Proceedings of GT2007
ASME Turbo Expo 2007: Power For Land, Sea and Air
May 14-17, 2007, Montreal, Canada

GT2007-27474

USE OF CROSS FLOW FUEL FILTRATION FOR GAS TURBINE ENGINES

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ABSTRACT

U.S. Navy surface combatants use pre-filters and filter separators in the fuel oil service system to filter out sediment and water in order to meet the fuel oil cleanliness requirements to operate the gas turbine engines and generators. The ships have reported high usage rates of the pre-filters necessitating the replacement of the pre-filter elements. High replacement rates of the elements obviously increases the burden on ships force but it also increases the operating costs due to the cost of the replacement elements and the storage, handling and disposal of the hazardous material generated. One of the causes of the poor quality fuel oil is the purifier's inability to remove all sediment and water from the fuel oil when transferring fuel from storage to service.

A prototype two-stage self-cleaning cross flow filtration unit was installed in parallel with a fuel oil purifier on a surface combatant. This unit was operated during a deployment cycle and had a through put in excess of one million gallons of fuel. The purpose of this paper is to discuss the background leading to the design of the unit, the installation, operation, data, results and future design changes

INTRODUCTION

Surface combatants of the U.S. Navy have, basically, two fuel oil systems. One system is the fuel oil fill, transfer and purification system. The other system is the fuel oil service system. The fuel oil fill, transfer and purification (FOT&P) system is a sea water compensated system that is designed to receive and store fuel oil and to transfer and purify fuel oil from the storage tanks and deliver the fuel to the fuel oil service tanks. The fuel oil service (FOS) system is designed to deliver clean fuel at the proper temperature and pressure to the propulsion and electrical generation gas turbine engines.

When transferring fuel from storage tanks to the service tanks, the fuel is normally transferred via a centrifugal purifier to remove sediment and water. The fuel oil service system passes the fuel through a prefilter and filter/separator to remove additional sediment and water that may have accumulated in the fuel oil. The surface combatants have experienced problems with fuel oil samples exceeding the allowable 2.64 mg/l limit of sediment in the service tanks, reference 1, and forcing the operator to recirculate the fuel oil service tanks using the centrifugal purifier. In addition, the surface combatants have experienced excessive pre-filter element usage in the service system.

The US Navy, in an effort to improve the quality of the fuel oil, reduce the prefilter element usage and to reduce the manhours expended to repair and maintain the centrifugal fuel oil purifier, started to look at new technologies. The system selected is designed and manufactured by Filtration Solutions, Incorporated (FSI) that not only meets the above but is also simple in design, self-cleaning, has few moving parts and is easy to maintain.

NOMENCLATURE

FSI- Filtration Solutions, Inc.
FOT&P- Fuel Oil Transfer and Purification
FOS- Fuel Oil Service
Mg/L- milligrams/Liter
DFM- Diesel Fuel Marine
F-76- Diesel Fuel Marine
Ppm- Parts Per Million
FWD- Free Water Detector
CFD- Contaminated Fuel Detector

SYSTEM DESIGN

The system is a two-stage design. The first stage is a 5 µm self-cleaning filter for solids separation and the second stage is a water-selective membrane filter for water separation. This combination provides a highly effective system to remove contaminants in marine diesel fuel. A prototype unit was installed aboard a surface combatant in the fuel transfer system right after the seawater compensated fuel/ballast tanks as shown in Figure 1. The prototype unit proved that the design can satisfactorily replace the centrifugal purifier. Shipboard testing will be discussed later in this paper.

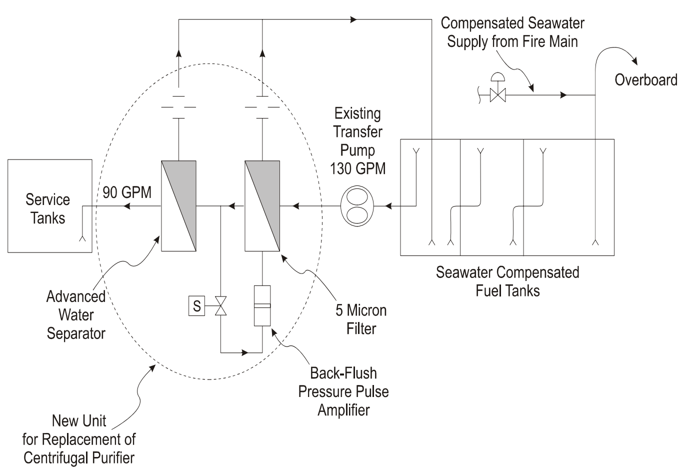

Figure 1: System Combining 5 Micron Filter and Water Separation Filter to Replace Centrifugal Purifier

To ensure long term service life of the filters, both stage filters have a cross-flow design as opposed to conventional dead-end filtration. Cross-flow filtration differs from dead-end filtration because in addition to the feed fluid being pressurized through the filter media surface as in the dead-end filtration (Figure 2), a small portion of the feed sweeps tangentially along the surface of the media to prevent the formation of the cake layer.

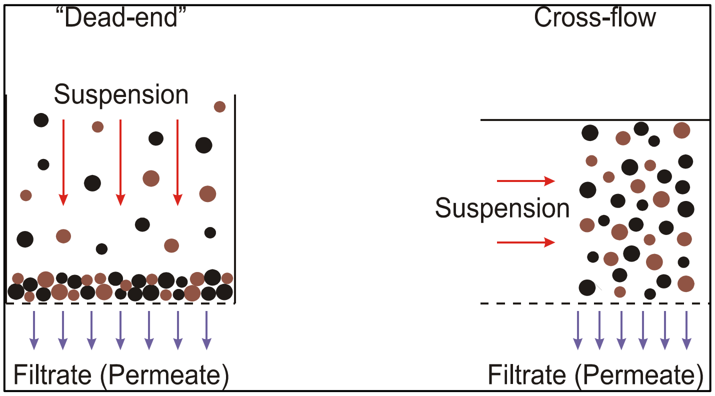

Figure 2: Dead-End vs. Cross-Flow Filtration

In addition to the cross-flow filtration, a beneficiary secondary flow is also generated on the first stage filter surface through a flow passage formed by a spiral guide between the cartridge and housing (Figure 3). This secondary flow, also known as Dean Flow and is only used in the first stage, has a dual vortex flow pattern with higher shear force close to the boundary layers. The high shear force will dislodge and remove any particles that may adsorb to the filter surface. At the same time, since suspended solids in a high shear field will move to positions of lower shear, this provides particle trajectory control by moving particles from the high velocity flow at the filter's surface and essentially "stores" them in the low shear regions within the vortex. The Dean Flow process significantly reduces the plugging concern in filtration (Figure 4).

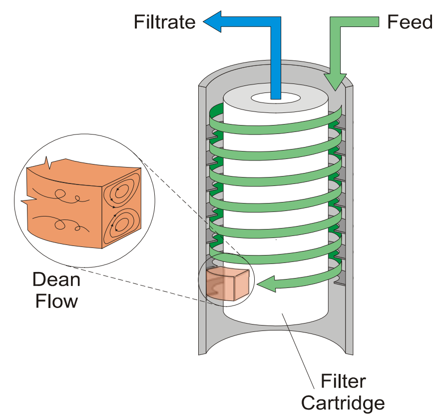

Figure 3: Dean Flow Enhanced

To further the self-cleaning function, a back-wash feature is also built into the first stage filter. The cross-flow and the Dean Flow also greatly increase the back-wash efficiency by carrying away the debris broken loose from the back-washing process. These combinations result in superior fouling control and thus enhance the overall filtration performance.

Figure 4: Cartridge Showing Dean Flow Effect

A proprietary water-selective membrane is used in the second stage filter for water separation. It allows only fuel oil to wet through the membrane pores and leaves debris and water droplets, even in a highly emulsified condition, trapped on the membrane surface to be carried away by the cross-flow (Fig. 5). The membrane is packaged as a spiral-wound filter cartridge. This design provides a high membrane area for a given cartridge volume, which allows a compact and modular design.

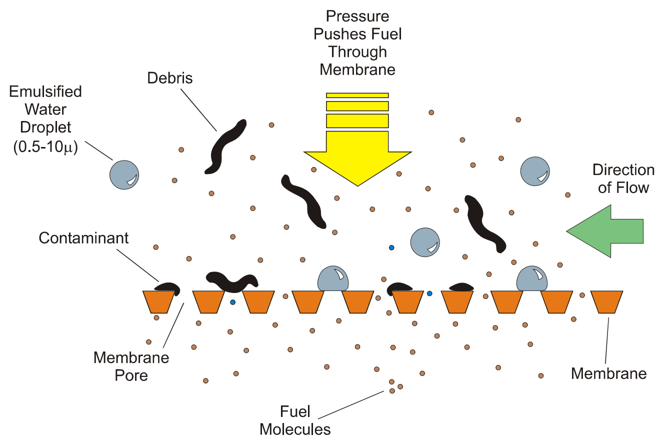

Figure 5: Water Selective Membrane

In a shipboard test, the cross-flows from both stages are cycled back to the seawater compensated fuel/ballast tank. For fuel systems with a different tank arrangement, a separate working tank can be used for the cross-flows. With careful arrangement to minimize the disturbance of the returned cross-flow, both the concentrated debris (which are mostly asphaltic substances that will settle at the fuel and oil interface) and water
will settle to be drained. Figure 6 shows an example of the test result from this advanced fuel filtration system. In this case, the

Figure 6: Proof of performance

feed DFM contained 5% water and 100 mg/liter ISO fine test dust as shown in the right beaker in the figure. After one pass of the fuel through FSI's fuel filtration system, the fuel had a water content less than 3 ppm and a solids content less than 0.26 mg/liter as shown in the left beaker. This far exceeds the Navy fuel spec requirements for centrifugal purifiers and also meets the fuel quality requirement for post final polishing from the service tank.

LAND-BASED TEST

Due to the costs to install a filter unit and to modify a ship's systems, a land based test was conducted on the prototype unit. Since this filtration unit was designed to replace the legacy centrifugal purifier, the test plan was developed using the performance requirements for the purifier, reference 3. Tests included endurance, challenge and surge load tests using marine diesel fuel, F-76, as the process fluid and using ISO fine dust, red iron oxide and tap water as the contaminants. The test configuration is depicted in figure 7. Maximum allowable free water and solid content in processed fuel was 30 ppm and 4 mg/L, respectively.

The endurance test was 40 hour test using F-76 contaminated with 10 mg/L of test dust and 50 ppm of water. The results showed total suspended solids to be 1 mg/L and an average of 4.1 ppm of water concentration in the filtrate.

The challenge test was performed starting with 250 mg/L dust concentration and 1% water in F-76. The test dust concentration was increased by 250 mg/L after each 2 hour period until the dust concentration reached 1 g/L. Additional testing was performed at the 1g/L concentration by doubling the dust concentration to 2g/L. The system cleanup filters were not used in the test loop for this test. The results showed essentially zero mg/L of total suspended solids and an average of 5 ppm of water in the filtrate.

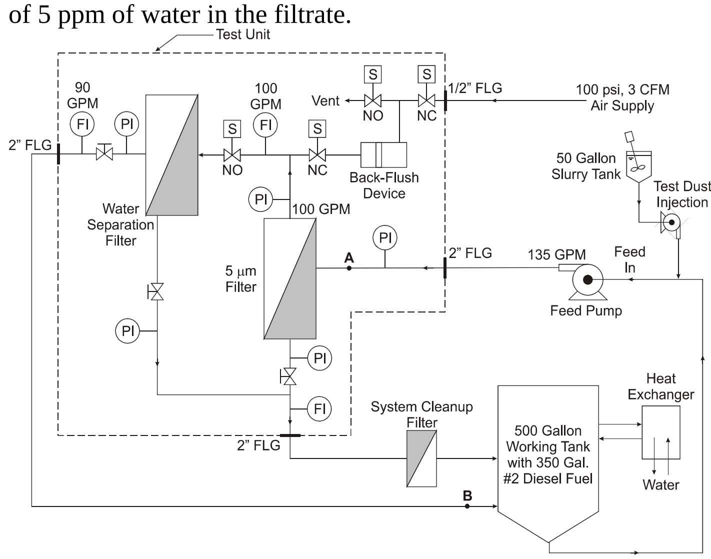

Figure 7: Land-based Test Configuration

The surge load test consisted of feeding the unit with 100% of water for a minimum of five minutes. The result showed zero filtrate output for a period of 15 minutes. The prototype filtration unit passed all land based testing and showed:

1. Fouling was well controlled for both the 1st and 2nd stages.
2. Pressures and flowrates remained constant during the 40 hour endurance and challenge tests.
3. Dust content was essentially zero and water content was on the order of 5 ppm in the filtrate.
4. The filtration unit met the highest challenge of 2g/L dust concentration and 1% water concentration during the challenge test in the influent feed resulting in acceptable concentrations in the filtrate.
5. The filter unit is effective in blocking bulk water under extreme surge conditions.

Based on its performance, the tested prototype filtration unit showed that it should be effective in replacing the centrifugal purifier that is currently in use.

SHIPBOARD TEST

Subsequently, the prototype filtration unit was installed aboard a DDG-51 Class surface combatant and tested through the ship's deployment. The unit was installed in the fuel oil fill, transfer and purification system, basically, as depicted in Figure 1. The filtration unit was installed in parallel with the centrifugal purifier with the retentate line tied into the existing defuel line. Ship's force was trained on the operation of the unit and provided a logistics package that included operating instructions, new ship's piping diagrams and filtration unit technical manual. Data sheets were provided to ships force to record system and unit pressures and flow rates.

During pre-deployment testing the first stage elements were changed from 5 micron nominal to 1 micron nominal. It was observed that during the life span of the second stage membrane filters, the first stage filters had only a minor change in differential pressure and maintained a constant differential pressure. Subsequent inspection revealed that the elements were only lightly fouled. Since the first stage filters are less costly and a tighter first stage would prolong the second stage membrane filters it was decided to install a 1 micron nominal filter.

Also during pre-deployment testing it was noticed during operation that black particles were commonly found in the shipboard F-76, which were different from the particles used in the land based test. The black substance was identified as an organic substance, containing both aromatic and oxygen containing compounds, most probably oxidized products of F-76. Fuel quality was directly related to the black particles found in the fuel, which varied in concentration on a day to day basis. Since the black particles tended to adhere to the membrane surface easily and, in some cases, fine enough to pass through the first stage one micron nominal filter to the second stage membrane filters, an operational procedure to flush the unit before and after each transfer evolution was incorporated into the operating procedures.

To determine shipboard fuel quality normally testing consists of performing a visual inspection of the fuel to ensure it is clear and bright. The term clear refers to the absence if visible particulate matter in the sample. The term bright refers to the absence of visible suspended water in the sample. As the amount of suspended water increases, the sample becomes hazy or cloudy. If the sample fails clear and bright a Free Water Detector (FWD) and a Contaminated Fuel Detector (CFD) is used to determine fuel quality. The Contaminated Fuel Detector (CFD) is used to quantify sediment contaminants within a fuel sample. The Free Water Detector is used to quantify free water (un-dissolved) within a fuel sample. To quantify sediment contamination, an 800 milliliter fuel sample is filtered through two 0.65 micron absolute filter membranes. Each membrane is then placed under a light source to determine the intensity of light (in milliamps), which passes through the membrane. The difference between the two readings is taken and charted against a standard calibration curve to obtain a value in terms of milligrams per liter. Standard ASTM methods for sediment contaminants cannot be used due to the ships' motion at sea. Free water is quantified using the Free Water Detector. A 500 milliliter volume of fuel is passed through a Fluorecein dye impregnated membrane and scanned under a black light along with a standard. A comparison is made between the two to obtain a free water value. During shipboard testing of the prototype filtration unit FWDs and CFDs were periodically conducted to check fuel sample quality.

The FWD and CFD results during the shipboard testing showed that the filtration unit consistently removed sediment levels to less than 2 mg/L with the influent sediment levels greater than 5 mg/L and water content to zero or near zero when the influent water content was 5 ppm. Ships force, during the shipboard testing, had to temporarily switch back to the operating the purifier due to a minor leak in one of the filtration unit vessels. When operating the purifier, the ship had to, again, recirculate service tanks and CFD results showed sediment levels in excess of 5 mg/L.

The prototype filtration unit was designed to process approximately 130 gpm of fuel with a filtrate flow rate of 90 gpm which is equivalent to that of the centrifugal purifier. During land-based testing with a feed rate of 130 gpm the unit consistently provided a filtrate flowrate in excess of 90 gpm. During shipboard testing the filtrate flow rate was consistently less than half of the design filtrate flow rate. This lack of performance was attributed to two issues. The first issue was the location of the filtration unit on the upper platform, coupled with the additional piping and fittings required to support the installation. This accounted for a 15-20 PSI pressure drop, between the fuel transfer pump and the prototype, depending on operating conditions of the seawater compensating system for the fuel storage tanks. The second issue was related to the output capacity of the fuel oil transfer vane pump, which had low volumetric efficiency for the required operating pressures needed to supply the prototype on the upper platform. A permanent installation would have the unit on the lower level in close proximity to the transfer pump in the same manner in which the purifier was installed.

CONCLUSIONS & FUTURE PLANS

The shipboard testing proved that the filtration unit can effectively remove water and sediment contaminants in F-76. During the deployment 910,000 gallons of clean fuel was transferred from storage tanks to service tanks using one set of elements. Pressure and flow data shows that element life was sustained. The ship, in which the filtration unit was installed, received poor quality fuel during an underway replenishment at sea. When transferring this fuel from storage tanks to service it was noted that the pressures increased on each stage of the unit due to clogging; however, the pressures returned to normal over time indicating that the self-cleaning features were working. Due to the higher quality of fuel transferred, the ship experienced a 70% reduction in prefilter and filter/coalescer usage in the service system. As stated earlier, it was common practice for surface combatants to recirculate service tanks using the purifier because sediment levels exceeded the 2.64 mg/L requirement.

Current plans are to design a shipboard unit that will be grade A and vibration qualified unit with modifications due to lessons learned during shipboard testing. One major modification is to use a 6” x 20” filters instead of 4” x 40” filters to reduce filtration system resistance, which is more suitable for the existing transfer pump and will increase the filtrate flow rate. Another improvement is to install orifices instead of valves to regulate flow, eliminating operator required adjustments and possibly dead ending either the first or second stages. Sensors will also be added to monitor flow rates and pressure drops of the filter elements.

The shipboard unit will replace the existing centrifugal purifier and will be installed on the lower level of the machinery space in close proximity of the fuel oil transfer pump. This will eliminate any losses due height and long piping runs.

ACKNOWLEDGMENTS

The authors wish to thank the following for assistance is the development and testing of the filtration unit:

1.) Mr. Peter Yu, Filtration Solutions, Inc.
2.) Mr. David Beardsley, Naval Sea Systems Command, 05Z9
3.) Mr. Lucio Salvucci, Naval Surface Warfare Center Carderock Division, Ships Systems Engineering Station, Code 923

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