CROSSFLOW FILTRATION FOR GAS TURBINE DISTILLATE FUELS

BY

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ABSTRACT

Whilst Gas Turbine prime movers have developed markedly in the decades they have been in service the associated fuel clean up (boost) systems have remain fundamentally unaltered. This article outlines the work carried out by DERA on behalf of the Directorate of Marine Engineering. This project is at an advanced stage preparing trials to provide future surface warships with a simpler, low maintenance, more flexible and much more cost effective Gas Turbine fuel system.

Introduction

For some time now the Directorate of Marine Engineering (DME) has been investigating the possibility of improving the performance of the fuel systems for prime movers in the Fleet. This has led to many initiatives; some of which have resulted in further studies by the Defence Evaluation and Research Agency (DERA). One of the most promising paths of progress has been the ceramic crossflow filter and this led to a paper being presented at San Antonio, Texas.[1] This article will describe some of the developments since that conference.

Aim

DME wishes to obtain a fuel processing system for distillate fuel prime movers that exceeds current fuel system performance and at improved value for money. While doing this, the preferred system should have lower maintenance requirements and meet or exceed current and anticipated safety and environmental legislation. Ideally the system solution should effectively be a 'black box' that requires little or no intervention from Ship's Staff.

Why do we need change?

Gas turbines offer high power to weight ratios and fast response times as warship prime movers. However, to achieve reasonable fuel efficiency, they operate at high temperatures and high air mass flow rates. This means that the turbine blades are often operating near their metallurgical limits. The blades that are chosen to meet this requirement are susceptible to sodium and potassium contamination resulting in accelerated erosion and grain boundary attack. Limiting the influx of these contaminants has been achieved by controlling the amount of water and particulate in the fuel and air systems.

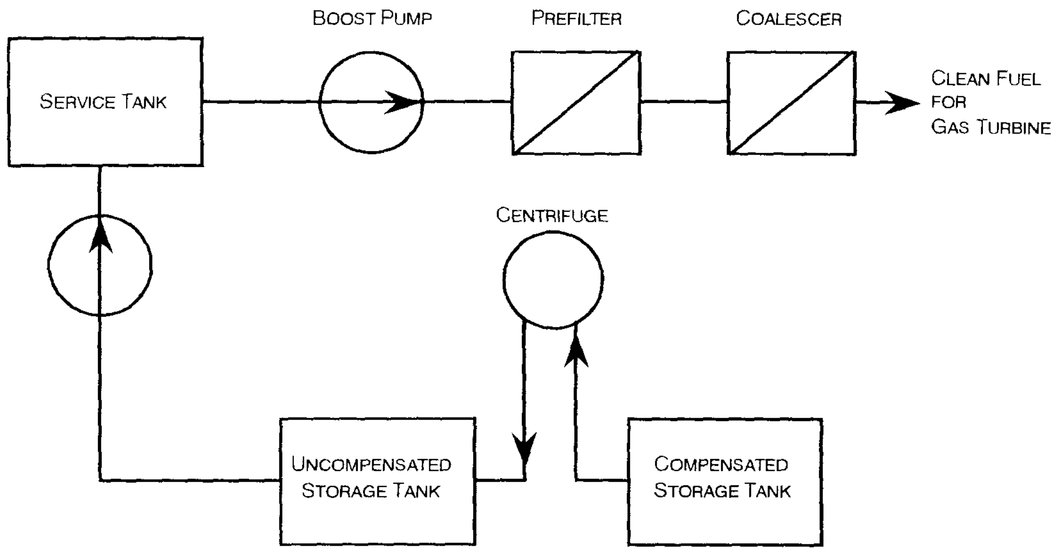


FIG.1 — TYPICAL CURRENT GAS TURBINE FUEL SYSTEM

Current gas turbine fuel systems (FIG.1) as fitted to RN warships use a multi-stage clean up system (boost system) to remove dirt and free water from distillate fuel. Following settling and stripping in the tanks the gross dirt and water is removed by a centrifugal separator, the fine dirt is held back by a particulate pre-filter and entrained water is removed by a filter coalescer. The pre-filter's primary purpose is to protect the coalescer. This complete system is very sensitive to input fuel quality which has led to rigorous checking of received fuel by Ship's Staff and others in the supply chain.

Both the pre-filter and the coalescers have replaceable elements. These require frequent replacement if rough weather is encountered or dirty fuel is embarked and this leads to problems in storing new elements and disposing of used elements. We are long past the stage where a plastic bag in the Ship Control Centre, Marine Engineering Officer's cabin or machinery space bilge is a satisfactory element disposal route prior to discharge ashore.

The capital cost of centrifugal separators is considerable and the rotating assembly presents a hazard to personnel. Separators are excellent for removing slugs of water and contaminants of different density to the process fluid. They are far less effective in removing the natural fuel dirt from diesel fuel that is of comparable density to the bulk fuel. Whilst separator technology has improved greatly the continued use of centrifuges carries a significant maintenance load.

Although many attempts have been made to correlate replaceable element consumption with input fuel quality none have proved fully satisfactory. This has led to precautionary early replacement of filters prior to full power trials, deployment away from home waters etc. and in areas where received fuel is anecdotally suspect. Data is unreliable in this area. Instances commonly occur of microbiological growth (MBC) contaminating distillate fuel systems. In certain cases this may be prevented from growing by the addition of a biocide. Unfortunately some biocides create problems with disarming the filter coalescer and the best biocides may not be compatible with the environment or the prime mover. Additionally, where substantial MBC is present the prefilters are easily blocked.

How did we get here?

The tighter specifications for F76 Dieso in the Fleet have developed with gas turbine propulsion systems. Earlier propulsion systems could tolerate lower dirt standards. Additionally, modern formulations of F76 contain far more cracked stock than was common previously. This considerably affects the storage stability and the amount of natural dirt in the fuel.

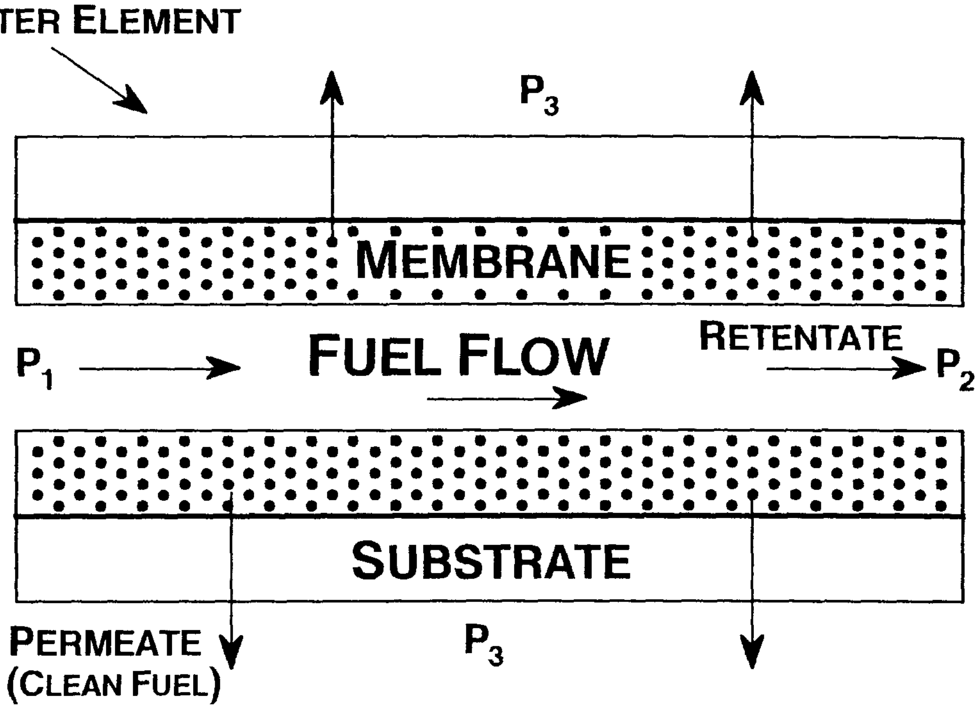
The use of water compensation in some ships has produced fuel/water interface problems as well as environmental discharge issues. Environmental and safety legislation is toughening up.

With reduced manning on warships we must try to remove regular labour intensive tasks such as element replacement as well as reducing personnel exposure to distillate fuels. The industrial climate is now right to consider some of the alternatives available. Crossflow filtration has been used widely in industry albeit at lower fluid volume flows. As the San Antonio paper demonstrated, there is ample evidence to justify a more substantial investigation of ceramic crossflow membranes for fuel filtration in warships.

What is crossflow filtration?

Crossflow filtration is now a well-developed technology used, amongst other areas, in the water and blood products industries. The MoD has units already at sea operating as oily water separators. The area of novel use for this method of filtration comes with the requirement to filter at the high flow rates demanded by gas turbines using F76 distillate fuel.

The fuel crossflow filter works by replacing the current centrifuge, pre-filter and coalescer with a bank or banks of tubes. Fuel from the ship's tanks is pumped at low pressure through these tubes and a certain percentage of clean, filtered fuel 'permeates' through the tube walls and is delivered to the prime mover. The remaining fuel and the retained dirt is recirculated back to the 'retentate' tank. This retentate tank is topped up with fuel from the ship's tanks according to demand. The basic principle is illustrated at (FIG.2).



Q_f = CROSSFLOW
A_f = CROSS SECTIONAL AREA
P_1 = FEED PRESSURE
P_2 = RETENTATE OUTLET PRESSURE
P_3 = PERMEATE PRESSURE
Q_p = PERMEATE FLOW
A = MEMBRANE INTERNAL SURFACE AREA
μ = DYNAMIC VISCOSITY
ρ = DENSITY
d_H = HYDRAULIC DIAMETER
V = FEED VELOCITY
R_e = REYNOLDS NUMBER
TMP = TRANSMEMBRANE PRESSURE

$$\text{FLOW} = \frac{\text{DRIVING PRESSURE}}{\text{RESISTANCE}}$$

$$\text{FLUX} = \frac{\text{TMP}}{\mu R}$$

$$\text{WHERE FLUX} = J = \frac{Q_p}{A}\,[\text{l/m}^2\text{h}]$$

$$\text{TMP} = (P_1 + P_2)/2) - P_3[\text{BAR}]$$

OVERALL RESISTANCE

$$R_0 = \mu R[\text{bar s/M}]$$

$$V = Q_f / A_f \qquad R_e = \rho V d_H / \mu$$

FIG.2 — CROSSFLOW FILTRATION PRINCIPLES

The filter tubes themselves (FIG.3) have star shaped bores running through them to maximize the surface area presented to the distillate fuel. The surface of these bores is coated with a fine membrane that acts as the primary filtration mechanism.

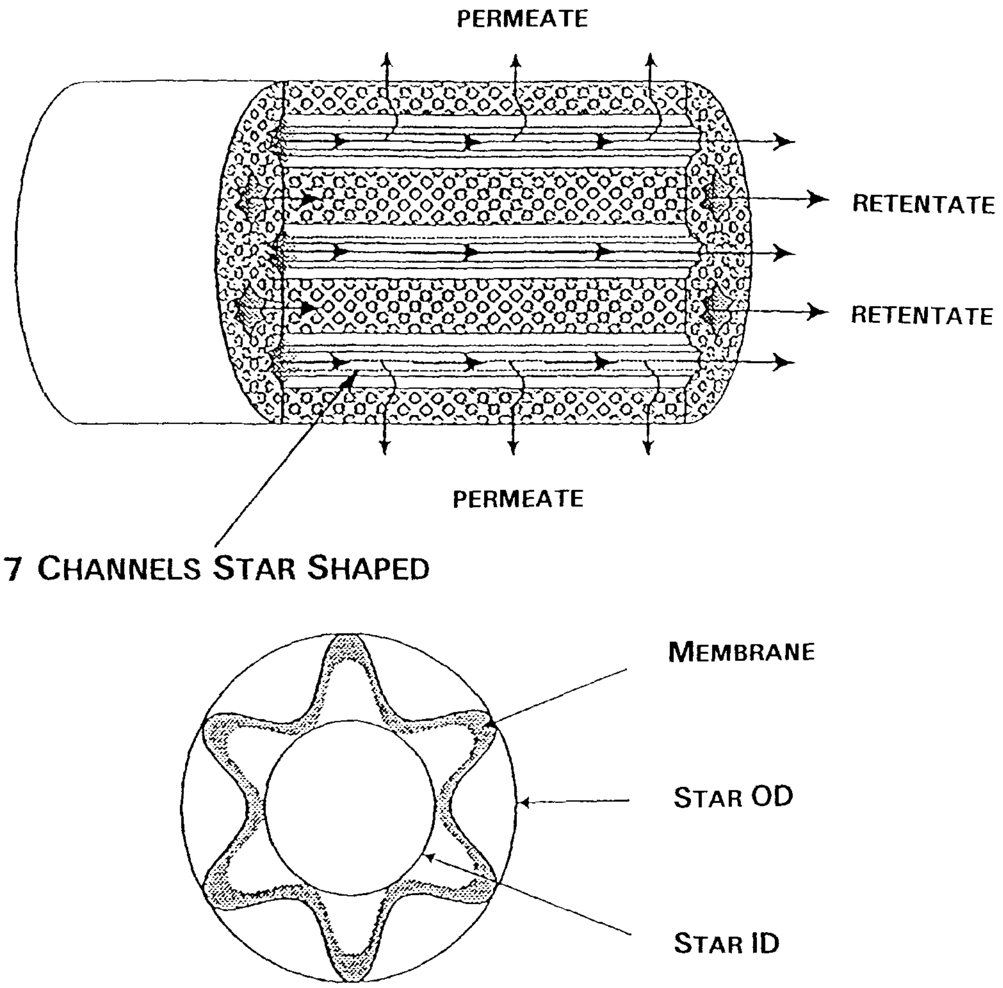


FIG.3 — CERAMIC TUBES DETAILS

As time passes and more and more fuel is passed to the prime mover, the dirt on the membrane surface of the tubes and the dirt level in the retentate tank increases until flow rate drops off from the permeate. This eventually means that insufficient fuel would be available for the prime mover at full power. Although the quantity available would drop off gradually (FIG.4) it is important to emphasise that the quality of the fuel permeate remains high. To reduce this performance drop off, the fuel in the retentate tank may be replaced at regular intervals (say every few months) and the filter elements themselves may be chemically cleaned (anticipated to be annually or biannually). These intervals would be influenced by the quality of the received fuel. The filter cleaning would normally be carried out during planned base port time. The precise details of element cleaning and changing retentate tank contents are a matter of design choice. The fuel displaced from the retentate tank is not lost but may be cleaned up and reissued by an Oil Fuel Depot. The crossflow filter shows indications of being very flexible and many combinations may be possible subject to the operational requirement.

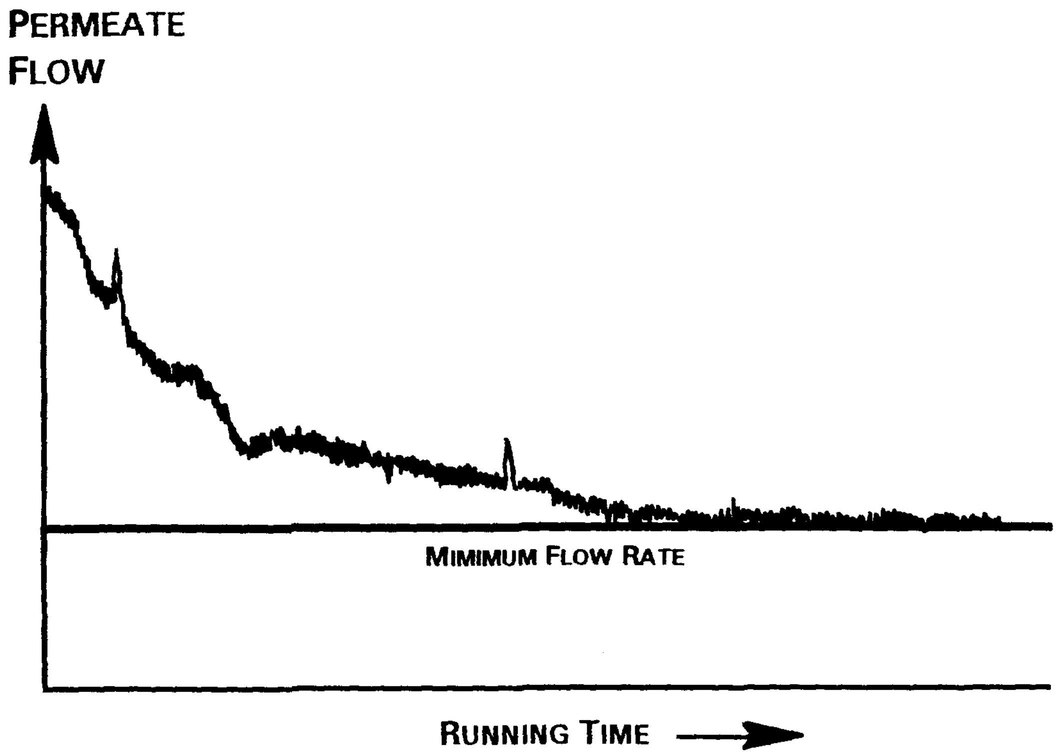


FIG.4 — PERMEATE DECLINE OVER TIME

DERA Crossflow Filtration trials

DERA have been undertaking trials with ceramic crossflow filter elements for a considerable time. Long term tests on a single element test rig have demonstrated the performance anticipated from the earlier trials already published.

The fuel for the trials has been at the very poor quality end of the range for Marine Gas Oil (MGO) with a filterability, as measured by the Diesel Fuel Test Kit (DFTK), of some 100ml or less. This is a level that would be unacceptable to current RN ships on refuelling. Both dry fuel and wet fuel up to 1000ppm entrained water have been trialled and their effects on element performance analyzed. Slugs of water have been passed to the filter to simulate operator error and the filter recovery time has been measured. The filter output quality remains high although a large slug of water slows output of fuel from the filter. This effect is temporary and the filter recovers as soon as clean, water free fuel is passed through it.

Trials and modelling to examine the effects of operating in different climates have been carried out and the consequences of differing hydraulic resistance are being examined. Further work in this area is planned for sea trials.

DERA have also examined a variety of methods of cleaning the filter elements. Results have been very encouraging and simulations have been run for a use/cleaning cycle of 10 year's normal ship operation with no loss of element performance.

Larger scale tests have been carried out at DERA Haslar to examine performance of a multi-element filter bank to understand the issues associated with a practical system. Interim results show that the larger scale unit demonstrates the performance anticipated from the earlier single element trials. A full-scale trial system is due to be installed in a CVSG at the end of 2000. The trial will test the crossflow system for one year on a Rolls-Royce OLYMPUS engine.

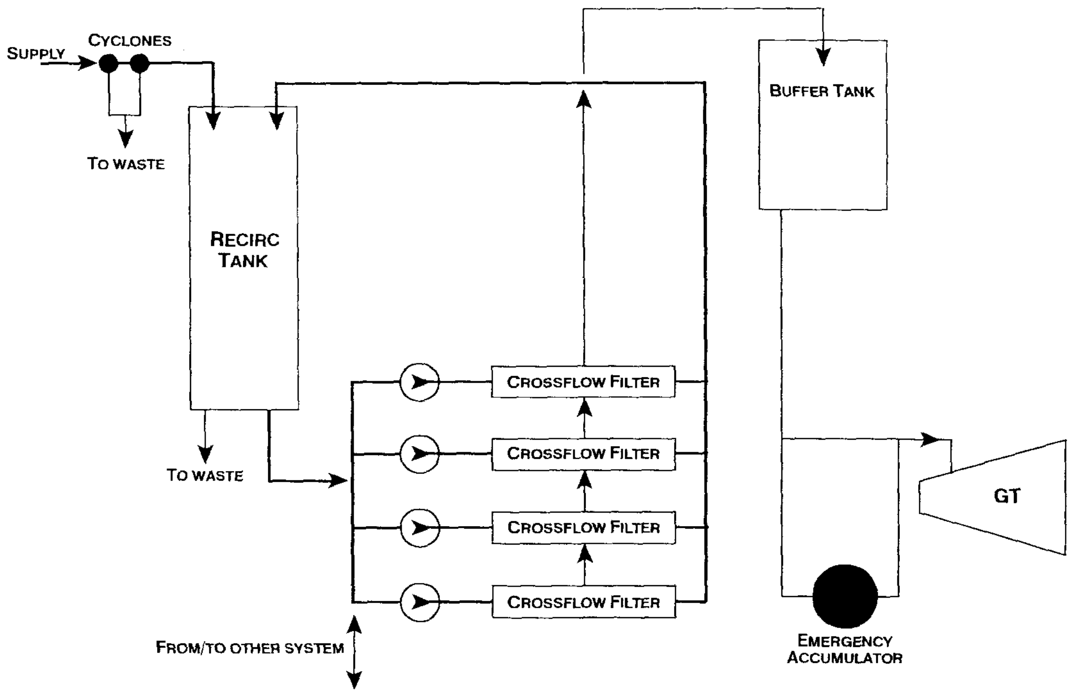


FIG.5 — SCHEMATIC OF A POSSIBLE SYSTEM

Operational considerations

Whilst DERA have been investigating the feasibility of using crossflow filtration the emphasis has been on achieving a practical system (FIG.5) that can meet all the RN operating criteria. This includes such diverse issues as ease of use, temperature variations, volume of equipment in machinery spaces and all the common onboard fuel handling issues. It is imperative that the crossflow filter maintains full power delivery of permeate to the prime mover. Trials so far have indicated the possibility of the crossflow filter providing a full capability for the average ship use with no maintenance carried out onboard except for an annual chemical clean carried out in a base maintenance period. Even when the need for a clean is indicated the slow fall off in permeate means that extending the cleaning interval will not prevent the system maintaining high quality permeate although total volume will reduce slowly. Sea trials are programmed to investigate the hot and cold weather responses of the proposed new system. It is anticipated that suitable passive design of tanks combined with hydrocyclones will require only a simple control system. The crossflow system will have improved redundancy over the conventional system in the event of action damage.

The trials conducted at Haslar indicate to DME that the crossflow filter can be the key element of a very flexible fuel clean up system. This can be simply modified to accommodate the staff requirement. For instance a balance can be struck between:

- Tank sizes
- Element numbers
- Acceptable cleaning intervals.

Potential benefits of Crossflow filtration

Initial indications from DERA have shown that it may be possible to build a system which will require little or no routine maintenance from Ship's Staff and can demonstrate much improved reliability.

The early trials showed that the ceramic elements have a much higher tolerance to high dirt concentrations than the conventional boost system leading to easier handling of poorer quality MGO when deployed.

The filter, once contaminated, has a limited self-cleaning ability and has a predictable performance drop off rate.

Trials so far have indicated that even with high water content (up to 1,000 ppm) in the fuel the sodium passed to the gas turbine is well within acceptable limits.

The crossflow system has an easy and robust waste disposal route. In normal circumstances Ship's Staff will not come into contact with the ceramic elements.

The proposed system will have greater redundancy and flexibility than the current system with the same reversionary mode (i.e. bypass the boost system) as present.

The design requirement is for through-life costs to be considerably reduced. Direct comparisons between in-service equipment and new generation technology are notoriously difficult. Nevertheless, whilst the major benefits of the crossflow filter are in whole-life savings such as training, lower maintenance and improved safety and environmental aspects, there are also immediate payback returns. Preliminary studies by DERA have shown that the cost reduction per system fitted for 12 months in a new generation frigate is at least 30% with forthcoming trials expected to provide further significant savings as the concept is refined.

Conclusions

- Current trials indicate the benefits of the crossflow filter are manifold.
- Cost, simplicity, ease of maintenance, flexibility.
- Crossflow filtration should be trialled at sea to refine concept.
- Potential future savings are even greater.
- The operational problems associated with substandard fuel quality will be significantly diminished.

Reference

1. *B.Drew; D.Redpath. 'Crossflow, An Alternative Means of Cleaning Up Contaminated Diesel Fuel Supplied to Gas Turbines in Warships'.* DERA. A paper for the Second International Filtration Conference, San Antonio, Texas. April 1998.