

Advanced Filtration Systems for Fuels and Oils

Fuel treatment is an integral part of any fuel oil system for protection of fuel injection systems and fuel-burning engines. Water and solids removal from fuels and oils is a problem familiar to the marine and land based diesel and gas turbine market. Traditional methods for removal include dead-end filtration, coalescing and centrifugation. Among the three technologies, there are tradeoffs in cost, performance, reliability, maintenance, and physical space required. Several research and development projects for cost reduction and performance improvement of shipboard fuel and hydraulic oil systems have been initiated by the US Navy in recent years. Through these projects a Fuel Reconditioning System (FRS) and an Oil Reconditioning System (ORS) have been developed and demonstrated at full scale for over 1 year by Filtration Systems, Inc. (FSI). These systems are now commercially available and consist of two stages. The first stage is a self cleaning prefilter for solids separation and the second stage contains a water selective membrane filter for water separation. The result is a low cost, compact system that can process fuels and oils with high solids and high water content and reliably produce high quality treated fuels and oils in a single pass.

Marine diesel fuel (DFM), similar to ASTM 2D fuel except that a higher cetane number and flash point are specified, is a common fuel used onboard Navy ships. The fuel system for these military ships, which is typical of most marine vessels, is shown in Figure 1. The Navy requires the fuel to have a debris level less than 2.5 mg/liter, particle size restricted to less than 5 microns, and a water concentration less than 10 ppm before being transferred to the fuel injection system. As shown in Figure 1, the major fuel treatment is performed on the fuel between the storage tank and the service tank by a centrifugal purifier to remove water and solid contaminants. It is then polished by a 5 micron prefilter and a coalescer filter before entering the fuel injection system of a gas turbine.

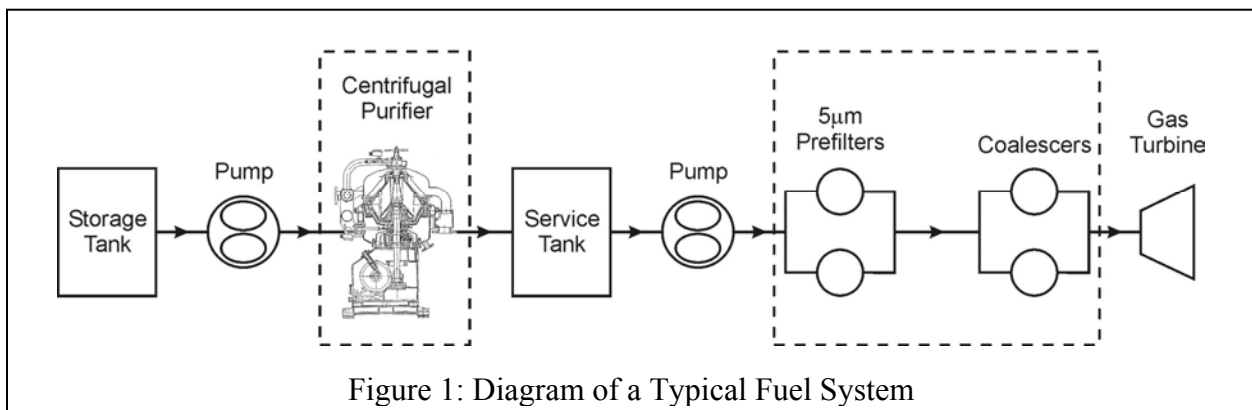


Figure 1: Diagram of a Typical Fuel System

The centrifugal purifier is essentially a motor-driven centrifuge. The purifier used for this application in the US Navy is a disk type self-cleaning purifier. It consists of a rotating bowl assembly (with disks stacked inside) enclosed within a stationary frame with a hinged cover. Centrifugal purifiers are high maintenance and high operating cost machines, even self-cleaning purifiers. Their operation requires not only electrical power for the driving motor, but also a water and lube oil supply. Water is used to establish a priming seal in the rotating bowl and is

used in the self-cleaning shoot cycle. Lube oil, which is contained in the reservoir that is an integral part of the structural base, is used for the lubrication of the drive assembly. Throughout the process of purifying fuel, solid contaminants build up on the inside surface of the bowl and disk stack. Periodically, purifiers must be disassembled and manually cleaned to remove the sludge buildup in the bowl assembly and disk stack. Self-cleaning purifiers are disassembled less frequently than manually cleaned purifiers but the maintenance is still no easy job. There are many mechanical components associated with the assembly. Because it is a high speed rotating machine, the rotating bowl needs to be balanced after each assembly. This complexity translates into cost.

In addition to maintenance and operation issues, there is an issue with fuel quality. The water and sediment removal efficiencies of a centrifugal purifier are greatly affected by the specific gravity of the fuel and sediments, which have been known to vary from different suppliers and sources. Moreover, the centrifugal purifier can only remove solid contaminants that are heavier than both fuel and water. Contaminants that are lighter than fuel cannot be removed by a centrifugal purifier. An example is colloidal solids, which are suspended solids commonly found in seawater and have a specific gravity lighter than fuel. For fuel with seawater contamination, centrifugal purifiers are not effective for solids removal and must be supplemented with dead-end filtration. This is especially true for seawater compensated fuel storage tanks where seawater is used for ballast and colloids are commonly introduced to the fuel system.

To combat these problems, a patented advanced fuel filtration system with a two-stage design was developed by Filtration Solutions, Inc. The system was used to replace the Navy shipboard centrifugal purifiers. A schematic of the fuel filtration system arrangement for the replacement of the centrifugal purifier in the shipboard fuel transfer system with seawater compensated fuel storage tanks is shown in Figure 2.

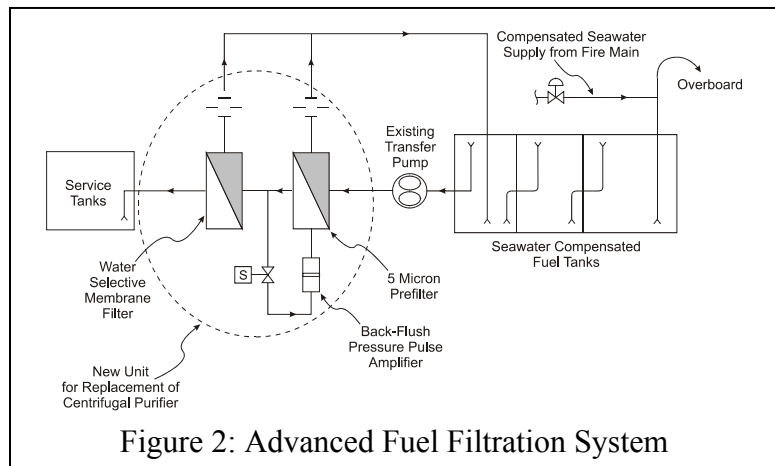


Figure 2: Advanced Fuel Filtration System

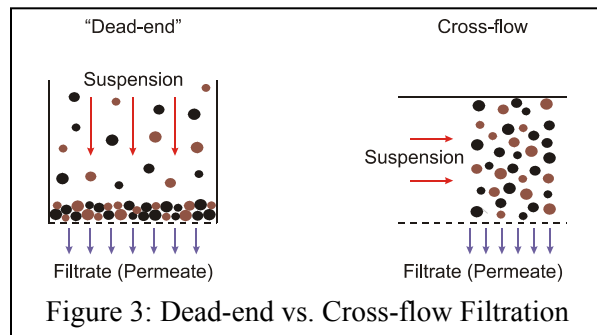


Figure 3: Dead-end vs. Cross-flow Filtration

Both stage filters are cross-flow filters as opposed to conventional dead-end filtration as shown in Figure 3. In dead-end filtration, the fuel oil is pushed through the filter by the system pumping pressure and therefore the filter is prone to plugging due to cake formation. Cross-flow filtration differs from dead-end filtration. In this method, a portion of the fuel oil permeates through the filter media and the

balance of the fuel oil sweeps tangentially along the surface of the media to retard the formation of the cake layer. Therefore the cake layer will be much thinner, yielding a lower hydraulic resistance, and a higher filtrate flux.

In addition to the cross-flow filtration, the prefilter also features a secondary flow and a back-flush to prevent filter clogging. The cylindrical shape prefilter cartridge is mounted in a housing cavity equipped with a continuous spiral shape flow passage (formed by a spiral guide) between the cartridge and the housing, as shown in Figure 4. As the feed flow

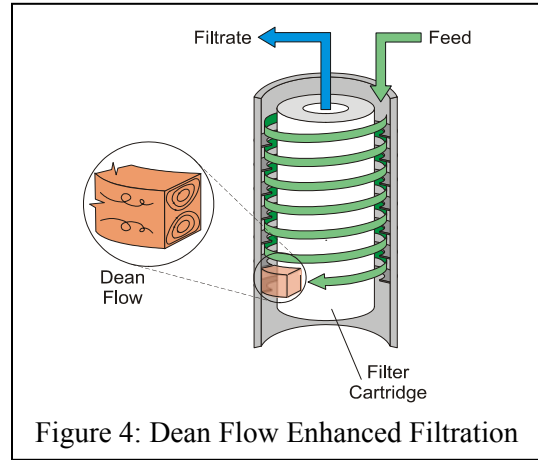


Figure 4: Dean Flow Enhanced Filtration

travels down the passage at a designed velocity, a secondary flow (also called Dean Flow) with a distinct counter-rotating double-vortex pattern is created in the passage as shown in the inset of

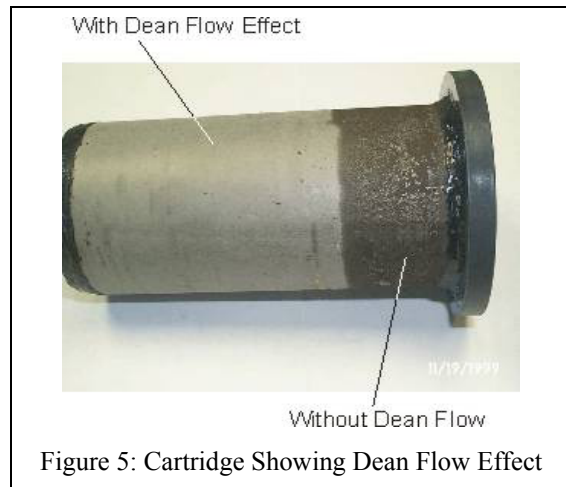


Figure 5: Cartridge Showing Dean Flow Effect

Figure 4. The high shear forces from the vortices act on the filter media to remove the debris trapped on the surface and transport it away. The cross-flow and the secondary flow also significantly increase the back-flush efficiency by carrying away the debris broken loose from back-flushing. These combinations result in superior fouling control and thus enhance the filtration performance.

As an example, a prefilter cartridge was tested in diesel fuel with 0.1% ISO fine test dust. In this test, the lower 2/3 of the cartridge was located in the filter housing with the spiral shape flow passage to promote Dean Flow and the upper 1/3 of

the cartridge was located in a part of the housing with the spiral guides removed. Figure 5 shows the cartridge after testing, a vivid contrast is shown with and without cake layer formation. The lower part has no visible cake layer formation due to the vortices generated by the Dean Flow, which kept the surface clean. This test result clearly reveals the advantage of using Dean Flow for fouling control in filtration.

Figure 6 shows the test result of a performance comparison between FSI's self-cleaning filtration technique with the features described above and conventional dead-end filtration using a 5 micron filter cartridge commonly available on the

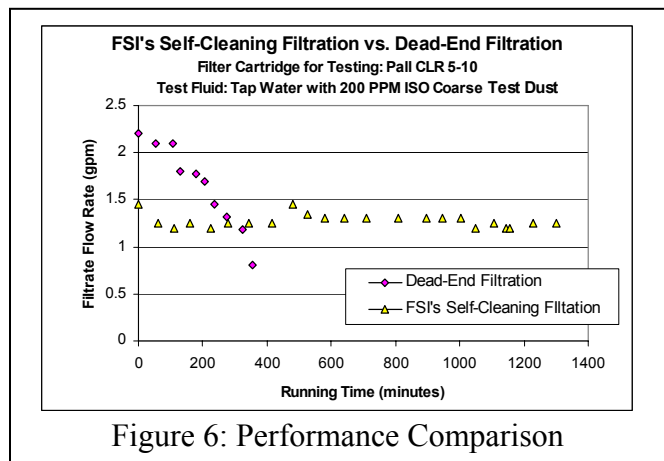
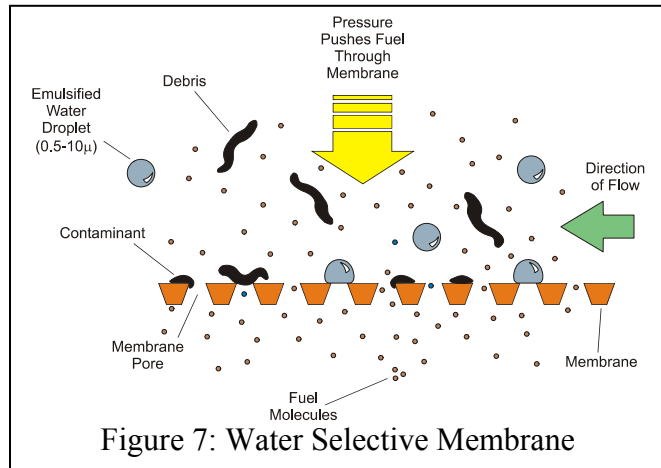


Figure 6: Performance Comparison

market. The test fluid was tap water with 200 ppm ISO coarse test dust. The result shows that the filter using dead-end filtration was plugged after 350 minutes of service, while the filter utilizing FSI's filtration technique still maintained a constant output rate after 1,300 minutes of service.

The second stage filters, which are used for water separation, are spiral wound membrane cartridges. The membrane used in the cartridges is proprietary water-



selective membrane which only allows fuel oil to pass through its pores and leaves water droplets and debris trapped on the membrane surface to be carried away by the cross-flow (Figure 7). The spiral wound filter design has a very high packing ratio (membrane area versus cartridge volume) which allows a compact and modular design. This is especially valuable for shipboard applications.

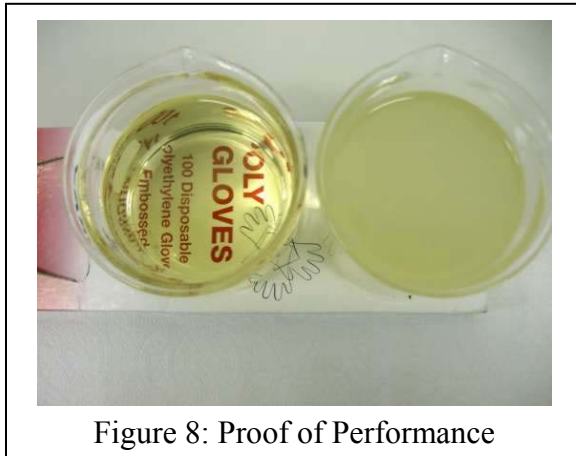


Figure 8 shows an example of the test result from FSI's advanced fuel filtration system. In this case, the feed DFM contained 5% water and 100 mg/liter ISO fine test dust as shown in the right beaker in the figure. After one pass of the fuel through FSI's fuel filtration system, the fuel had a water 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.

The picture in Figure 9 shows the fuel filtration system that was used to replace an existing shipboard centrifugal purifier with a capacity of 135 gal/min for DFM. The vessel in front is the self-cleaning prefilter. The membrane filter cartridges for water separation are located behind the prefilter and the gauges and power panel. The footprint of this unit is the same as the



existing shipboard centrifugal purifier except there is no need for extra ancillary components such as a working tank, heater, and water supply lines. Table 1 shows the comparison of the benefits between the existing centrifugal purifier and FSI's advanced fuel filtration system.

Description	Existing Centrifugal Purifier	FSI's Fuel Reconditioning System
Front End Equipment Cost *	\$140,000 - \$160,000	\$85,000 - \$95,000
Operation Mode	High Rotating Speed @4100 RPM	Stationary
Maintenance Requirement	108-135 man-hours/deployment	10 man-hours/deployment
Ancillary Mechanical Components	Working Tank and Preheater	Preheater
Fuel Quality	Water Content Varies	Water Content < 5 PPM
Energy Cost	High (25 hp motor)	Low
Replacement Parts	\$17,500/deployment	\$2,500/deployment
Equipment Size & Weight	Bulky	Compact

* Based on 135 gpm commercial unit

Table 1: Benefits Comparison between Centrifugal Purifier and FSI's FRS

For the purification of DFM, it is obvious that FSI's advanced fuel filtration system has significant advantages over centrifugal purifiers in terms of maintenance, operation, fuel quality, and total life cycle cost. This has been demonstrated by a full scale prototype in the fuel system onboard a Navy destroyer for nine months. The quality of the processed fuel consistently exceeds the requirements and the sailors are satisfied with the simple operation and effortless maintenance. In general, this advanced fuel filtration system is ideal for processing No.1 and No. 2 Grade fuel oils (ASTM) and has been usefully tested on some No. 4 Grade fuel. For fuels with high viscosity and ash contents, such as No. 5 and No. 6 Grade fuel oils, further development is required.

In addition to fuel filtration, the advanced filtration technology developed by FSI was also successfully applied to hydraulic oil and lube oil systems in the marine industry. Marine vessels rely on hydraulic and lube oils for numerous important functions, such as steering, gear reduction, and elevator systems. For Navy vessels the applications can be even broader including ram tensioners and missile and torpedo launchers.

In another Navy project, filtration systems for oil reconditioning were developed. Seawater contamination (as high as 10-20%) in hydraulic oil is a major problem that occurs on the Navy vessels. Centrifugal purifiers are not effective in this application and a method that uses evaporation under vacuum pressure is a common alternative process. However, in addition to high energy consumption, the evaporation process leaves water soluble minerals in the hydraulic oil, causing rust and wear problems.



Besides seawater contamination, there is also a profound problem with contaminated oils that may result in valve plugging which is caused by a golden, sticky coating from varnish formation. Varnish consists of oil degradation by-products resulting from additive depletion, oxidation and/or thermal degradation. These by-products are usually soluble in nature when first formed. But after the fluid becomes saturated with these by-products, they transition to insoluble soft contaminants. These soft contaminants usually have sub-micron sizes and make up the majority of contaminants in hydraulic and lube oils. They cannot be removed effectively by conventional filters and centrifugal purifiers for the same reasons as the colloidal solids discussed previously in respect to fuel oils.

The advanced filtration system developed by FSI has been used with two different hydraulic oils with successful results. 2075-T-H (ISO 32) is a general purpose hydraulic fluid containing anticorrosion and antioxidation additives for use in hydraulic systems. 2190-TEP (EP Oil 78) is commonly used in turbines and major gear reducers aboard marine vessels. A prolonged challenging test with water content up to 25% was performed with both oils and the processed oils had a water content less than 50 ppm, which is the allowable limit in most applications.

When comparing FSI's advanced oil filtration system with centrifugal purifiers and thin film thermal vacuum systems, similar benefits to those described in Table 1 for fuel filtration can be derived in terms of maintenance, operation, fuel quality, physical space, and total life cycle cost for hydraulic and lube oil filtration. Standard systems for fuels and oils are available from FSI. The FRS, which is designed for fuel filtration, is available with process capacities from 5 to 300 gpm. The ORS, which is designed for oil filtration, is available with process capacities from 2 to 30 gpm. Customized systems are also available from FSI to accommodate any specific application.