Filtration Handbook
Filtration and flushing strategy
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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 Diesel & Turbo 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
The concept of the code can be seen in Table II. 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 II.

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>8,000,000</td>
<td>16,000,000</td>
</tr>
<tr>
<td>23</td>
<td>4,000,000</td>
<td>8,000,000</td>
</tr>
<tr>
<td>22</td>
<td>2,000,000</td>
<td>4,000,000</td>
</tr>
<tr>
<td>21</td>
<td>1,000,000</td>
<td>2,000,000</td>
</tr>
<tr>
<td>20</td>
<td>500,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>19</td>
<td>250,000</td>
<td>500,000</td>
</tr>
<tr>
<td>18</td>
<td>130,000</td>
<td>250,000</td>
</tr>
<tr>
<td>17</td>
<td>64,000</td>
<td>130,000</td>
</tr>
<tr>
<td>16</td>
<td>32,000</td>
<td>64,000</td>
</tr>
<tr>
<td>15</td>
<td>16,000</td>
<td>32,000</td>
</tr>
<tr>
<td>14</td>
<td>8,000</td>
<td>16,000</td>
</tr>
<tr>
<td>13</td>
<td>4,000</td>
<td>8,000</td>
</tr>
<tr>
<td>12</td>
<td>2,000</td>
<td>4,000</td>
</tr>
<tr>
<td>11</td>
<td>1,000</td>
<td>2,000</td>
</tr>
<tr>
<td>10</td>
<td>500</td>
<td>1,000</td>
</tr>
<tr>
<td>9</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>8</td>
<td>130</td>
<td>250</td>
</tr>
<tr>
<td>7</td>
<td>64</td>
<td>130</td>
</tr>
<tr>
<td>6</td>
<td>32</td>
<td>64</td>
</tr>
</tbody>
</table>

Table I: The ISO 4406 standard is a decisive tool defining the quantity of solid particles in the fluid in MAN Diesel & Turbo installations

<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>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>125</td>
<td>22</td>
<td>4</td>
<td>1</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>8,000</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>102,400</td>
<td>182,400</td>
<td>32,400</td>
<td>5,760</td>
<td>1,024</td>
</tr>
</tbody>
</table>

Table II
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.

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
**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 $\beta_6 = 200$.

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

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

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

---

**New oil is dirty!**

**Main tank**
- Expected Cleanliness
- Level min. ISO 4406 Code xx/16/13

**Filter Unit**
- Filter cartridge Beta6=200
- Filtration ability:
  - From ISO 4406 Code 23 to Code 16

Fig. 3: Filtration ability of filter cartridge: $\beta_6 = 200$

---

**Example of contaminants amount to be removed**

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 cm$^3$/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>From Code 19 to Code 16 for particles &gt; 6 microns</td>
<td>1.0</td>
</tr>
<tr>
<td>From Code 16 to Code 13 for particles &gt; 14 microns</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Table III
**Filling New Oil to Tank**

**Example:** How to choose the correct filter cartridge size.

**Tasks:**
- Oil amount of 48,000 litres must be moved to hydraulic tank.
- Pump equipment (flow): 200 l/min. \( \rightarrow 12 \text{ m}^3/\text{h} \)

- To be cleaned from ISO 4406 Code 19 to ISO 4406 Code 16 for particles > 6 microns.
- Contaminants > 6 microns to be removed, i.e. 48 m\(^3\) x 1.0 cm\(^3\) = 48 cm\(^3\)

**Equipment needed:**
- Filter element: 0250 DN 6 BN/HC /-V
- Filtration time: 48,000/200 = 240 min \( \rightarrow 4 \text{ hours.} \)
- Final cleanliness level: ISO 4406 Code 16 (for particles > 6 microns).

---

**Filter element specifications**

<table>
<thead>
<tr>
<th>Filter type</th>
<th>ISOMTD contamination retention capacity in g at ( \Delta p = 5 \text{ bar} ) for BN/HC elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 µm</td>
<td>6µm</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>

**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>2750 cm(^2)</td>
</tr>
<tr>
<td>250</td>
<td>4400 cm(^2)</td>
</tr>
<tr>
<td>400</td>
<td>6730 cm(^2)</td>
</tr>
</tbody>
</table>

**Table IV:**

<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 V:**

---
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, Code 4/6/14

<table>
<thead>
<tr>
<th>ISO 4406 chart</th>
<th>Range number</th>
<th>Number of particles per 100 ml</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>More than</td>
<td>Up to and including</td>
</tr>
<tr>
<td>24</td>
<td>8,000,000</td>
<td>16,000,000</td>
</tr>
<tr>
<td>23</td>
<td>4,000,000</td>
<td>8,000,000</td>
</tr>
<tr>
<td>22</td>
<td>2,000,000</td>
<td>4,000,000</td>
</tr>
<tr>
<td>21</td>
<td>1,000,000</td>
<td>2,000,000</td>
</tr>
<tr>
<td>20</td>
<td>500,000</td>
<td>1,000,000</td>
</tr>
<tr>
<td>19</td>
<td>250,000</td>
<td>500,000</td>
</tr>
<tr>
<td>18</td>
<td>130,000</td>
<td>250,000</td>
</tr>
<tr>
<td>17</td>
<td>64,000</td>
<td>130,000</td>
</tr>
<tr>
<td>16</td>
<td>32,000</td>
<td>64,000</td>
</tr>
<tr>
<td>15</td>
<td>16,000</td>
<td>32,000</td>
</tr>
<tr>
<td>14</td>
<td>8,000</td>
<td>16,000</td>
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<tr>
<td>13</td>
<td>4,000</td>
<td>8,000</td>
</tr>
<tr>
<td>12</td>
<td>2,000</td>
<td>4,000</td>
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<tr>
<td>11</td>
<td>1,000</td>
<td>2,000</td>
</tr>
<tr>
<td>10</td>
<td>500</td>
<td>1,000</td>
</tr>
<tr>
<td>9</td>
<td>250</td>
<td>500</td>
</tr>
<tr>
<td>8</td>
<td>130</td>
<td>250</td>
</tr>
<tr>
<td>7</td>
<td>64</td>
<td>130</td>
</tr>
<tr>
<td>6</td>
<td>32</td>
<td>64</td>
</tr>
</tbody>
</table>

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. 5: Filtration requirement for ME/ME-C/ME-B
**Cleanliness Requirement**

The cleanliness level of oil used for flushing must, as a minimum, be according to ISO 4406 Code xx/16/13.

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.

**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 3000, see also Fig. 6.

Formula for calculating the Reynolds number:

\[ \text{Re} = \frac{(V \times D)}{\sqrt{\nu}} \times 1000 \]

- \( \text{Re} \) – Reynolds number
- \( \sqrt{\nu} \) – kinematic viscosity (cSt)
- \( V \) – flow velocity (m/s)
- \( D \) – inner pipe diameter (mm)

Example:

Reynolds number 3000
Inner pipe diameter 300 mm (0.3 m)
Oil viscosity 112 cSt

Calculation of minimum flow velocity:

\[ V = \left( \frac{\text{Re}}{1000} \right) \frac{\sqrt{\nu}}{D} = 1.12 \text{m/s} \]

Calculation of minimum pump flow:

\[ Q = D^2 \left( \frac{\pi}{4} \right) \times 1.12 \times 3600 = 285 \text{ m}^3/\text{h} \]

**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 Diesel & Turbo 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 Diesel & Turbo 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. 6 can be used for estimation of the flow velocity required to reach a Reynolds number higher than 3000.
Flow needed for Re = 3000 at 112 cSt

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

Flow velocity needed for Re = 3000 at 112 cSt

Min. flow velocity via "Ru" inlet – 0.86 m/s

Fig. 6: Flow/flow velocity nomograms
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 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).
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.

![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. 7: Hydraulic oil tank filled
Step II
Oil cleanliness improvement in the existing tank
Flush pipes and additional installations, and use additional filter $\beta_6 = 200$ to minimise flushing time.

Fig. 8: 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)  
MAN Diesel & Turbo recommends use of an additional filter for parallel filtration to reduce flushing time. A separate backflushing tank is also needed.

**Fig. 9: Preventing hydraulic failures, flushing on the test bed and at the shipyard**
Step IV
Engine flushing

Fig. 10: Flushing of engine on the test bed and at the shipyard
New improved flushing procedure for ME installations

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 B6 = 16 and B14 = 100 to the ME redundancy filter and then directing the main lube oil flow through this filter.

The above-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.

Fig. X: Flushing through ME redundancy filter fitted with a high-filtration ability filter cartridge
Filtration and flushing strategy

**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 $B_6$ (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.

---

**Fig. 11: Installations in service, max. 3% of tank capacity per day**

**Fig. 12: Installations in service, max. 1% of tank capacity per day**
Temporary Filters

A temporary filter with a mesh size of 3 microns 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.

When using these filters, the cleanliness level of the ME system oil can be according to ISO 4406 Code xx/17/14.

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. 13: FIVA unit with temporary filter

Fig. 14: The Hydac sandwich filter has been tested successfully without any performance change on ELFI-B3-45 at the MAN Diesel & Turbo research centre in Copenhagen
How to define contamination level

Quick 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.

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 70°C 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.

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.

The method described is a decisive tool for onsite system fluid analysis. This method cannot determine the exact particle count, but allows you to estimate the cleanliness level.

For documentation, particle counting can be ordered from a local laboratory.
**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**

1. **Cleaning of main tank**
2. **Filling of the oil tank + oil cleaning (use of the filling fileter recomended)**
3. **Cleaning of pipes and new installations (use of the filling fileter recomended)**
4. **Engine flushing (use of the filling fileter recomended)**
5. **ME-system, flow cleaning (use of ME filter necessary)**
6. **Shop test**

Fig. 17: 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.

Fig. 18: Flushing of shipyard installations only
**Filtration Ability of ME filter**

**Filtration ability for particles > 6 microns**

Metal fibre fleece can remove min. 55% of particles larger than 6 microns for every pass through the filter.

**Filtration ability for particles > 14 microns**

Metal fibre fleece can remove min 95% of particles larger than 14 microns for every pass through the filter.

Example: ISO 4406 Code xx/xx/19, max 500,000 particles > 14 microns → (500,000 − (500,000 × 0.95)) = 25,000 → ISO Code 15.

The oil cleanliness level for particles > 14 microns will be improved from ISO 4406 Code 19 to Code 15 after first pass through the ME filter.

**ISO 4406 Chart**

<table>
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*Table VI*
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 Diesel & Turbo 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.