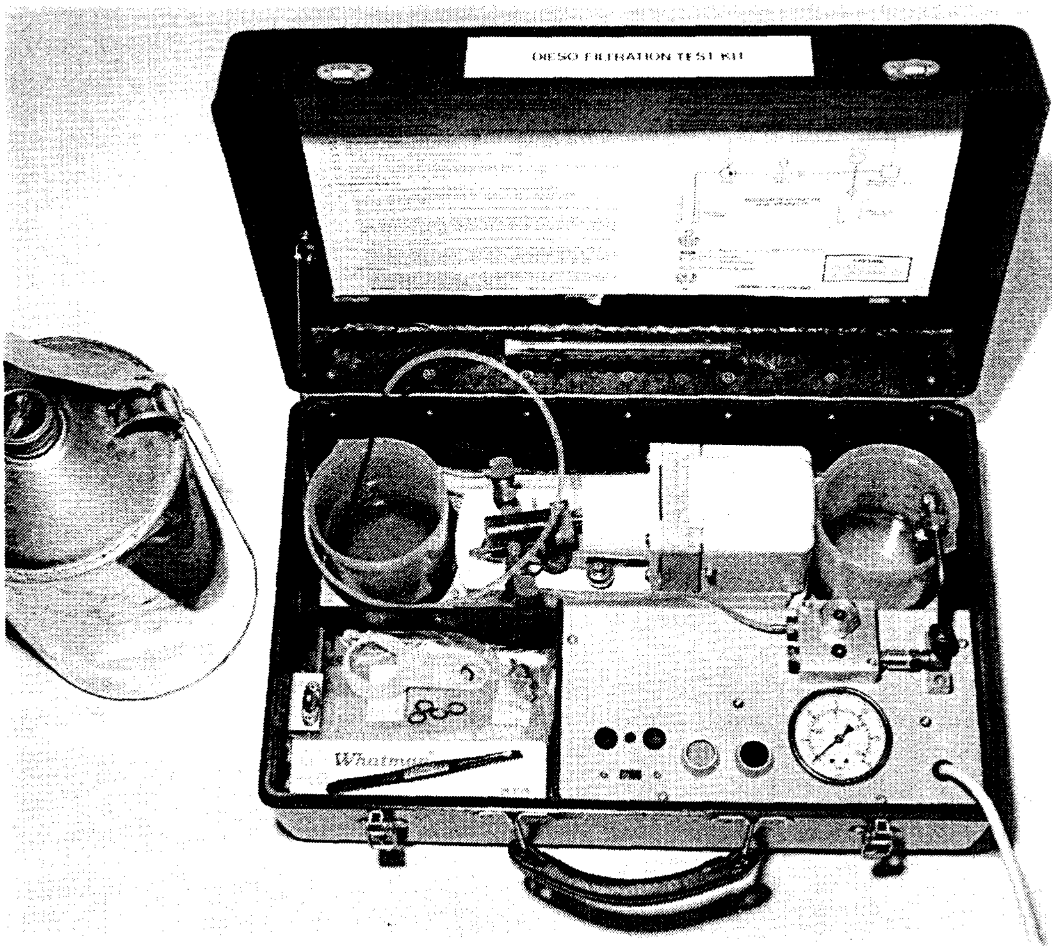

FIG. 4—DIESEL FUEL FILTRATION TEST KIT, PRODUCTION VERSION

Microbiological Contamination (MBC)

Some MBC is bound to occur wherever fuel is in contact with water, but experience over the past few years has shown that the problem can be contained by regular stripping and draining of water from tanks and fuel systems and by cleaning of tanks. In water compensated fuel tanks MBC has not been a problem due to the relatively rapid turnover of fuel and the precautions taken to ensure that only clean sea water is taken into the tanks by not using fuel from these tanks in inshore waters. Experiments have shown that with clean sea water there is very little MBC even after two years in contact with fuel, provided no nutrients are added. Unacceptable levels of MBC are more likely to form in uncompensated storage tanks where the intrusion of water from, for example, condensation is thought to extract some nutrients from the fuel. The debris from MBC can be removed by centrifuges where these are fitted, although this will not prevent the spores reaching the service tanks where growth may take place at the interface with any water bottom. Regular monitoring of the service tank water bottom by the ship staff should allow any MBC contamination to be recognized in time for it to be countered by cleaning the tank.

Biocide treatment is only used if MBC has got completely out of hand and even then only after cleaning the system, since dead MBC fragments are just as effective as live ones in blocking filters and coalescers. As a precaution three different biocides have been identified as suitable for use in ship systems. Many others have been tested but rejected for reasons such as adverse effects on coalescers and lack of effectiveness. The reason for selecting more than one biocide is to insure against the possibility of a strain of MBC evolving that is resistant to that one. This is also a strong reason for not using biocide on a regular basis, quite apart from the high cost.

Because of the many factors involved, the decision to use biocide in an operational ship is only taken by headquarters in close consultation with the specialist laboratory.

Conclusion

As a result of commercial pressures on the production of F-76, the trend towards increasing storage instability and consequently greater fine organic dirt content is expected to continue, causing potential problems for gas turbine warship fuel clean-up systems. Currently the problems are being contained by the use of modified pre-filters and coalescers. It is hoped that the work described will lead to other remedies and ultimately remove the need for frequent pre-filter and coalescer element replacement. Whilst MBC is always a potential hazard for ships' fuel systems, attention to good housekeeping by ships staff has been successful in containing it.

Acknowledgement

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References

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2. Defence Standard 91-4: 'Fuel, naval distillate NATO code no. F-76 joint service designation Dieso F-76', issue 5, July 1986.