GREEN FUEL FOR THE ROYAL NAVY?

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ABSTRACT

This article outlines the changes that have taken place in diesel fuel over the years and the latest predictions of future trends which have resulted from pressure to protect the environment. The effect of these trends on the RN and its response to the predictions are described.

Introduction

Diesel fuel is a commodity that changes continuously and frequently gives surprises, sometimes pleasant, sometimes unpleasant. The changes may have serious implications for ships' equipment such as gas turbines, diesel engines and fuel handling systems. Consequently it is important for the RN to have as much warning as possible and it is fortunate to be advised by a body of specialists from the oil industry and equipment manufacturers known as the Naval Advisers on Fuels and Lubricants (NAFL). Until 1979 the quality of diesel fuel had been very very good and gave rise to few problems. In 1979 the NAFL reviewed trends in quality, availability and costs up to the year 2000 and concluded in broad terms that increasing world demand would be likely to lead to accelerating price increases for RN fuel. Following a dramatic change in world fuel supply, the NAFL again reviewed the position and undertook a study which in 1989 predicted that diesel fuel would be available well into the 21st century and would be stable in price but more variable in quality with a trend of deteriorating properties. In 1990 it became apparent that a new factor was likely to effect fuel quality trends—the 'green' environment. This article sets out to describe the effects on fuel quality of this latest development and the impact on the RN.

Equipment Demands

Before dealing with the fuel quality changes and to put them in context it may be helpful to give a brief outline of the demands made by the equipments and the current fuel handling systems in ships.

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

Property	*Applying in 1983*	*Applying in 1992*
Dirt (mg/l based on 5 micron filtration standard)	1·0	3·0
Free Water (ppm by volume)	50	500
Sodium (ppm by weight)	0·3	0·3

The equipment which makes the greatest demands on fuel quality in respect of contaminants is, by a clear head, the gas turbine. The manufacturer's specification for limits of impurities in fuel are given in TABLE 1. As explained in an earlier article[1] the RN is still working to the more demanding 1983 figures because in order to achieve the 0·3 ppm sodium requirement the particulate dirt and water requirements are easily met. Limits are imposed by gas turbine requirements on the actual properties of the fuel in terms of sulphur, water separability, and carbon/hydrogen ratio (the latter affects combustion properties). For diesel engines, the most critical properties are cetane number (which affects combustion performance) and lubricity which could affect fuel pump wear, although it is not a problem with current fuel.

A fuel system of the type shown in FIG. 1 is used in gas turbine warships to ensure the fuel is cleaned up to the required standard before reaching the engines. The principle components are:

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

(*b*) Pre-filters, whose purpose is to protect the coalescers from dirt.

(*c*) Coalescers (also known as filter/water separators). Their primary task is to remove water and the sodium which might be dissolved in it in the form of sodium chloride. In order to work effectively the coalescer elements must have a very fine filtration standard and consequently they can rapidly become clogged by fine dirt if the pre-filters do not do their job. From the point of view of the fuel handling system, the most important features of the fuel are that it should not contain particulate dirt and that the cloud point of the fuel should be low enough to prevent wax forming in the fuel at low temperatures.

After that brief outline the main demands made by the ships systems and equipments on the fuel, the predicted changes in fuel quality and the impact on the RN are discussed in more detail.

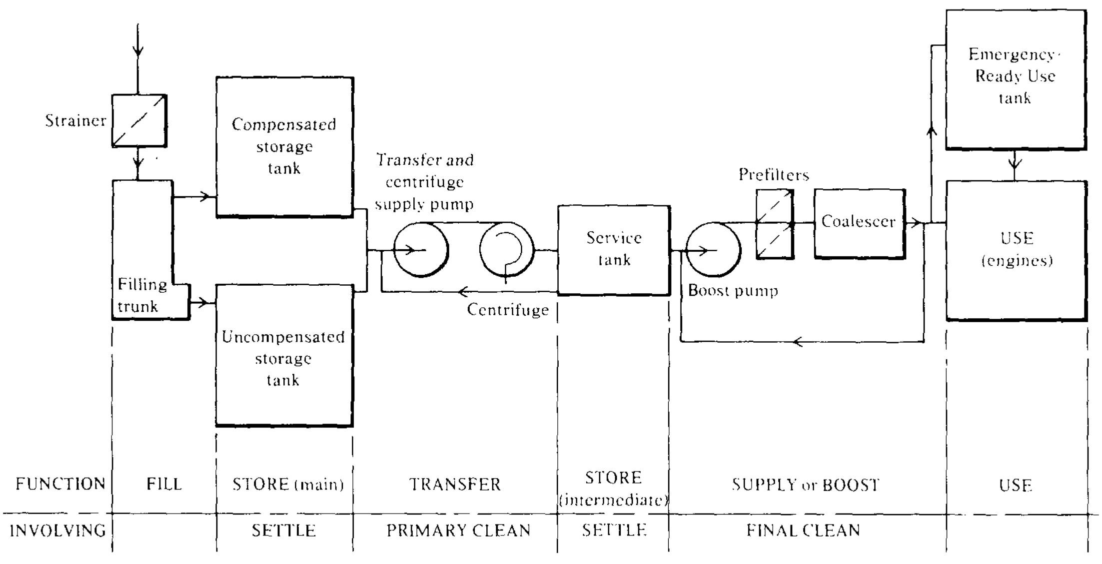

FIG. 1—SIMPLIFIED DIAGRAM OF TYPICAL GAS TURBINE WARSHIP FUEL SYSTEM

Fuel Quality Changes

The bulk of the fuel used by the RN is Dieso F-76 (which is the RN joint service designation) procured to the MOD specification[2] and having the NATO Code F-76. Dieso F-76 is a more tightly specified version of the marine gas oil (MGO) widely available on the commercial market. Much of the MGO available is of high quality and it often complies with the Dieso F-76 specification in most respects—indeed warships are authorized to use MGO in emergency provided its properties are within certain limits. The difficulty with MGO is that its specification can be very variable, particularly in terms of properties important to gas turbine warships such as cleanliness and water separability, and this prevents its unrestricted use in place of Dieso F-76. The problems are frequently compounded by contamination of the MGO in the supply systems of remote ports.

Before 1979, most Dieso F-76 was prepared by 'straight run' distillation and gave very few problems. The review carried out by NAFL in 1979 predicted that rising demand would cause accelerating price increases and increased use of cracking processes for preparing fuel. These cracking processes break down the long chain molecules in the heavier fractions of crude oil and allow a greater part of the crude oil ('a greater part of the barrel' in the jargon) to be converted to the more commercially valuable middle and light distillate fuels. Unfortunately this procedure also has some adverse effects on fuel properties and consequently it was predicted that cloud point, flash point, viscosity, cetane number and storage stability would be adversely affected. In the early 1980s, the adverse effects on storage stability and cloud point were beginning to be felt. In the case of storage stability, the long chain molecules which have been broken down in the cracking process tend to join up again and typically fuel containing cracked product throws fine organic dirt into suspension when about six months old. This dirt rapidly blocks fine filters such as coalescer elements and cannot be removed easily by centrifuges because of its small particulate size and small difference in density from that of fuel. When fuel having bad storage stability was encountered it exposed a design deficiency in the gas turbine ship fuel clean-up systems in that the pre-filter was too coarse to protect the coalescer and the coalescer element life was unacceptably short. The work undertaken to correct the filtration standard of the pre-filters was described in the earlier article[1]. The significance of cloud point is that if the fuel is cooled to a temperature below its cloud point, wax separates out and blocks strainers and filters. Cloud points rose in the early 80s to the limits of the specification and led to the tightening of the cloud point requirement in the specification from a maximum of $-1°C$ to a maximum of $-4°C$—this particular change was precipitated by the Falklands War as a precaution to eliminate the chance of waxing in the South Atlantic.

The next review of future fuel trends by NAFL resulted in a paper completed in 1989. This predicted that the expected trends in the main properties of Dieso F-76 over the period up to approximately AD 2015 would be as shown in TABLE II. Overall the quality of the fuel was expected to deteriorate and this gave a strong incentive to carry out R&D on engines and fuel handling equipment to enable the Dieso F-76 specification to be relaxed so that the predicted lower quality fuel could be used. Otherwise there could be a growing

TABLE II—*1989 View of trends in Dieso properties*

Property	*Direction of Change*	*Effect*
Viscosity	Upwards	Difficulty in starting gas turbines
Aromaticity, Carbon/ Hydrogen Ratio, carbon residue	Upwards (i.e. more carbon less hydrogen)	Smoke; gas turbine hot end erosion due to particulate carbon
Sulphur	Upwards	Corrosion of gas turbine hot end components
Cetane Number	Downwards	Difficulties in cold starting and low load running in diesel engines
Storage Stability	Worse	Sediment contamination of fuel systems
Cloud Point	Upwards	Difficulty in operating in cold climates
Water Separability	Downwards	Greater tendency of fuel to retain water and hence increased risk of sodium attack on gas turbines

cost premium over commercial fuel and diminishing world-wide availability. There would be obstacles to carrying out this R&D because the characteristics of the future fuel could not be accurately predicted and until that could be done there was no point in carrying out expensive development work on engines.

Only a year later, in 1990, it became apparent that as a consequence of governments supporting measures to protect the environment, legislation was likely to be introduced in the European Community (EC) and North America which might halt the previously predicted deterioration in fuel properties. A further review was carried out by NAFL in 1991 and the salient points of this follow.

Salient Points of 1991 Review

World-wide concern for the environment builds steadily, but governmental policies differ according to the relative magnitude of local pollution problems and the abilities of regions to deal with them. In Europe the concern is more with carbon dioxide emissions with probably some form of carbon tax to limit fuel usage. In the USA the emphasis is more on improving local air quality by fuel reformulation to reduce pollution by ozone, carbon monoxide and toxic gases (e.g. benzene) rather than global issues. But there is overall pressure on the sulphur content of fuel, primarily to reduce sulphur dioxide emissions, but with specific emphasis on reducing output of particulates and smoke from diesel vehicles.

In the European Community, sulphur ceilings for diesel fuel and for gas oil are changing rapidly. The following proposals have been put forward as amendments to an EC Sulphur Directive:

For diesel road transport fuel (maximum sulphur by weight):

- 0·2% from 1 October 1994
- 0·05% from 1 October 1996
- to have available on the market by 1 October 1995 a balanced (that is geographically) distribution of 0·05% sulphur diesel (at least 25% of the market in each member's state).
  (current limits are 0.3%)

For gas oil, including bunker gas oils (maximum sulphur by weight):

- 0·2% from 1 October 1994
- 0·1% from 1 October 1999
  (currently there is no limit)

At present it is not clear what is covered by 'bunker gas oils'—for example whether the term applies for inland waterways, coastal use or full marine use and this is still under discussion in the EC. The chances of these proposals being accepted are believed to be high in the case of the diesel road transport fuel but lower for the gas oil. The amended directive is expected to be adopted in the second half of 1992.

In the USA a 0·05% sulphur specification for diesel fuel for land use will come into effect from the 1 October 1993. At present there are no proposals that tighten gas oil specifications beyond 0·2% sulphur, but the US Environmental Protection Agency (EPA) is active in the development of emission limits on off-highway diesel engines including marine operations, which may require reductions in fuel sulphur content.

In practice these reductions in sulphur content will generally be achieved by treatment at the refineries which will inevitably increase the cost of the fuel.

Other diesel fuel quality issues are under investigation in Europe and the USA which might improve the ignition qualities of fuel, although refinery costs would increase and calorific value (and hence ship endurance) would be reduced. Legislation controlling these by tax has already been promulgated both in the State of California and in Sweden and may be adopted more widely in the future. Although warships are usually exempted from such regulations, it is MOD policy to comply as far as possible.

Distillate fuel to the Dieso specification is expected to be widely available in the foreseeable future. However to maximize the number of potential supply sources the sulphur content may be up to the 1·0% limit; a trend is already apparent for Dieso to have either a low sulphur content (around 0·2%) when procured from a refinery equipped with sulphur removal plant or a content approaching the limit when procured from a refinery not so equipped. Clarification of the term 'bunker gas oils' mentioned earlier could reduce this sulphur content for marine fuel purchased in the EC area, although other areas and in particular the Third World may in any case continue to allow relatively high sulphur conents. Another uncertainty is whether oil producers will standardize on producing low sulphur fuel for both the land and marine markets, or whether they will 'dump' high sulphur fuels on the marine market if the regulations allow it.

The good news for the RN is that, apart from fuels having low sulphur contents giving longer gas turbine life, hydrogen treatment of distillate fuels to achieve low sulphur contents should lead to improvements in fuel storage stability and associated cleanliness, which we have already seen are a cause of concern for RN fuel handling systems and equipments. Because of the number of processing options available for the F-76 supplier the potential problem of fuel storage instability will still remain but at a lower level than at present.

Turning our attention to other Dieso specification requirements such as density, flash point, viscosity and ignition quality (cetane number), the oil industry should have no problem in maintaining these at the present level, contrary to the earlier predictions. However within the constraints of the specification, at any one time there is likely to be considerable variation in quality of fuel depending on source. New problems may arise, for example components from new processing routes behaving differently from those derived from more traditional routes, very low sulphur fuels causing unacceptable wear of fuel lubricated components, and mixing fuels produced from novel and existing processes having adverse effects on stability and physical properties, leading to a potential need for improved control procedures for fuel blending and storage. It is not expected however that these will be major problem areas.

To summarize, Dieso F-76 quality is expected to remain similar to that of today, but subject to divergence between low and high sulphur content and with the potential for unstable fuel remaining, although at a lower level than at present.

RN Response to Latest Predictions

The general effect of the latest predictions is to reduce the need for the RN to devote extensive resources to R&D on fuel, fuel systems and equipments. However the potential for unstable dirty fuel will still exist, albeit at a lower level, and so there is still a need to:

(*a*) Continue fundamental chemical research into the mechanism of storage instability for fuels produced by current processes and new processes as they come into being.

(*b*) Continue with existing or improved fuel handling systems in gas turbine warships to cope with dirty fuel and also continue the use of the diesel fuel filtration test kit (DFTK), used to guide ship's staff in their tactics for dealing with dirty fuel (the DFTK is a device which assesses the propensity of a fuel to block fine filters—details are given in the earlier article[1]).

(*c*) Be alert to any new developments in equipment for handling fuel in ships which might allow ships to accept poorer quality fuel without operational penalty or technical risk.

Because the properties other than fuel storage stability are not now expected to deteriorate there is less incentive to devote resources to relaxing the specification for these other properties. However there is still some incentive if we are to maximize our ability to use world-wide sources of fuel, since the quality of fuel in Third World countries may continue to deteriorate if those countries are slower to implement measures to protect the environment. There may also be financial advantage in relaxing the specification for properties such as cloud point.

The justification for R&D work on engines, both gas turbine and diesel, is now greatly reduced. With the new situation, fuel combustion properties are expected either not to deteriorate (non Third World) or to be variable and possibly deteriorate (Third World). In the first case engine development work is not needed and in the second it cannot be justified at present because the fuel quality cannot be reliably predicted.

A brief description of some of the work in progress in these areas now follows.

Basic Chemistry

The DQA/TS oil laboratory at Cobham carries out fundamental chemical research into the mechanism of instability in fuels with the aims firstly of predicting when a particular fuel is likely to be unstable and secondly of developing a fuel stabilizing treatment to prevent storage instability and the associated particulate dirt formation. Cobham has been very successful in the first aim and has developed a simple test taking about 10 minutes which makes use of colour change in a tube to predict storage instability. The test has been patented and is still being assessed against fuel samples from as wide a range of sources as possible. Caution is needed before the test is put into operational use as it depends on a particular instability mechanism which might not apply for all types of fuel. To date it has proved successful on samples of freshly produced fuel although less reliable on aged fuel. Its greatest use will probably therefore be as a procurement test. This is fortunate as aged fuel is likely to have already thrown down the fine dirt and thus can be assessed by the DFTK. Work on additives is continuing—if a successful additive could be developed, it would be incorporated as part of the refinery process.

Fuel Handling Systems and Equipment

Measures which have been evaluated or are being implemented are:

(*a*) Heating fuel before passing it through the centrifuge. The theory is that reduced viscosity and enhanced density difference between the particles and the fuel should improve the effectiveness of the centrifuge in removing the very fine particles of organic dirt (which it normally finds difficult). Trials were carried out at NAMD Haslar but unfortunately have shown that in practice there is no apparent advantage.

(*b*) Addition of water to fuel before passing through the centrifuge. It has long been known that if water is distributed in the fuel it improves the ability of the centrifuge to remove fine organic dirt and this was apparent again when water was added in the heated fuel trials just described. Trials are planned at NAMD to assess the optimum quantity of water to be added—there would be obvious difficulties if the quantities of water required are large.

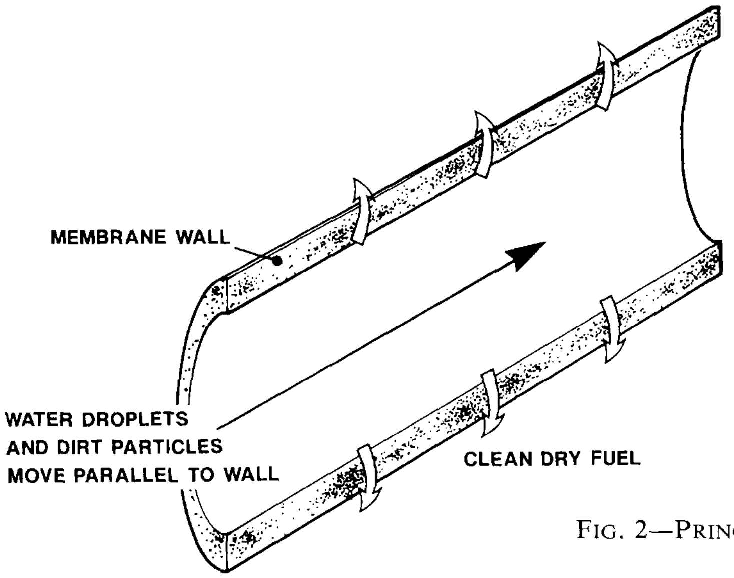

FIG. 2—PRINCIPLE OF CROSSFLOW FILTRATION

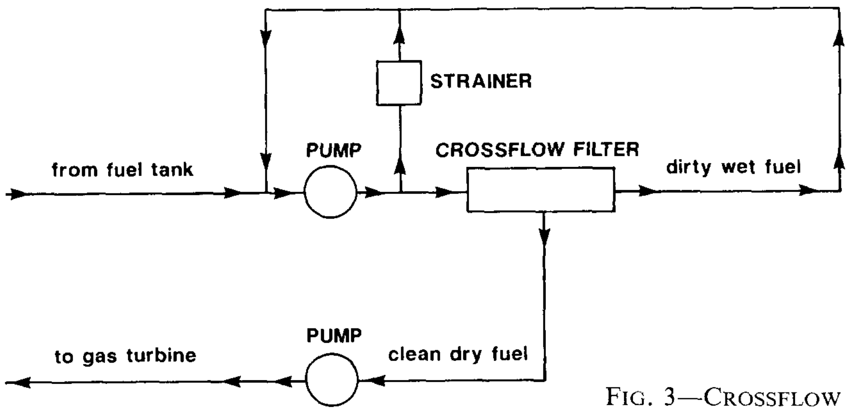

FIG. 3—CROSSFLOW FILTER FLOW DIAGRAM

(*c*) Crossflow filtration. The principle is illustrated in FIGS. 2 and 3. Fuel containing dirt and water is passed into a tube formed by a membrane—the theory is that clean fuel emerges through the membrane walls while a more concentrated soup of fuel and water is passed out of the end of the tube and recirculated after being filtered in a conventional coarse filter. Because of the high levels of dirt and water and the relatively relaxed clean-up required, in theory this coarse filter can be a simple re-usable strainer. A unit has been assessed at NAMD and while it was capable of removing dirt from dry fuel, the presence of water caused it to block in a short time. While the unit appears to have great potential, it seems unlikely that it will reach a satisfactory stage of development in the near future. Its great advantage if successful would be the elimination of the need for replacing filter elements and the associated costs in money, manpower and logistics.

(*d*) The DFTK has been in use for several years now and has been most successful in assessing the filter blocking properties of fuel. Until now sampling of gas turbine ship fuel systems has been carried out on the basis of testing every ship's system at approximately six-month intervals by the Fuel Sampling Rating (FSR). This has been invaluable but has had the drawback that ships were usually alongside when tested and therefore fuel flow rates were low. A 'Diesopack' is shortly to be introduced which will enable ship's staff to send back fuel samples for analysis at Cobham and this will allow samples to be taken at higher fuel flows while at sea.

Relaxation of F-76 Specification

Some progress has been made in this direction. The tightening of the limit of cloud point of fuel to a maximum of $-4\,^{\circ}C$ already mentioned involved a cost premium. Consequently rig work was carried out at NAMD to assess whether the cloud point could be relaxed to $-1\,^{\circ}C$ as formerly without appreciable risk. The rig simulated a ship's fuel tank in contact with cold water and examined the formation of wax. It was found that after the initial start of the period the wax formed a stable configuration on the tank bottom and was not drawn through into the fuel suction. The wax which is drawn through in the start-up period is deposited on the transfer pump strainers and can readily be removed by immersing the strainers in hot water after fitting spares. This rig work has given the confidence to allow restoration of the maximum cloud point to $-1\,^{\circ}C$ if there is sufficient financial advantage.

Although there is no pressure on flash point of fuel at present, Cobham are carrying out R&D on this for two main reasons:

(*a*) There may be difficulty in meeting our current minimum flash point of 61° in some geographical areas.

(*b*) It would be very attractive for sea land and air forces to use a single fuel. Although at present it appears very unlikely that this concept can be realized in the foreseeable future, any relaxation that could be made in required flash point of shipboard fuel would ease the supply position for single fuel candidates.

Conclusion

As a result of policy responses by governments to concern about environmental pollution, legislation is likely to halt the previously predicted trend of deterioration in distillate fuel quality. Some properties such as sulphur content and storage stability (and associated fuel cleanliness) are likely to improve in Europe and North America. The quality of diesel fuel is expected to remain similar to that of to-day, but subject to divergence between low and high sulphur content and with the potential for unstable fuel remaining, although at a lower level than at present. The impact of this on the RN is that less resources need be directed to R&D to counter the effects of poor quality fuel on equipment, although there are still areas such as fundamental chemical research and fuel handling systems where effort is justified in view of the continuing potential for fuel having poor storage stability and a high content of fine organic dirt.

Acknowledgements

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