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CIMAC Guideline

Filter treatment of residual fuel oils

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Content

1 Introduction

Marine diesel engines designed for residual fuel oil operation will generally be able to handle any of the ISO 8217 RM grade fuels, provided the fuel is adequately treated prior to use. For this purpose, a well-designed fuel cleaning system is required. Separators in combination with a settling tank are generally accepted within the marine industry as the core elements of the fuel cleaning system of choice [1].

The fuel goes through various treatment processes on its way from the bunker tanks to the engine inlet. This paper will focus on the filtration treatment stage. Details about the other processes can be found in CIMAC recommendation No. 25 [2].

Until now, filters were generally only considered as a safeguarding measure; installed to prevent substantially sized extraneous material from reaching the engine rather than a device for actual fuel cleaning. However, a more precise filtration process can protect the engines from potentially harmful material which may have slipped through the other fuel treatment processes.

2 Filtration efficiency

A long established standard in marine industry to measure the filtration efficiency is ASTM F795.

Traditionally, the smallest gap between the woven mesh wires is termed the “absolute mesh size” because, according to the ASTM F795 test method, the mesh is able to take out nearly 100 % particles of that size. The particles used for testing are ball-shaped glass beads, which do not act in the same manner as the particles existing in real systems such as fuel, hydraulic oil or lubrication oils.

In test methods for hydraulic systems, such as ISO 16889, particles consisting of sand dusts are used. Approximately 50 % of those dust particles with the size of the smallest gap between the wires are removed by the filter (Fig. 1), i.e. one out of two particles would still pass through the filter.

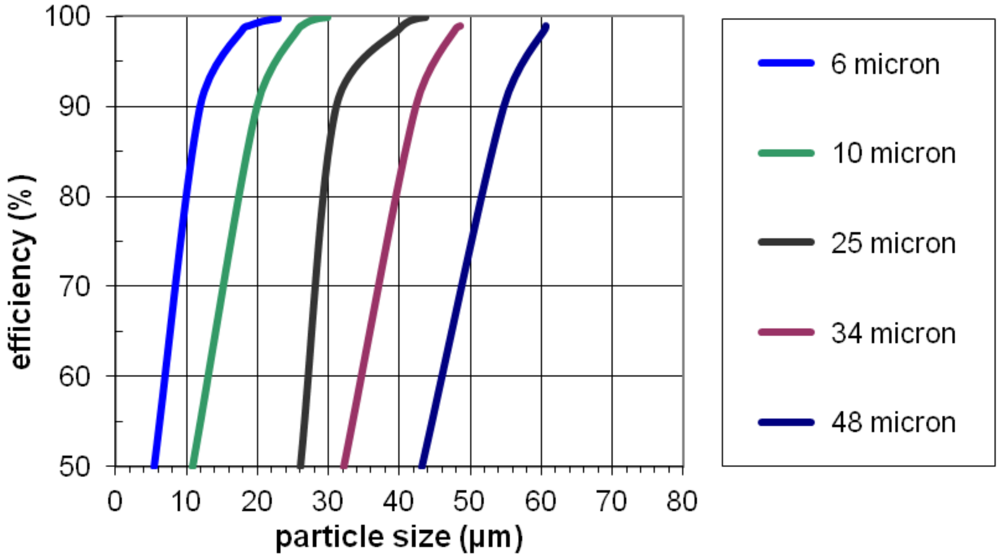


Figure 1: Filtration efficiency by ISO 16889 of 6 to 48 micron “absolute” meshes [3]

As shown, the 10 micron absolute mesh retains only some 70% of particles with a size of 15 micron and only about 50 % of particles with a size of 10 micron. This testing method demonstrates that particles up to 30 micron can slip through a 10 micron “absolute” mesh.

Thus, the smallest gap between the wires is not a quality criterion on its own, but at least it gives an indication about the 50 % efficiency of a mesh [3].

3 Location of automatic back-flushing fuel treatment filters

Automatic back-flushing filters are placed downstream of the service or day tank. Their purpose is to capture those particles that passed through the centrifuging stage of the fuel cleaning system. To date most automatic back-flushing filters are positioned after the supply pumps in which case they operate at moderate temperatures, typically lower than 100°C.

Additionally, a manually cleanable filter is placed at the engine inlet as the final safeguard component. The task of this filter is to indicate whether or not the automatic filter is working correctly and it is also used to indicate if wear is ongoing in any components between the automatic filter and the engine. For this purpose, its filter mesh should be coarser than the back-flushing filter mesh. Typically, a 25 micron mesh is used downstream of a 10 micron back-flushing filter mesh.

However, the trend is now to install the automatic back-flushing filter into the circulation (or booster) system with the manually cleanable filter still retained at the engine inlet.

In the circulation system the temperatures can reach 160 °C, depending on the fuel viscosity grade. Such environments require very resilient gasket materials (which will nevertheless still have a limited lifetime) but at this position the back-flushing filter additionally serves to protect against harmful wear material particles which may be generated by the circulation pumps or are present in the recirculated fuel stream.

4 Minimising filter blocking

Filters are controlled by the back-pressure resulting from the accumulation of particles partially blocking the filter mesh openings. In case the automatic filter fully blocks, a differential pressure alarm is generated in the engine control system. In most such cases, the filter itself is operating as intended but either an extraordinary high concentration of particles was present in the fuel or sludges, or other adhering components, have agglomerated on the mesh structure of the filter elements.

4.1 Particles

Various types of particles, inorganic and organic, can be present in residual fuel oils and will reach the engines if not removed by the fuel treatment system. Whereas some of these particles are harmless to engine operation, others can result in serious damage.

4.1.1 Inorganic particles

Various inorganic particles are commonly found in residual fuel oils. They can originate from the refinery processes (i.e. catalytic fines, a mix of highly abrasive Al_2O_3 and SiO_2 - commonly referred to as ‘cat-fines’) or enter the fuel either in the supply chain or onboard the ship itself, e.g. from the ship's cargo or the environment. Although rare, there are examples of bauxite, rust scale, sand or airborne dust having been found in the fuels.

Some of the inorganic particles, e.g. the cat-fines, are very hard and abrasive and must be reduced as much as possible by the onboard fuel treatment. High wear rates and scuffing of key engine components can be the consequence if cat-fines enter the engine.

If properly sized and operated, a separator has the capability to remove nearly all of the cat-fines larger than 5 to 10 micron. However, the majority of cat-fines smaller than 5 micron will not be efficiently removed due to their relatively high surface area to weight ratio. To protect the engines from these particles, a more precise filtration process stage is required.

Whilst often relatively few large cat-fine particles can be responsible for heavy damage of machinery parts, like bearing seizures, erosion is related to the overall number of particles, including cat-fines, scratching and grinding on the contact surfaces.

With the use of the high fuel injection pressures associated with common rail systems erosive wear has become the critical factor influencing the lifetime of injectors. For that reason, it is necessary to remove as many particles as possible from the fuel oil before use, regardless of their size.

4.1.2 Organic particles

Residual fuel oils consist primarily of organic components. Depending on the actual composition and fuel condition, these components can form, or be present as particles, which may be challenging to filtration. An example of such organic particles is asphaltenes.

Residual fuel oils contain asphaltenic material, naturally present in crude oil. A stable fuel contains sufficient aromatic components to keep the asphaltenes in suspension; however, if mixed with a more paraffinic fuel, e.g. distillates, the fuel can become unstable. When the fuel becomes unstable the asphaltenes drop out of solution resulting in asphaltenic sludge. At high levels such sludge may overload the separators and may block filters.

Under the right temperature conditions, asphaltenes may occasionally agglomerate into discrete particles which may block filters on the upstream side. Such asphaltenes are however relatively soft and so can also be squeezed through the mesh but then re-agglomerate and adhere on the downstream side of the mesh (Fig. 2) causing further blocking which is of course not removed by backwashing.

The same happens with any waxy material in the fuel. Those accumulations of waxy, semi-solid material also prevent backflushing of the filter.

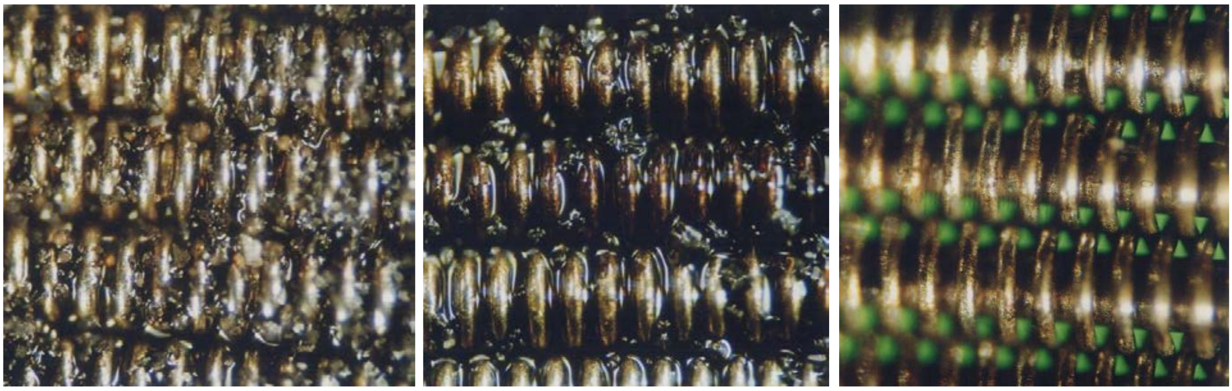


Figure 2: **Left: Asphaltenes and cat-fines retained on the upstream side of a 25 micron mesh**
Middle: More asphaltenes on the downstream side of this 25 micron mesh
Right: The same mesh after washing with distillate fuel

4.2 Operational recommendations to reduce the risk of filter blocking

4.2.1 High concentration of cat-fines in the fuel

Reasons:	Countermeasures:
Rough sea and a rolling vessel stirs up previously settled material in the fuel tanks	Frequent and prolonged tank draining where possible
	Periodic manual tank cleaning
	Tanks with sloping bottoms are a design criterion to assist in the removal of settled material
Fuel supplied with high content of cat-fines	Reduce flow rate through the separators to increase efficiency, e.g. use standby separator in parallel to divide flow in half. Operate on consumption rate Latest separator systems allow automatic adjustment of flow rate and process temperature to optimize separation efficiency
Insufficient separation	Check the temperature at separator
	Clean the disc stack of the separator
	Check the separator is correctly assembled and all seals are intact
	Check the flow rate through the separators

4.2.2 Sludge in the fuel

Reasons:	Countermeasures:
Asphaltenic sludge in the fuel, fuel unstable as supplied or mixing of incompatible fuels resulting in asphaltene precipitation	Use the fuel „first-in, first-out"
	Do not mix fuels from different consignments
	Test fuel for stability and compatibility with fuels already on board
	Drain tanks of previous residual fuel oils before refilling
	Minimize mixing during change-over
In the presence of water biochemical growth is possible in the tanks. Increased risk with prolonged storage of fuel	For better analysis take separate samples from top, middle and bottom of each tank.
	Completely empty tanks before refilling and frequently drain any settled water from tanks in order to minimize oil-water interface area
	Avoid water ingress to fuel oils in storage (i.e. via tank deck fitting, air pipes and heating coil leaks)
	Frequently drain any settled water from tanks in order to minimize oil-water interface area
Fall-out of wax	Heat filters and separators
	Ensure that fuels are stored sufficiently above their pour points that they remain fully fluid and when pumped the temperature is such as to avoid wax precipitation

5 Cleaning of filter elements

In the laboratory it is quite easy to clean filter elements with solvent hydrocarbons capable of diluting oil. However, as these liquids can be quite aggressive, the environmental risk is too high for use in engine room workshops. Cleaning should therefore be done with a hot water high pressure cleaner after soaking the elements in hot water with an added cleaning agent. Ultrasonic cleaning accelerates the effect.

It should be noted that even if the surface of a filter element looks clean, it may still be blocked internally. The filter mesh is clean when water can flow through the whole surface or light is transmitting easily (Fig. 3 and Fig. 4).

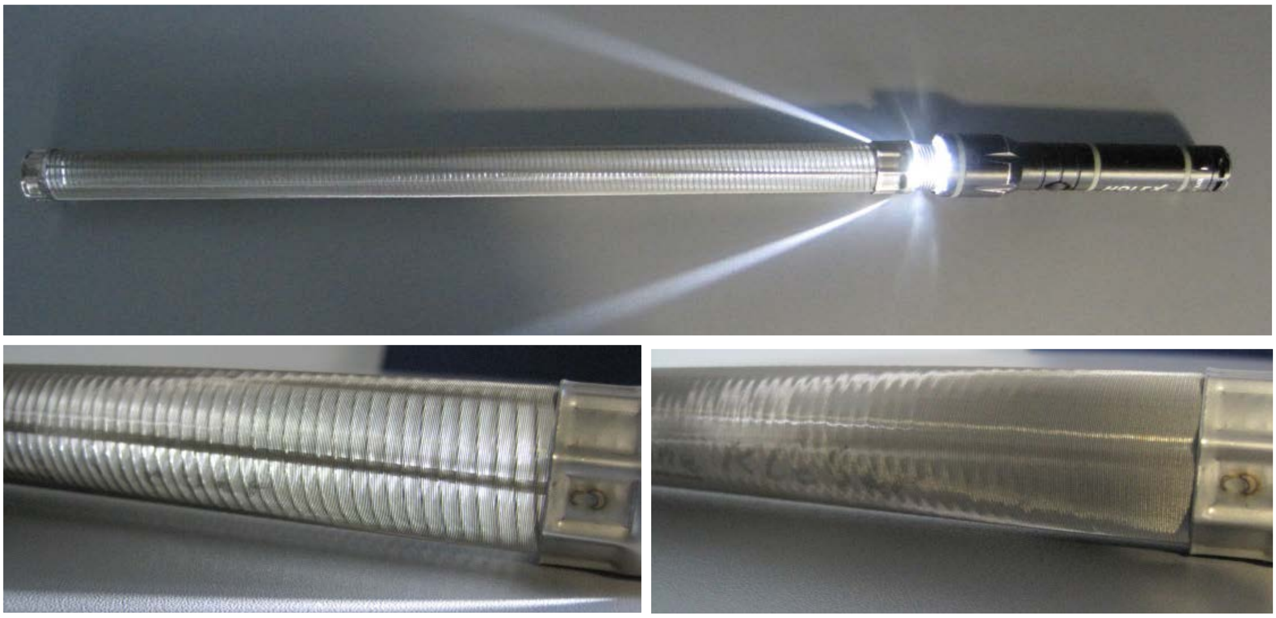


Figure 3: Clean mesh is translucent (upper and left) whereas blocked mesh is not (right)

Figure 4: Clean mesh allows the ready passage of water (left); and light, seen here against a disc element (right)

6 Recommendations to the crew for handling filters

- Follow the instruction manuals and the health and safety rules about hot and flammable fuel handling.

- In the case of an automatic back-flushing fuel oil filter coupled with a change-over valve and by-pass filter the latter is a standby system. If the automatic filter fails, the by-pass filter takes over to ensure continued engine operation and protection at any time.
  - Never use the change-over valve between automatic filter and by-pass filter in position other than full over to one filter or the other.
  - After the bypass filter has been used its mesh should be cleaned so that it is ready for the next usage.

- When the automatic filter indicates a high differential pressure which does not recover on back-flushing, it has to be manually cleaned. Cleaning of filter elements needs time and it is therefore recommended to have a set of spare elements readily available (new or cleaned elements), in order to replace the used ones quickly whilst continuing to run the engine.
  - To clean the automatic filter with the engine in operation, change over to the by-pass filter.
  - Exchange the used filter elements against clean spare ones and replace gaskets if needed.
  - After carefully re-filling with fuel, change over to the automatic filter.
  - Replace the elements of the by-pass filter as soon as possible after using it.

- All elements disassembled from the automatic and the by-pass filters have to be cleaned and stored correctly.
  - Filter meshes are very sensitive to damage. Ensure elements are never knocked or allowed to rub against each other during handling and do not come into contact with other components or edges. They have to be stored individually in appropriate boxes e.g. those from the supplier.

- For cleaning, use distillate or hot water with cleaning agent for soaking the filter elements for at least several hours.
  - Ensure that health and safety regulations are followed.
  - When using water, an ultrasonic treatment will supplement the soaking procedure.
  - Do not pile the elements in the ultrasonic bath but use individual baskets to separate them from each other.
  - After soaking the elements, use a high pressure cleaner with hot water to remove the dirt.
  - Do not use brushes as they do not reach the dirt in the filter mesh and instead may actually damage the mesh.
  - Clean each element individually.

- The filter mesh can be considered to be clean when water or light can be seen to flow through the whole surface.
  - After cleaning with water, dry the elements with an air gun before packing and storing.
  - Compressed air does not have a high enough temperature to allow it to rinse dirt out of the mesh. Therefore, air guns do not substitute a high pressure cleaning with hot water.

- Filter elements have a limited lifetime. When visibly damaged, or when water does not readily pass through the mesh anymore after cleaning, they must be replaced.

- Ensure that defective elements do not find a way back into the filter – the most effective way is to destroy them.
- The mesh openings of such elements are too small to be visible to the naked eye. Hidden defects may jeopardize the operational safety of the engine. Follow the instructions of the filter manufacturer.

7 Advanced filtration to overcome erosional wear

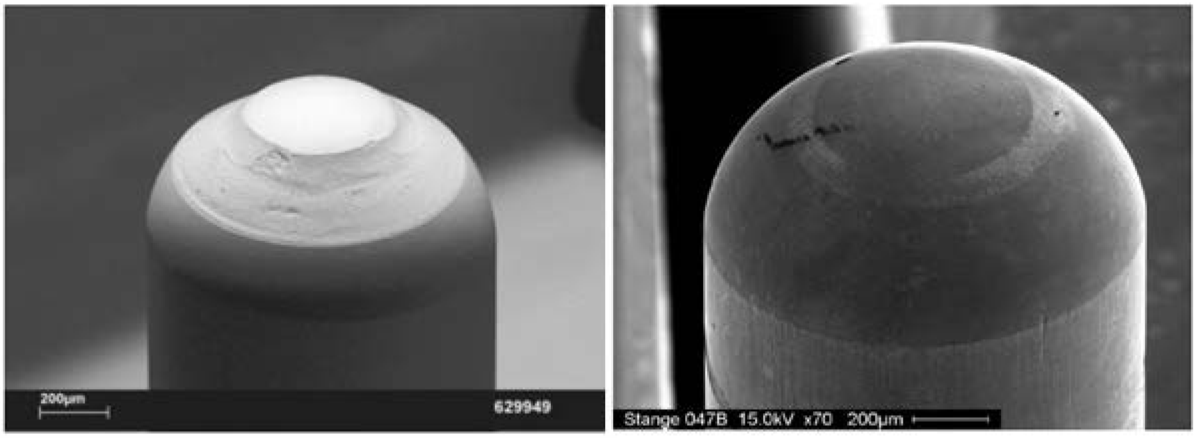
In conventional engine designs, the fuel injection system components were relatively insensitive to particles. Hence, the chosen filter mesh sizes have been 48 micron, 34 micron or 25 micron “absolute”.

Nearly all particles which pass the centrifugal separators are smaller than 10 micron in size. During normal operating conditions, the particles passing the centrifugal cleaning system prior the filters are far too small to be retained by a 48 or 34 micron absolute filter mesh. Even a filter of 25 micron absolute mesh does not build up differential pressure over time in normal operation.

Typically, filters with such “coarse” mesh sizes initiate a differential pressure signal only when the fuel cleaning system gets out of control, or external incidents such as incompatible fuel mixtures or rough seas occur. In those cases, the filters can protect engine components against severe wear.

Today, with the introduction of common rail injection systems, the impact of small particles on wear has increased dramatically due to the high pressures encountered [4].

In order to better protect these components, finer filter meshes have been tested (Fig.5).



After 500 hours with 34 micron "absolute" mesh

After 500 hours with 10 micron "absolute" mesh

Figure 5: Wear on control pins after 500 running hours with different filter treatment of the residual fuel [4]

7.1 Case study

The lifetime of a control pin in a commercial common rail fuel injector was found unacceptable when using a 34 micron absolute mesh size. A filter with 10 micron absolute mesh was installed instead and the wear was reduced by a factor of more than 10 when filtering the same heavy fuel oil.

Although the results were significant and the functionality did not deteriorate to an unacceptable level, abrasion still began during the warranty period of 8,000 running hours.

Further tests in the same installation with a 6 micron absolute filter mesh achieved even better results. During field tests on-board commercial ships, wear was visible but insignificant.

All tests were performed with correctly adjusted centrifugal fuel cleaning systems upstream of the service tanks. The test showed that even a correctly adjusted and well performing standard fuel treatment system will not adequately protect the sensitive common rail injectors against abrasive wear. For full protection, the filtration stage has to be optimized.

In a modern fuel treatment system the automatic back-flushing filter is more than a control device and a 10 micron, or less, absolute mesh size should be considered necessary for common rail systems.

8 Conclusion

High pressurized injection systems for residual fuel oils demand an optimized automatic filtration with an absolute filter mesh size of not more than 10 micron or even finer.

Automatic back-flushing filters block either due to an extraordinary high concentration of cat-fines in the fuel or sludge-like components coming from the fuel which have agglomerated on the mesh structure of the filter elements.

In any case, it is of paramount importance to follow the recommendations of the manufacturers on how to monitor, manage and maintain good housekeeping of the fuel cleaning system (both separators and filters) in order to maintain the whole fuel treatment system in a correct and optimized condition and consequently ensure the safe operation of the ship.

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