Future in the making
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Introduction

The exacting tolerances in today’s hydraulic systems require tight control of the system contamination.

Experience has shown that impurities found in the system originate from the installation and from new oil.

If not removed, particles will cause damage to valves, pumps and bearings and, eventually, lead to malfunction of the system and increased wear on the hydraulic components.

To avoid the above and reduce flushing time to a minimum, the whole system must be absolutely clean before filling up with oil and starting up the engine.

Purpose of this paper

It is vital that hydraulic system installations are carried out in accordance with the best practices, as described in this paper.

This will prevent difficulties during start-up of the equipment and reduce the risk of suffering damage to the system.

By following the guidelines given in this paper, a quicker and more efficient flushing process is achieved.

Definitions and standards

MAN Energy Solutions specifies the international ISO 4406 standard to be used when defining the quantity of solid particles in the fluid used in a given hydraulic power system.

ISO 4406

The scale numbers are allocated according to the number of particles per 100 ml of the fluid sample. A step ratio of generally two, as given between the upper and lower limits for the number of particles per 100 ml, has been adopted to keep the number of scale numbers within a reasonable limit and to ensure that each step is meaningful, see Table I.

NAS 1638

NAS 1638 is an older american standard developed by National Aerospace Standard in 1964 to define classes of contamination in aircraft components and hydraulic fluids.

The classes refer to the maximum number of particles in 100mL in different size classes.

The concept of the code can be seen in Table 2. It is based on a fixed particle size distribution of the contaminants over a size range of >5 to >100 microns. From this basic distribution, a series of classes covering clean or dirty levels has been defined. The interval between each class is double the contamination level, see Table 2.

The standard officially became invalid in 2001 which is why MAN Energy Solutions specifies the international ISO 4406 standard to be used.

ISO 4406 chart

<table>
<thead>
<tr>
<th>Range number</th>
<th>More than</th>
<th>Up to and including</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td></td>
<td>8,000,000</td>
</tr>
<tr>
<td>23</td>
<td></td>
<td>4,000,000</td>
</tr>
<tr>
<td>22</td>
<td></td>
<td>2,000,000</td>
</tr>
<tr>
<td>21</td>
<td></td>
<td>1,000,000</td>
</tr>
<tr>
<td>20</td>
<td></td>
<td>500,000</td>
</tr>
<tr>
<td>19</td>
<td></td>
<td>250,000</td>
</tr>
<tr>
<td>18</td>
<td></td>
<td>130,000</td>
</tr>
<tr>
<td>17</td>
<td></td>
<td>64,000</td>
</tr>
<tr>
<td>16</td>
<td></td>
<td>32,000</td>
</tr>
<tr>
<td>15</td>
<td></td>
<td>16,000</td>
</tr>
<tr>
<td>14</td>
<td></td>
<td>8,000</td>
</tr>
<tr>
<td>13</td>
<td></td>
<td>4,000</td>
</tr>
<tr>
<td>12</td>
<td></td>
<td>2,000</td>
</tr>
<tr>
<td>11</td>
<td></td>
<td>1,000</td>
</tr>
<tr>
<td>10</td>
<td></td>
<td>500</td>
</tr>
<tr>
<td>9</td>
<td></td>
<td>250</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>130</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>64</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>32</td>
</tr>
</tbody>
</table>

Table 1: The ISO 4406 standard is a decisive tool defining the quantity of solid particles in the fluid in installations designed by MAN Energy Solutions
<table>
<thead>
<tr>
<th>Class</th>
<th>5-15</th>
<th>15-25</th>
<th>25-50</th>
<th>50-100</th>
<th>&gt;100</th>
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<tr>
<td>0</td>
<td>125</td>
<td>22</td>
<td>4</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>0</td>
<td>250</td>
<td>44</td>
<td>8</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>500</td>
<td>89</td>
<td>16</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1,000</td>
<td>178</td>
<td>32</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>2,000</td>
<td>356</td>
<td>63</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>4,000</td>
<td>712</td>
<td>126</td>
<td>22</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>6,000</td>
<td>1,425</td>
<td>253</td>
<td>45</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>16,000</td>
<td>2,850</td>
<td>506</td>
<td>90</td>
<td>16</td>
</tr>
<tr>
<td>7</td>
<td>32,000</td>
<td>5,700</td>
<td>1,012</td>
<td>180</td>
<td>32</td>
</tr>
<tr>
<td>8</td>
<td>64,000</td>
<td>11,400</td>
<td>2,025</td>
<td>360</td>
<td>64</td>
</tr>
<tr>
<td>9</td>
<td>128,000</td>
<td>22,800</td>
<td>4,050</td>
<td>720</td>
<td>128</td>
</tr>
<tr>
<td>10</td>
<td>256,000</td>
<td>45,600</td>
<td>8,100</td>
<td>1,440</td>
<td>256</td>
</tr>
<tr>
<td>11</td>
<td>512,000</td>
<td>91,200</td>
<td>16,200</td>
<td>2,880</td>
<td>512</td>
</tr>
<tr>
<td>12</td>
<td>1,024,000</td>
<td>182,400</td>
<td>32,400</td>
<td>5,760</td>
<td>1,024</td>
</tr>
</tbody>
</table>

Table 2
Cleanliness requirement – ISO 4406
versus NAS 1638

The recommended standard for
definition of oil cleanliness level is ISO
4406.

If NAS 1638 is used, the number of
particles in a 100 ml sample larger than
6 and/or 14 microns must be within the
range specified by the ISO 4406 code.

**Cleanliness level required for ME-System - ISO 4406 Code xx/16/13**

ISO 4406 Code 16 → range…min. 32,000………………..max. 64,000 particles > (5)6 microns

NAS 1638 Code 7 → 38,924 particles > 5 microns

NAS 1638 Code 8 → max 77,849 particles > 5 microns

ISO 4406 Code 13 range………min. 4,000………………..max. 8,000 particles > (15)14 microns

NAS 1638 Code 7 → max 6,924 particles > 15 microns

NAS 1638 Code 8 max 13,849 particles > 15 microns

* Number of particles defined for 100 ml sample
** "max 64,000 particles > (5)6 microns” = (5) microns acc. to ISO 4406 (1987-1999), 6 microns acc. to ISO 4406 (1999→)

Fig. 1: ISO 4406 vs. NAS 1638 - cleanliness level required for ME/ME-C engines
Filtration ability

There are many different ways to make filter elements. Although they have same size, interface and flow capacity they can be very different in terms of their ability to clean the oil from large and small particles.

Many producers and users tend to mention “Absolute” and “Nominal” filtration rating when specifying and talking about filters.

The absolute rating of a filter refers to the diameter of the maximum particle which could pass through the filter. Typically a filtration rating in datasheets can be mentioned as absolute 3µm, 6µm, 10µm, ...

However no matter how precise the filtration media is made, it is impossible to ensure that all open areas fulfil these sizes. Particles are also not perfectly shaped and might be small in one direction, but large in the other direction.

The absolute rating can also be seen as a non-realistic definition since no particle larger than the rating can pass through the filter which is not true. The nominal rating is in this respect more realistic since it indicates the filters ability to prevent the passage of solid particles greater than the rating together with a percentage of efficiency.

No industry standard for this percentage of efficiency has been made for the nominal rating which also here makes it difficult to compare similar filters from different suppliers as they might define their filters with a different filtration efficiency. Due to this MAN Energy Solutions prefer to use Beta Ratio when defining and talking about filtration ability of filters.

Beta Ratio is a method based on laboratory multi-pass tests where a specified contaminate of known sizes is added regularly in measured quantities to the oil which is being pumped through the filter. Oil samples are taken at timed intervals at inlet and outlet of the filter. Hereafter the particles in each sample are measured and counted.

Based on these results, a beta ratio is determined by dividing the number of particles of a particular size in the inlet flow with the number of particles of the same size in the outlet flow.

For example, if the numbers of 6 micron particles are halved in number from inlet to outlet the Beta Ratio is 2/1 = 2 which also means the filtration efficiency is 50% and 50% of the 6 micron particles are retained in the filter element.

How to define a filter?

The following parameters are decisive for a filter definition:

- oil flow
- system pressure
- pressure drop
- operating viscosity
- filtration ability.

ISO 4406 chart

<table>
<thead>
<tr>
<th>Range number</th>
<th>Number of particles per 100 ml</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>More than</td>
</tr>
<tr>
<td>24</td>
<td>8,000,000</td>
</tr>
<tr>
<td>23</td>
<td>4,000,000</td>
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<tr>
<td>22</td>
<td>2,000,000</td>
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<td>21</td>
<td>1,000,000</td>
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<td>500,000</td>
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<td>19</td>
<td>250,000</td>
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<td>130,000</td>
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<td>17</td>
<td>64,000</td>
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<tr>
<td>16</td>
<td>32,000</td>
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<tr>
<td>10</td>
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</tr>
<tr>
<td>9</td>
<td>250</td>
</tr>
<tr>
<td>8</td>
<td>130</td>
</tr>
<tr>
<td>7</td>
<td>64</td>
</tr>
<tr>
<td>6</td>
<td>32</td>
</tr>
</tbody>
</table>

Minimum requirement of cleanliness level – ME hydraulic system

ISO 4406, Code XX/16/13

Particle > 14 microns

Particle > 6 microns

Particle > 4 microns

This corresponds to a quantity interval of:

Number of particles > 4 microns, cleanliness code omitted

Number of particles > 6 microns from 32,000 to 64,000 in 100 ml sample.

Number of particles > 14 microns from 4,000 to 8,000 in 100 ml sample.

Fig. 2: Filtration requirement for ME/ME-C/ME-B
**Fluid maintenance**

All fluid stored in sealed containers or delivered from an oil company must be filled through a filter cartridge with a filtration ability of $\beta_6$ (beta) = 200.

Beta ratio: example of filtration ability, valid for particles > 6 microns

$$\beta_6 = \frac{8,000,000 \text{ particles > 6 microns at filter inlet}}{40,000 \text{ particles > 6 microns at filter outlet}} = 200 \Rightarrow \beta_6 = 200$$

From ISO 4406 Code 23 to ISO 4406 Code 16 after first pass

**New oil is dirty!**

**Example of contaminants amount to be removed**

Given that we assume that the particles are cubic sized.
For example 6 micron => $(0.0006 \times 0.0006 \times 0.0006) \times \text{particle amount in specific ISO 4406 code (100 mL)} \times 10,000 = \text{cm}^3/1000 \text{litres oil tank}$

The table below can be used to define the filter-cartridge dirt and contaminants capacity

<table>
<thead>
<tr>
<th>ISO 4406 Code xx → Code xx</th>
<th>Max. contaminants amount to be removed in cm³/1000 litres oil tank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Code 23 to Code 16 for particles &gt; 6 microns (new oil at delivery date)</td>
<td>17.1</td>
</tr>
<tr>
<td>Code 19 to Code 16 for particles &gt; 6 microns</td>
<td>1.0</td>
</tr>
<tr>
<td>Code 16 to Code 13 for particles &gt; 14 microns</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Table 3
Filling new oil to tank

Data sheets of filter elements often mention retention capacity in gram at a certain pressure drop since the test method is to weight the filter elements after testing.

In order to use this when sizing a filter element we might assume that 1 gram = 1 cm³.

Steel and rust particles are heavier, but normally a minority compared with dust and cloth particles which are lighter.

Example: How to choose the correct filter cartridge size.

Steps to follow:
- Oil amount of 48,000 litres must be moved to hydraulic tank.
- Pump equipment (flow): 200 l/min. → 12 m³/h
- To be cleaned from ISO 4406 Code 19 to ISO 4406 Code 16 for particles > 6 microns = 1.0 cm³/m³ (Table 3).
- Contaminants > 6 microns to be removed, i.e. 48 m³ x 1.0 cm³/m³ = 48 cm³ (from look-up in table 4: filtertype 250 and 6 µm).

Conclusion of example:
- Filter element: 0250 DN 6 BN/HC/-V
- Filtration time: 48,000/200 = 240 min → 4 hours.
- Final cleanliness level: ISO 4406 Code 16 (for particles > 6 microns).

<table>
<thead>
<tr>
<th>Size</th>
<th>0160, 0250, 0400</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>DN</td>
</tr>
<tr>
<td>Filtration rating µm</td>
<td>BN/HC: 3, 6, 10, 25</td>
</tr>
<tr>
<td></td>
<td>W/HC: 25, 50, 100, 200 (on request)</td>
</tr>
<tr>
<td>Filter material</td>
<td>BN/HC</td>
</tr>
<tr>
<td></td>
<td>W/HC</td>
</tr>
<tr>
<td>Supplementary details</td>
<td>V = FPM seals, filter suitable for rapidly biodegradable oils and phosphate esters (HFD-R)</td>
</tr>
</tbody>
</table>

Fig. 4: Data for filter element

3.2.1 Element specifications

<table>
<thead>
<tr>
<th>Filter type</th>
<th>ISOMTD contamination retention capacity in g at ∆p = 5 bar for BN/HC elements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3 µm</td>
</tr>
<tr>
<td>160</td>
<td>27.5</td>
</tr>
<tr>
<td>250</td>
<td>46.0</td>
</tr>
<tr>
<td>400</td>
<td>76.2</td>
</tr>
</tbody>
</table>

3.2.2 Filter surface area W/HC

<table>
<thead>
<tr>
<th>Filter type</th>
<th>Filter surface area</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>2,750 cm²</td>
</tr>
<tr>
<td>250</td>
<td>4,400 cm²</td>
</tr>
<tr>
<td>400</td>
<td>6,730 cm²</td>
</tr>
</tbody>
</table>

Table 4

4. FILTER SPECIFICATIONS

<table>
<thead>
<tr>
<th>Filter type</th>
<th>Port</th>
<th>Element size</th>
<th>Weight [kg] with element</th>
</tr>
</thead>
<tbody>
<tr>
<td>160</td>
<td>G 1 ¼</td>
<td>0160 DN...</td>
<td>10.3</td>
</tr>
<tr>
<td>250</td>
<td>G 1 ½</td>
<td>0250 DN...</td>
<td>11.6</td>
</tr>
<tr>
<td>400</td>
<td>DN 38 *</td>
<td>0400 DN...</td>
<td>13.0</td>
</tr>
</tbody>
</table>

* Flange SAE 1 1/2”, 3000 psi

Table 5
Cleanliness requirement

The cleanliness level for the lubricating oil used for flushing the main engine must comply with ISO 4406 Code xx/19/15.

The cleanliness level for the lubricating oil used for flow cleaning the ME system must comply with ISO 4406 Code xx/16/13.

However if using a ME-filter with a filtration ability $\beta_{6}=\text{min.} 8$ which often is installed in the redundancy part of the ME filter arrangement and known as SFF (Super Fine Filter), it is possible to clean the oil from ISO code xx/19/15 to ISO code xx/16/13 is a single pass through the filter.

This enable the opportunity to begin flushing of the ME-system when the cleanliness level in the tank in minimum ISO 4406 Code xx/19/15.

When the oil cleanliness level in the tank is according to the above, flushing of the main engine and ME-system can be performed in parallel.

The oil must circulate for more time during flushing since entrapped particles in the system will be loosened and affect the cleanliness.

We recommend to follow the flushing procedures from MAN Energy Solutions.

General flushing conditions

Preheat the oil to a temperature of 60-65 degrees Celsius.

To ensure a sufficiently turbulent flow in the system, the oil flow velocity must, as a minimum, reach a Reynolds number higher than 3,000, see also Fig. 5.

Formula for calculating the Reynolds number:

$$\text{Re} = \frac{(V \times D)}{\eta} \times 1,000$$

Re = Reynolds number

\(\eta\) = kinematic viscosity (cSt)

\(V\) = flow velocity (m/s)

\(D\) = inner pipe diameter (mm)

Example:

Reynolds number 3,000

Inner pipe diameter 300 mm (0.3 m)

Oil viscosity 112 cSt

Calculation of minimum flow velocity:

$$V = \frac{\text{Re}}{1,000} \times \frac{\eta}{D} = 1.12 \text{m/s}$$

Calculation of minimum pump flow:

$$Q = \frac{\pi}{4} \times (n) \times 3.600 = 4,750 \text{ L/min}$$

Use of flushing equipment

For filling and topping up, always use a filter cartridge with a filtration ability of $\beta_{6} = 200$.

For flushing, a filtration ability of minimum $\beta_{10} = 75$ is needed, however, MAN Energy Solutions recommends a filter with a minimum filtration ability of $\beta_{6} = 75$.

For additional flushing filters, so-called “off-line” filters, a minimum filtration ability of $\beta_{6} = 75$ is recommended, and a minimum filtration ability of $\beta_{10} = 75$ is needed.

Use of ME-filter for flushing is recommended. Backflushing oil must be returned to a separate backflushing tank and then back to the main tank via a $\beta_{6} = 200$ filter cartridge.

MAN Energy Solutions recommends use of a purifier during flushing. A portable vibrator or hammer can be used on the outside of the lube oil pipes to loosen impurities in the piping system.

It is also recommended to circulate oil through the system at maximum pump capacity, but not higher than the maximum capacity of the filters.

The nomograms shown in Fig. 5 can be used for estimation of the flow velocity required to reach a Reynolds number higher than 3,000.
Flow needed for Re = 3,000 at 112 cSt

Min. flow via "Ru" inlet – 6,185 l/min

Flow velocity needed for Re = 3,000 at 112 cSt

Min. flow velocity via "Ru" inlet – 0.86 m/s
**Treatment of tank**

Each single surface of the tank, horizontal and vertical, must be cleaned as described below:

- any slag (and other impurities) after welding must be removed mechanically

- clean all visible impurities

- treat scale on the surface with a de-scaling agent

- if rust is found, treat the surface with de-rust agent

- use a vacuum cleaner to remove small particles from the surface and corners

- wash the surface with grease-dissolving liquid.

Cleaned areas must be protected with an anti-rust agent immediately after they have been cleaned, so as to provide protection until the system is filled up. The agent must be of a type that can be mixed with lubricating oil.

**Cleaning of the oil tank**

New or repaired components are often the carriers of contamination. Before final assembly, this built-in contamination must be removed from the blocks, pipes, oil tank and any other components prepared for use in the system.

**Treatment of pipes and additional installations**

Hydraulic pipes should only be welded if absolutely necessary. If so, each welding point must be placed so that mechanical removal of any welding slag is possible.

All pipe dimensions larger than ø25 mm (externally) should be fitted with flanges if possible. The flanges and pipes must always follow the requirements of the class.

All cut surfaces must be ground, and the inner surface must be smooth. Any slag (and other impurities) must be removed mechanically. Clean all visible impurities. Scale on the inner surface must be treated with a de-scaling agent. If rust is found, the inner surface must be treated with de-rust agent. Use compressed air to remove small particles from the surface. Degrease all pipes using grease-dissolving liquid. Pipes that have been treated with acid are to be neutralised or washed in a combination of cleaning/neutralising agents.

Cleaned areas must be protected with an anti-rust agent immediately after being cleaned, so as to provide protection until the system is filled up. The agent must be of a type that can be mixed with lubricating oil.

When a pipe is treated with an internal protection agent, open connections must be blanked off (remember to remove all temporary gaskets and plugs, before assembly).

---

Fig. 7: Empty hydraulic oil tank
Step I
Filling of the oil tank (on the test bed, at shipyard, on board)

Use a filter unit for filling and simultaneous cleaning (filtration during filling):

- filter cartridge with a beta rating of $\beta_6 = 200$

- filter rating in accordance with Multi Pass Test ISO 16889 defined for an operating viscosity of 100 cSt and a pressure drop of $dP = 0.15$ bar.

![Diagram of hydraulic oil tank filled]

Filter position as close as possible to storage/main tank

Main tank
Expected cleanliness level min.
ISO 4406 Code xx/16/13

Filling unit
Filter cartridge filtration ability: $\beta_6 = 200$
From ISO 4406 Code 23 to 16 after one pass.

Sample point assembly (minimess): Always vertical position and connected to upper part of pipe

Fig. 8: Hydraulic oil tank filled
Step II

Oil cleanliness improvement in the existing tank when using the ME-filter (main filter)

Flush pipes and additional installations, and use additional filter $\beta_6 = 200$ to minimise flushing time.

Fig. 9: Cleanliness improvement in the existing oil tank, flushing of pipes and additional installations (test bed, shipyard, on board)
Step III
Flushing of shipyard installations (piping) when using the ME-filter (main filter)

MAN Energy Solutions recommends use of an additional filter for parallel filtration to reduce flushing time. A separate backflushing tank is also needed.

Flow control valve
Max. pressure difference between filter inlet and filter outlet 2.2 bar

Dirty backflushing oil can only be moved back to the main tank via a filling unit or filter arrangement equipped with a filter cartridge of β6 = 200.

Fig. 10: Preventing hydraulic failures, flushing on the test bed and at the shipyard
Step IV
Engine flushing when using the ME-filter (main filter)

Fig. 11: Flushing of engine on the test bed and at the shipyard
Flushing procedure for ME installations when using the ME-filter (redundancy filter)

The time required to clean the ME system to ISO 4406 Code xx/16/13 cleanliness level, can be greatly reduced by fitting a filter cartridge with a filtration ability of minimum $\beta_6 = 8$ to the ME redundancy filter and then directing the main lube oil flow through this filter.

The described configuration must be applied on all new installations on the test bed, during quay trial and sea trial, and for the following 14 days after that. After this period, the ME lube oil flow can be switched back to run through the main filter (Pos. 106) for normal engine service running.

This solution is time saving for the crew and has no negative effects on the service life of the redundancy filter.
**Topping-up of main tank**

Valid on test bed and for installations in service

All fluid delivered from an oil company must be filled through a filter cartridge with filtration ability of $\beta_6$ (beta) = 200.

As mentioned, this is not only important to prevent difficulties during start-up, but also when topping up the main tank for installations in service.

Unlimited topping-up of the main tank without the above filter will result in increased wear of valves, pumps and bearings and, eventually, will lead to malfunction of the systems.

For installations without the necessary filling equipment, the rules described in the following must be observed.

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**Fig. 13: Installations in service, max. 3% of tank capacity per day**

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**Fig. 14: Installations in service, max. 1% of tank capacity per day**
**Temporary filters**

A temporary filter can be used between the FIVA main valve and the FIVA pilot valve, and also the HPS pump and the pilot valve for pump control. However, the filters must be removed after sea trial.

The reason is to install an extra protection of all control valves which demands high oil cleanliness since the first hours of engine running will release particles that the flushing did not catch as illustrated at fig. 16.

In 2010, the same type of Hydac sandwich filter (3 microns) was installed for testing in service for two months on ELFI B3-45. The test result was positive with no performance change recorded.

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![Image](image_url)

**Fig. 15:** FIVA unit with temporary filter

**Fig. 16:**

In 2010, the same type of Hydac sandwich filter (3 microns) was installed for testing in service for two months on ELFI B3-45. The test result was positive with no performance change recorded.

**Fig. 17:** The Hydac sandwich filter has been tested successfully without any performance change on ELFI-B3-45 at the MAN Energy Solutions research centre in Copenhagen
Safety screen at Multiway Valves

In 2019 we introduced Multiway Valves like FIVA, ELFi, ELVA and PEVA with a safety screen in the oil line for the controlling proportional valve.

The safety screen is a small filter strainer with a mesh size of 100 µm which intend to minimize the risk of larger particle to enter and disturb the function the controlling proportional valve.

After a service test of almost 6,000 running hours the safety screen was inspected and large particles were found which could have resulted in a malfunction of the valve.

All Multiway Valves equipped with a safety screen will need to have the filter strainer inspected and cleaned every 6,000 running hours or approximately once a year.
How to define contamination level

Cleanliness of hydraulic oil is normally examined by the laser method. However, this is not a suitable method for system oil, as system oil is black containing soot, small water-droplets, air-bubbles etc. which the laser method (ISO 11500) counts as particles, but which do not harm the engine components. The microscope method removes the soot etc. and do merely look at actual particles. MAN Energy Solutions therefore recommends to use the microscope method (ISO 4407).

The results show, that for used oil samples the microscope method measures 4-6 cleanliness classes below the laser method.

MAN Energy Solutions recommend on regular basis, when lube oil samples are send ashore for analyse, that a particle counting are also performed on the ME Hydraulic System oil according ISO 4407 which is particle counting by microscope method.

A filter diaphragm with all contaminants from a 100 ml sample must be prepared. The recommended sample point position is diagram Pos. 340 or Pos. 425. In the P2 line of the ME system. Minimess sample points at the ME-filter inlet and outlet are also recommendable.

Sample bottles should be clean to reduce the interference of contaminants from the bottles. Use the bottles cleaned and validated in accordance with ISO 3722 and BS 5540.

Using a vacuum pump, a representative sample of hydraulic fluid, usually 100 ml, is drawn from the 70ºC preheated system through a 47 mm diameter laboratory membrane filter disc with a filter mesh size of 1.2 microns.

All contaminants larger than 1.2 micron are collected on the surface of the filter disc. Residual sample fluid is washed from the filter disc using a suitable solvent filtered through a 1.2 micron filter mesh, and the membrane filter disc is transferred to a suitable protected container.

Analyse the membrane filter disc under microscope and compare a view on a prepared filter diaphragm with the "comparator" picture with the same magnification. Use of a comparator book for this analysis is recommended.
Oil analysis procedure

1. Heat oil samples in an oven to around 70°C. This will usually take one hour. The heating of the oil samples is important in order to be able to draw the oil through the filter discs.

2. Prepare the test equipment.

3. Take one 1,2 micron filter disc by forceps and place it at the top of the funnel.

4. Clamp the measuring glass on the top.

5. Take a well-heated oil sample and shake it thoroughly for half a minute. Remove the screw cap and fill the measuring glass to the 100 mL mark.

6. Start the vacuum pump and the oil will be drawn through the filter disc to the bottle below. Stop the vacuum pump when the oil is through.
7. Spray solvent / benzine onto the sides of the measuring glass and wait a minute so the solvent can dissolve the black soot particles.

8. Start the vacuum pump and the solvent / benzene will be drawn through the filter disc. Stop the vacuum pump afterwards and remove the clamp together with the measuring glass.

9. Place by forceps the filter disc into the suitable container. Now the filter disc is ready to examine under microscope.

Normally the filter disc would visually look fairly clean since our eyes cannot see particles smaller than 40 µm. However sometimes it is possible to determine if the cleanliness is not okay or not before analyse under microscope.

Fig. 23: Example of too dirty filter disc
Air amount in oil

Another important factor together with keeping the oil clean is to ensure a low amount of air in the oil.

A high content of air in the oil will decrease the efficiency of the hydraulic system as well as increase cavitation and wear at the hydraulic components.

It is the responsibility of the ship designer to ensure that the amount of air in the oil \( X_{\text{air}} \) put into the engine by the main lube oil pumps, does not exceed a maximum 1.5%.

This is to be confirmed on sea trial with the engine running in 100% load. An oil sample is to be made from the main low pressure supply line on the main engine downstream after the de-aerating nozzle shown in the main lubricating oil system diagram.

Such an oil sample must be made by using a bottle similar to the ones shown in fig. 24.

First the initial oil volume must be noted, see fig. 24 (A). The oil sample volume is to be evaluated after 24h in order to assume no air content in the final oil volume, see fig. 24 (B).

Recommendations for Design of Lubricating Oil Sump Tank

A way to keep the air content low is to ensure that the oil level in the tank never is under minimum level.

Because if the oil circulating rate is too high the oil will not have sufficient time for deaeration.

1. Considerations about Design of Lubricating Oil Sump Tank

The lubricating oil sump tank for the two-stroke marine diesel engines has several functions which are shortly listed here, as a basis for the recommendations that will be given later on:

- To settle the solid particles that will be separated by the centrifuges
- To de-aerate and degas the lubricating oil
- To act as a storage tank of the total volume of lubricating oil
- To contain the necessary oil volume in order to avoid a too high circulating rate
- To avoid that air be sucked by the lubricating oil pumps

The tank is located under the crankcase oil pan, in order to facilitate the oil flow from the crankcase outlets. It has to be designed with a symmetrical cross section to avoid bedplate distortions.

Usually, there is a cofferdam under the lubricating oil sump tank.

If the ship is not equipped with a cofferdam below the lubricating oil

![Fig. 24: Design proposal](image1)

![Fig. 25: A: Cofferdam below oil tank. B: No cofferdam below oil tank and valve in oil outlet](image2)
bottom tank, the lubricating oil outlet from the engine can be equipped with valves in the outlet, if required by the classification society. This can also be arranged with emergency suction from the engine oil pan.

2. Lubricating Oil Volume and Circulating Rate

The lubricating oil sump tank has to be dimensioned in accordance with the main lubricating oil pump capacity and the recommended circulating rate, which should be between 15 and 18 times per hour.

In some cases, when space is limited, it might be necessary to reduce the tank size to a minimum. However, it will not – under any circumstances – be advisable to increase the circulating rate to more than 20 times per hour.

In other cases, especially for engines with a large numbers of cylinders the tank size might be too big using the length extension of the engine as tank boundaries. For those engines the lub. oil bottom tank can be designed as below fig. 26.

Example:
Pump capacity: 280 m³/h
No. of oil circulations per hour: 15 1/h

That means that the total oil volume should be between:
- Recommended maximum oil volume (in circulation): 280/15=18.7 m³
- Recommended minimum oil volume (in circulation): 280/18=15.6 m³

It is good practice to design the tank volume with a capacity of approx. 5% to 10% more than the initial oil filling volume with pumps stopped.

When taking the above into consideration, the normally acceptable range of tank volume will be between:

Maximum tank volume:
18.7×1.10=20.6 m³

Minimum tank volume:
15.6×1.05=16.4 m³

Therefore, the tank volume is to be increased corresponding to the volume of the oil from the system outside the engine – if such a system is present.

Fig. 26: Design proposal
Guide to contamination control

When the engine is delivered in several parts, flushing of the engine at the shipyard is needed.

Dismantling of ME parts before sending to yard
During dismantling of the ME-system, open connections must be hermetically sealed using rubber seals and blind flanges. In this way, flushing of ME parts at the yard can be avoided.

Guide to System Contamination Control

- Engine builder
- Sub-supplier

Cleaning of main tank

Filling of the oil tank + oil cleaning (use of the filling filter recomended)

Cleaning of pipes and new installations (use of the filling filter recomended)

Engine flushing (use of the filling filter recomended)

ME-system, flow cleaning (use of ME filter necessary)

ISO 4406 Code xx/19/15
ISO 4406 Code xx/16/13

Shop test

Fig. 27: Flushing at the shipyard
When the engine is delivered finish-assembled, flushing of the engine at the shipyard can be avoided. However, flushing of shipyard installations is always required.
Summary

The starting point for every filtration and flushing strategy is that all new oil is dirty. The proper cleaning and flushing of hydraulic systems is therefore vital to ensure reliable and longterm operation without unexpected downtime of the system for maintenance and repair.

MAN Energy Solutions recommends following the standards and guidelines described in this paper, so as to achieve the best possible system condition on low speed MAN B&W two-stroke diesel engines.

This includes application of the ISO 4406 standard and use of the proper filter cartridges for filtration and the proper filters for flushing. Furthermore, it is important to monitor the cleanliness level of the oil by means of onsite fluid analyses, in order to be able to control the level of contamination.