6. Fuel System

6.1 Acceptable fuel characteristics

6.1.1 Gas fuel specification

As a dual fuel engine, the Wärtsilä 50DF engine is designed for continuous operation in gas operating mode or diesel operating mode. For continuous operation without reduction in the rated output, the gas used as main fuel in gas operating mode has to fulfill the below mentioned quality requirements.

Table 6.1 Fuel Gas Specifications

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower heating value (LHV), min 1)</td>
<td>MJ/m³N 2)</td>
<td>80 (IMO Tier 2)</td>
</tr>
<tr>
<td>Methane number (MN), min 3)</td>
<td>% volume</td>
<td>70</td>
</tr>
<tr>
<td>Methane (CH₄), min</td>
<td>% volume</td>
<td>0.05</td>
</tr>
<tr>
<td>Hydrogen sulphide (H₂S), max</td>
<td>% volume</td>
<td>3</td>
</tr>
<tr>
<td>Hydrogen (H₂), max 4)</td>
<td>% volume</td>
<td>3</td>
</tr>
<tr>
<td>Ammonia, max</td>
<td>mg/m³N</td>
<td>25</td>
</tr>
<tr>
<td>Chlorine + Fluorines, max</td>
<td>mg/m³N</td>
<td>50</td>
</tr>
<tr>
<td>Particles or solids at engine inlet, max</td>
<td>mg/m³N</td>
<td>50</td>
</tr>
<tr>
<td>Gas inlet temperature</td>
<td>°C</td>
<td>0…60</td>
</tr>
</tbody>
</table>

1) The required gas feed pressure is depending on the LHV (see section Gas feed pressure in chapter Fuel system).
2) Values given in m³N are at 0°C and 101.3 kPa.
3) The methane number (MN) is a calculated value that gives a scale for evaluation of the resistance to knock of gaseous fuels. Above table is valid for a low Methane Number optimized engine. Minimum value is depending on engine configuration, which will affect the performance data. However, if the total content of hydrocarbons C5 and heavier is more than 1% volume Wärtsilä has to be contacted for further evaluation.
4) Hydrogen content higher than 3% volume has to be considered project specifically.
5) Dew point of natural gas is below the minimum operating temperature and pressure.

6.1.2 Liquid fuel specification

The fuel specifications are based on the ISO 8217:2010 (E) standard. Observe that a few additional properties not included in the standard are listed in the tables. For maximum fuel temperature before the engine, see chapter "Technical Data".

The fuel shall not contain any added substances or chemical waste, which jeopardizes the safety of installations or adversely affects the performance of the engines or is harmful to personnel or contributes overall to air pollution.

Marine Diesel Fuel (MDF)

Distillate fuel grades are ISO-F-DMX, DMA, DMZ, DMB. These fuel grades are referred to as MDF (Marine Diesel Fuel).

The distillate grades mentioned above can be described as follows:

- DMX: A fuel which is suitable for use at ambient temperatures down to -15°C without heating the fuel. Especially in merchant marine applications its use is restricted to lifeboat engines and certain emergency equipment due to the reduced flash point. The low flash point which is not meeting the SOLAS requirement can also prevent the use in other marine applications, unless the fuel system is built ac-
cording to special requirements. Also the low viscosity (min. 1.4 cSt) can prevent the use in engines unless the fuel can be cooled down enough to meet the min. injection viscosity limit of the engine.

- DMA: A high quality distillate, generally designated as MGO (Marine Gas Oil).
- DMZ: A high quality distillate, generally designated as MGO (Marine Gas Oil). An alternative fuel grade for engines requiring a higher fuel viscosity than specified for DMA grade fuel.
- DMB: A general purpose fuel which may contain trace amounts of residual fuel and is intended for engines not specifically designed to burn residual fuels. It is generally designated as MDO (Marine Diesel Oil).

### Table 6.2 MDF specifications

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>ISO-F-DMA</th>
<th>ISO-F-DMZ</th>
<th>ISO-F-DMB</th>
<th>Test method ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity before pilot fuel pump, min. ¹)</td>
<td>cSt</td>
<td>2.0</td>
<td>2.0</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Viscosity, before pilot fuel pump, max. ¹)</td>
<td>cSt</td>
<td>11.0</td>
<td>11.0</td>
<td>11.0</td>
<td></td>
</tr>
<tr>
<td>Viscosity, before main injection pumps, min. ¹)</td>
<td>cSt</td>
<td>2.8</td>
<td>2.8</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Viscosity, before main fuel injection pumps, max. ¹)</td>
<td>cSt</td>
<td>24.0</td>
<td>24.0</td>
<td>24.0</td>
<td></td>
</tr>
<tr>
<td>Viscosity at 40°C, min.</td>
<td>cSt</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>ISO 3104</td>
</tr>
<tr>
<td>Viscosity at 40°C, max.</td>
<td>cSt</td>
<td>6</td>
<td>6</td>
<td>11</td>
<td>ISO 3675 or</td>
</tr>
<tr>
<td>Density at 15°C, max.</td>
<td>kg/m³</td>
<td>890</td>
<td>890</td>
<td>900</td>
<td>12185</td>
</tr>
<tr>
<td>Cetane index, min.</td>
<td>% mass</td>
<td>40</td>
<td>40</td>
<td>35</td>
<td>ISO 4264</td>
</tr>
<tr>
<td>Sulphur, max.</td>
<td>% mass</td>
<td>1.5</td>
<td>1.5</td>
<td>2</td>
<td>ISO 8574 or</td>
</tr>
<tr>
<td>Flash point, min.</td>
<td>°C</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>14596</td>
</tr>
<tr>
<td>Hydrogen sulfide, max.</td>
<td>mg/kg</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>IP 570</td>
</tr>
<tr>
<td>Acid number, max.</td>
<td>mg KOH/g</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>ASTM D664</td>
</tr>
<tr>
<td>Total sediment by hot filtration, max.</td>
<td>% mass</td>
<td>—</td>
<td>—</td>
<td>0.1 ³)</td>
<td>ISO 10307-1</td>
</tr>
<tr>
<td>Oxidation stability, max.</td>
<td>g/m³</td>
<td>25</td>
<td>25</td>
<td>25 ⁴)</td>
<td>ISO 12205</td>
</tr>
<tr>
<td>Carbon residue: micro method on the 10% volume distillation residue max.</td>
<td>% mass</td>
<td>0.30</td>
<td>0.30</td>
<td>—</td>
<td>ISO 10370</td>
</tr>
<tr>
<td>Carbon residue: micro method, max.</td>
<td>% mass</td>
<td>—</td>
<td>—</td>
<td>0.30</td>
<td>ISO 10370</td>
</tr>
<tr>
<td>Pour point (upper), winter quality, max. ⁵)</td>
<td>°C</td>
<td>-6</td>
<td>-6</td>
<td>0</td>
<td>ISO 3016</td>
</tr>
<tr>
<td>Pour point (upper), summer quality, max. ⁵)</td>
<td>°C</td>
<td>0</td>
<td>0</td>
<td>6</td>
<td>ISO 3016</td>
</tr>
<tr>
<td>Appearance</td>
<td>—</td>
<td>Clear and bright ⁶)</td>
<td>³) 4) ⁷)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water, max.</td>
<td>% volume</td>
<td>—</td>
<td>—</td>
<td>0.3 ³)</td>
<td>ISO 3733</td>
</tr>
<tr>
<td>Ash, max.</td>
<td>% mass</td>
<td>0.01</td>
<td>0.01</td>
<td>0.01</td>
<td>ISO 6245</td>
</tr>
<tr>
<td>Lubricity, corrected wear scar diameter (wsd 1.4) at 60°C, max. ⁸)</td>
<td>µm</td>
<td>520</td>
<td>520</td>
<td>520 ⁷)</td>
<td>ISO 12156-1</td>
</tr>
</tbody>
</table>

Remarks:

1) Additional properties specified by Wärtsilä, which are not included in the ISO specification.

2) The implementation date for compliance with the limit shall be 1 July 2012. Until that the specified value is given for guidance.

3) If the sample is not clear and bright, the total sediment by hot filtration and water tests shall be required.

4) If the sample is not clear and bright, the test cannot be undertaken and hence the oxidation stability limit shall not apply.

5) It shall be ensured that the pour point is suitable for the equipment on board, especially if the ship operates in cold climates.

6) If the sample is dyed and not transparent, then the water limit and test method ISO 12937 shall apply.

7) If the sample is not clear and bright, the test cannot be undertaken and hence the lubricity limit shall not apply.
The requirement is applicable to fuels with a sulphur content below 500 mg/kg (0.050 % mass).

**NOTE!** Pilot fuel quality must be according to DMX, DMA, DMZ or DMB. Lubricating oil, foreign substances or chemical waste, hazardous to the safety of the installation or detrimental to the performance of engines, should not be contained in the fuel.

### Heavy Fuel Oil (HFO)
Residual fuel grades are referred to as HFO (Heavy Fuel Oil). The fuel specification HFO 2 covers the categories ISO-F-RMA 10 to RMK 700. Fuels fulfilling the specification HFO 1 permit longer overhaul intervals of specific engine components than HFO 2.

**Table 6.3 HFO specifications**

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Limit HFO 1</th>
<th>Limit HFO 2</th>
<th>Test method ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity, before injection pumps 1)</td>
<td>cSt</td>
<td>16...24</td>
<td>16...24</td>
<td>ISO 3104</td>
</tr>
<tr>
<td>Viscosity at 50°C, max.</td>
<td>cSt</td>
<td>700</td>
<td>700</td>
<td>ISO 3104</td>
</tr>
<tr>
<td>Density at 15°C, max.</td>
<td>kg/m³</td>
<td>991 / 1010 2)</td>
<td>991 / 1010 2)</td>
<td>ISO 3675 or 12185</td>
</tr>
<tr>
<td>CCAI, max. 3)</td>
<td>850</td>
<td>870</td>
<td></td>
<td>ISO 8217, Annex F</td>
</tr>
<tr>
<td>Sulphur, max. 4) 5)</td>
<td>% mass</td>
<td>Statutory requirements</td>
<td>ISO 8754 or 14596</td>
<td></td>
</tr>
<tr>
<td>Flash point, min.</td>
<td>°C</td>
<td>60</td>
<td>60</td>
<td>ISO 2719</td>
</tr>
<tr>
<td>Hydrogen sulfide, max. 6)</td>
<td>mg/kg</td>
<td>2</td>
<td>2</td>
<td>IP 570</td>
</tr>
<tr>
<td>Acid number, max.</td>
<td>mg KOH/g</td>
<td>2.5</td>
<td>2.5</td>
<td>ASTM D664</td>
</tr>
<tr>
<td>Total sediment aged, max.</td>
<td>% mass</td>
<td>0.1</td>
<td>0.1</td>
<td>ISO 10307-2</td>
</tr>
<tr>
<td>Carbon residue, micro method, max.</td>
<td>% mass</td>
<td>15</td>
<td>20</td>
<td>ISO 10370</td>
</tr>
<tr>
<td>Asphaltenes, max. 1)</td>
<td>% mass</td>
<td>8</td>
<td>14</td>
<td>ASTM D3279</td>
</tr>
<tr>
<td>Pour point (upper), max. 7)</td>
<td>°C</td>
<td>30</td>
<td>30</td>
<td>ISO 3016</td>
</tr>
<tr>
<td>Water, max.</td>
<td>% volume</td>
<td>0.5</td>
<td>0.5</td>
<td>ISO 3733 or ASTM D6304-C 1)</td>
</tr>
<tr>
<td>Water before engine, max. 1)</td>
<td>% volume</td>
<td>0.3</td>
<td>0.3</td>
<td>ISO 3733 or ASTM D6304-C 1)</td>
</tr>
<tr>
<td>Ash, max.</td>
<td>% mass</td>
<td>0.05</td>
<td>0.15</td>
<td>ISO 6245 or LP1001 1)</td>
</tr>
<tr>
<td>Vanadium, max. 5)</td>
<td>mg/kg</td>
<td>100</td>
<td>450</td>
<td>ISO 14597 or IP 501 or IP 470</td>
</tr>
<tr>
<td>Sodium, max. 5)</td>
<td>mg/kg</td>
<td>50</td>
<td>100</td>
<td>IP 501 or IP 470</td>
</tr>
<tr>
<td>Sodium before engine, max. 1) 5)</td>
<td>mg/kg</td>
<td>30</td>
<td>30</td>
<td>IP 501 or IP 470</td>
</tr>
<tr>
<td>Aluminium + Silicon, max.</td>
<td>mg/kg</td>
<td>30</td>
<td>60</td>
<td>ISO 10478 or IP 501 or IP 470</td>
</tr>
<tr>
<td>Aluminium + Silicon before engine, max. 1)</td>
<td>mg/kg</td>
<td>15</td>
<td>15</td>
<td>ISO 10478 or IP 501 or IP 470</td>
</tr>
<tr>
<td>Used lubricating oil, calcium, max. 8)</td>
<td>mg/kg</td>
<td>30</td>
<td>30</td>
<td>IP 501 or IP 470</td>
</tr>
<tr>
<td>Used lubricating oil, zinc, max. 8)</td>
<td>mg/kg</td>
<td>15</td>
<td>15</td>
<td>IP 501 or IP 470</td>
</tr>
<tr>
<td>Used lubricating oil, phosphorus, max. 8)</td>
<td>mg/kg</td>
<td>15</td>
<td>15</td>
<td>IP 501 or IP 500</td>
</tr>
</tbody>
</table>

**Remarks:**

1) Additional properties specified by Wärtsilä, which are not included in the ISO specification.

2) Max. 1010 kg/m³ at 15°C provided that the fuel treatment system can remove water and solids (sediment, sodium, aluminium, silicon) before the engine to specified levels.
Straight run residues show CCAI values in the 770 to 840 range and have very good ignition quality. Cracked residues delivered as bunkers may range from 840 to – in exceptional cases – above 900. Most bunkers remain in the max. 850 to 870 range at the moment. CCAI value cannot always be considered as an accurate tool to determine the ignition properties of the fuel, especially concerning fuels originating from modern and more complex refinery processes.

The max. sulphur content must be defined in accordance with relevant statutory limitations.

Sodium contributes to hot corrosion on the exhaust valves when combined with high sulphur and vanadium contents. Sodium also strongly contributes to fouling of the exhaust gas turbine blading at high loads. The aggressiveness of the fuel depends on its proportions of sodium and vanadium and also on the total amount of ash. Hot corrosion and deposit formation are, however, also influenced by other ash constituents. It is therefore difficult to set strict limits based only on the sodium and vanadium content of the fuel. Also a fuel with lower sodium and vanadium contents than specified above, can cause hot corrosion on engine components.

The implementation date for compliance with the limit shall be 1 July 2012. Until that, the specified value is given for guidance.

It shall be ensured that the pour point is suitable for the equipment on board, especially if the ship operates in cold climates.

The fuel shall be free from used lubricating oil (ULO). A fuel shall be considered to contain ULO when either one of the following conditions is met:
- Calcium > 30 mg/kg and zinc > 15 mg/kg
- Calcium > 30 mg/kg and phosphorus > 15 mg/kg

### 6.1.3 Liquid bio fuels

The engine can be operated on liquid bio fuels according to the specifications in tables "6.4 Straight liquid bio fuel specification" or "6.5 Biodiesel specification based on EN 14214:2003 standard". Liquid bio fuels have typically lower heating value than fossil fuels, the capacity of the fuel injection system must be checked for each installation.

If a liquid bio fuel is to be used as pilot fuel, only pilot fuel according to table "Biodiesel specification based on EN 14214:2003 standard" is allowed.

Table "Straight liquid bio fuel specification" is valid for straight liquid bio fuels, like palm oil, coconut oil, copra oil, rape seed oil, jathropha oil etc. but is not valid for other bio fuel qualities like animal fats.

Renewable biodiesel can be mixed with fossil distillate fuel. Fossil fuel being used as a blending component has to fulfill the requirement described earlier in this chapter.

#### Table 6.4 Straight liquid bio fuel specification

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Limit</th>
<th>Test method ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity at 40°C, max. 1)</td>
<td>cSt</td>
<td>100</td>
<td>ISO 3104</td>
</tr>
<tr>
<td>Viscosity, before injection pumps, min.</td>
<td>cSt</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>Viscosity, before injection pumps, max.</td>
<td>cSt</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Density at 15°C, max.</td>
<td>kg/m³</td>
<td>991</td>
<td>ISO 3675 or 12185</td>
</tr>
<tr>
<td>Ignition properties 2)</td>
<td></td>
<td></td>
<td>FIA test</td>
</tr>
<tr>
<td>Sulphur, max.</td>
<td>% mass</td>
<td>0.05</td>
<td>ISO 8574</td>
</tr>
<tr>
<td>Total sediment existent, max.</td>
<td>% mass</td>
<td>0.05</td>
<td>ISO 10307-1</td>
</tr>
<tr>
<td>Water before engine, max.</td>
<td>% volume</td>
<td>0.20</td>
<td>ISO 3733</td>
</tr>
<tr>
<td>Micro carbon residue, max.</td>
<td>% mass</td>
<td>0.50</td>
<td>ISO 10370</td>
</tr>
<tr>
<td>Ash, max.</td>
<td>% mass</td>
<td>0.05</td>
<td>ISO 6245 / LP1001</td>
</tr>
<tr>
<td>Phosphorus, max.</td>
<td>mg/kg</td>
<td>100</td>
<td>ISO 10478</td>
</tr>
<tr>
<td>Silicon, max.</td>
<td>mg/kg</td>
<td>15</td>
<td>ISO 10478</td>
</tr>
<tr>
<td>Alkali content (Na+K), max.</td>
<td>mg/kg</td>
<td>30</td>
<td>ISO 10478</td>
</tr>
<tr>
<td>Flash point (PMCC), min.</td>
<td>ºC</td>
<td>60</td>
<td>ISO 2719</td>
</tr>
<tr>
<td>Cloud point, max.</td>
<td>ºC</td>
<td>3)</td>
<td>ISO 3015</td>
</tr>
<tr>
<td>Cold filter plugging point, max.</td>
<td>ºC</td>
<td>3)</td>
<td>IP 309</td>
</tr>
<tr>
<td>Copper strip corrosion (3h at 50°C), max.</td>
<td>Rating</td>
<td>1b</td>
<td>ASTM D130</td>
</tr>
</tbody>
</table>
### Limit Units of Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Limit</th>
<th>Test method ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel corrosion (24/72h at 20, 60 and 120°C), max.</td>
<td>Rating</td>
<td>No signs of corrosion</td>
<td>LP 2902</td>
</tr>
<tr>
<td>Acid number, max.</td>
<td>mg KOH/g</td>
<td>15.0</td>
<td>ASTM D664</td>
</tr>
<tr>
<td>Strong acid number, max.</td>
<td>mg KOH/g</td>
<td>0.0</td>
<td>ASTM D664</td>
</tr>
<tr>
<td>Iodine number, max.</td>
<td>g iodine / 100 g</td>
<td>120</td>
<td>ISO 3961</td>
</tr>
<tr>
<td>Synthetic polymers</td>
<td>% mass</td>
<td>Report 4)</td>
<td>LP 2401 ext. and LP 3402</td>
</tr>
</tbody>
</table>

### Remarks:

1. If injection viscosity of max. 24 cSt cannot be achieved with an unheated fuel, fuel oil system has to be equipped with a heater.
2. Ignition properties have to be equal to or better than requirements for fossil fuels, i.e. CN min. 35 for MDF and CCAI max. 870 for HFO.
3. Cloud point and cold filter plugging point have to be at least 10°C below the fuel injection temperature.
4. Biofuels originating from food industry can contain synthetic polymers, like e.g. styrene, propene and ethylene used in packing material. Such compounds can cause filter clogging and shall thus not be present in biofuels.

### Table 6.5 Biodiesel specification based on EN 14214:2003 standard

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Limit</th>
<th>Test method ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Viscosity at 40°C, min...max.</td>
<td>cSt</td>
<td>3.5...5</td>
<td>ISO 3104</td>
</tr>
<tr>
<td>Viscosity, before injection pumps, min.</td>
<td>cSt</td>
<td>Pilot fuel: 2.0 Liquid fuel: 2.8</td>
<td>ISO 3675 / 12185</td>
</tr>
<tr>
<td>Density at 15°C, min...max.</td>
<td>kg/m³</td>
<td>860...900</td>
<td>ISO 3675 / 12185</td>
</tr>
<tr>
<td>Cetane number, min.</td>
<td></td>
<td>51</td>
<td>ISO 5165</td>
</tr>
<tr>
<td>Sulphur, max.</td>
<td>mg/kg</td>
<td>10</td>
<td>ISO 20846 / 20884</td>
</tr>
<tr>
<td>Sulphated ash, max.</td>
<td>% mass</td>
<td>0.02</td>
<td>ISO 3987</td>
</tr>
<tr>
<td>Total contamination, max.</td>
<td>mg/kg</td>
<td>24</td>
<td>EN 12662</td>
</tr>
<tr>
<td>Water, max.</td>
<td>mg/kg</td>
<td>500</td>
<td>ISO 12937</td>
</tr>
<tr>
<td>Carbon residue (on 10% distillation residue), max.</td>
<td>% mass</td>
<td>0.30</td>
<td>ISO 10370</td>
</tr>
<tr>
<td>Phosphorus, max.</td>
<td>mg/kg</td>
<td>4</td>
<td>EN 14107</td>
</tr>
<tr>
<td>Group 1 metals (Na+K), max.</td>
<td>mg/kg</td>
<td>5</td>
<td>EN 14108 / 14109</td>
</tr>
<tr>
<td>Group 2 metals (Ca+Mg), max.</td>
<td>mg/kg</td>
<td>5</td>
<td>EN 14538</td>
</tr>
<tr>
<td>Flash point, min.</td>
<td>°C</td>
<td>101</td>
<td>ISO 2719A / 3679</td>
</tr>
<tr>
<td>Cold filter plugging point, max. 2)</td>
<td>°C</td>
<td>-44...+5</td>
<td>EN 116</td>
</tr>
<tr>
<td>Oxidation stability at 110°C, min.</td>
<td>h</td>
<td>6</td>
<td>EN 14112</td>
</tr>
<tr>
<td>Copper strip corrosion (3h at 50°C), max.</td>
<td>Rating</td>
<td>Class 1</td>
<td>ISO 2160</td>
</tr>
<tr>
<td>Acid number, max.</td>
<td>mg KOH/g</td>
<td>0.5</td>
<td>EN 14104</td>
</tr>
<tr>
<td>Iodine number, max.</td>
<td>g iodine / 100 g</td>
<td>120</td>
<td>EN 14111</td>
</tr>
<tr>
<td>Ester content, min.</td>
<td>% mass</td>
<td>96.5</td>
<td>EN 14103</td>
</tr>
<tr>
<td>Linoleenic acid methyl ester, max.</td>
<td>% mass</td>
<td>12</td>
<td>EN 14103</td>
</tr>
<tr>
<td>Polysaturated methyl esters, max.</td>
<td>% mass</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Methanol content, max.</td>
<td>% mass</td>
<td>0.2</td>
<td>EN 14110</td>
</tr>
<tr>
<td>Monoglyceride content, max.</td>
<td>% mass</td>
<td>0.8</td>
<td>EN 14105</td>
</tr>
<tr>
<td>Diglyceride content, max.</td>
<td>% mass</td>
<td>0.2</td>
<td>EN 14105</td>
</tr>
<tr>
<td>Triglyceride content, max.</td>
<td>% mass</td>
<td>0.2</td>
<td>EN 14105</td>
</tr>
<tr>
<td>Free glycerol, max.</td>
<td>% mass</td>
<td>0.02</td>
<td>EN 14105 / 14106</td>
</tr>
<tr>
<td>Total glycerol, max.</td>
<td>% mass</td>
<td>0.25</td>
<td>EN 14105</td>
</tr>
</tbody>
</table>
Remarks:

1) Cold flow properties of renewable bio diesel can vary based on the geographical location and also based on the feedstock properties, which issues must be taken into account when designing the fuel system.
6.2 Operating principles

Wärtsilä 50DF engines are usually installed for dual fuel operation meaning the engine can be run either in gas or diesel operating mode. The operating mode can be changed while the engine is running, within certain limits, without interruption of power generation. If the gas supply would fail, the engine will automatically transfer to diesel mode operation (MDF).

6.2.1 Gas mode operation

In gas operating mode the main fuel is natural gas which is injected into the engine at a low pressure. The gas is ignited by injecting a small amount of pilot diesel fuel (MDF). Gas and pilot fuel injection are solenoid operated and electronically controlled common rail systems.

6.2.2 Diesel mode operation

In diesel operating mode the engine operates only on liquid fuel oil. MDF or HFO is used as fuel with a conventional diesel fuel injection system. The MDF pilot injection is always active.

6.2.3 Backup mode operation

The engine control and safety system or the blackout detection system can in some situations transfer the engine to backup mode operation. In this mode the MDF pilot injection system is not active and operation longer than 30 minutes (with HFO) or 10 hours (with MDF) may cause clogging of the pilot fuel injection nozzles.
6.3 Fuel gas system

6.3.1 Internal fuel gas system

Figure 6.1 Internal fuel gas system, in-line engines (DAAE010198b)

System components:

01 Safety filter
02 Gas admission valve
03 Cylinder
04 Venting valve

Pipe connections:

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Size</th>
<th>Pressure class</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>108</td>
<td>Gas inlet</td>
<td>DN100/150</td>
<td>PN16</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>708</td>
<td>Gas system ventilation</td>
<td>DN50</td>
<td>PN40</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>726</td>
<td>Air inlet to double wall gas system</td>
<td>M42x2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Sensors and indicators:

SE614A...SE6#4A  Knock sensor  PT901  Gas pressure
Figure 6.2 Internal fuel gas system, V-engines (DAAE010199c)

System components
01 Safety filter
02 Gas admission valve
03 Cylinder
04 Venting valve

Sensors and indicators
SE614A/B...SE6#4A/B Knock sensor
PT901 Gas pressure

Pipe connections
<table>
<thead>
<tr>
<th>Size</th>
<th>Pressure class</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>108 Gas inlet</td>
<td>DN100</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>708A/B</td>
<td>DN50</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>726A/B</td>
<td>M42x2</td>
<td>ISO 7005-2</td>
</tr>
</tbody>
</table>

When operating the engine in gas mode, the gas is injected through gas admission valves into the inlet channel of each cylinder. The gas is mixed with the combustion air immediately upstream of the inlet valve in the cylinder head. Since the gas valve is timed independently of the inlet valve, scavenging of the cylinder is possible without risk that unburned gas is escaping directly from the inlet to the exhaust.

The gas piping can be either of single or double wall type. The annular space in double wall piping installations is ventilated by underpressure. The air inlet to the annular space is located at the engine. Air can be taken directly from the engine room or from a location outside the engine room, through dedicated piping.
6.3.2 External fuel gas system

The fuel gas can typically be contained as CNG, LNG at atmospheric pressure, or pressurized LNG. The design of the external fuel gas feed system may vary, but every system should provide natural gas with the correct temperature and pressure to each engine.

The gas piping can be of either single or double wall type.

**Double wall gas piping and the ventilation of the piping**

The annular space in double wall piping is ventilated artificially by underpressure created by ventilation fans. The first ventilation air inlet to the annular space is located at the engine. The ventilation air is to be taken from a location outside the engine room, through dedicated piping. The second ventilation air inlet is located at the tank room end of the double wall piping. The ventilation air is taken from both inlets and lead through annular space of double wall pipe to the enclosure of the gas valve unit. From the enclosure of the gas valve unit a dedicated ventilation pipe is connected to the ventilation fans and from fans the pipe continues to safe area. The 1.5 meter hazardous area will be formed at the ventilation air inlet and outlet and is to be taken in consideration when the ventilation piping is designed.

**Gas valve unit (10N05)**

Before the gas is supplied to the engine it passes through a Gas Valve Unit (GVU). The GVU include a gas pressure control valve and a series of block and bleed valves to ensure reliable and safe operation on gas. The unit includes a manual shut-off valve, inerting connection, filter, fuel gas pressure control valve, shut-off valves, ventilating valves, pressure transmitters/gauges, a gas temperature transmitter and control cabinets.

The filter is a full flow unit preventing impurities from entering the engine fuel gas system. The fineness of the filter is 5 μm absolute mesh size. The pressure drop over the filter is monitored and an alarm is activated when pressure drop is above permitted value due to dirty filter.

**Figure 6.3** External fuel gas system (DAAF022750B)

<table>
<thead>
<tr>
<th>System components</th>
<th>Pipe connections</th>
</tr>
</thead>
<tbody>
<tr>
<td>10N05 Gas valve unit</td>
<td>108 Gas inlet</td>
</tr>
<tr>
<td></td>
<td>708 Safety ventilation</td>
</tr>
<tr>
<td></td>
<td>726 Air inlet to double wall gas system</td>
</tr>
</tbody>
</table>
The fuel gas pressure control valve adjusts the gas feed pressure to the engine according to engine load. The pressure control valve is controlled by the engine control system. The system is designed to get the correct fuel gas pressure to the engine common rail pipe at all times.

Readings from sensors on the GVU as well as opening and closing of valves on the gas valve unit are electronically or electro-pneumatically controlled by the GVU control system. All readings from sensors and valve statuses can be read from Local Display Unit (LDU). The LDU is mounted on control cabinet of the GVU.

The two shut-off valves together with gas ventilating valve (between the shut-off valves) form a double-block-and-bleed function. The block valves in the double-block-and-bleed function effectively close off gas supply to the engine on request. The solenoid operated venting valve in the double-block-and-bleed function will relieve the pressure trapped between the block valves after closing of the block valves. The block valves V03 and V05 and inert gas valve V07 are operated as fail-to-close, i.e. they will close on current failure. Venting valves V02 and V04 are fail-to-open, they will open on current failure. There is connection for inverting the piping with nitrogen, see figure "Gas valve unit P&I diagram". The inverting of the fuel gas pipe before double block and bleed valves is done from gas storage system and gas is blown out via vent valve V02 on the GVU.

During a stop sequence of DF-engine gas operation (i.e. upon gas trip, pilot trip, stop, emergency stop or shutdown in gas operating mode, or transfer to diesel operating mode) the GVU performs a gas shut-off and ventilation sequence. Both block valves (V03 and V05) on the gas valve unit are closed and ventilation valve V04 between block valves is opened. Additionally on emergency stop ventilation valve V02 will open and on certain alarm situations the V07 will inert the gas pipe between GVU and the engine.

The gas valve unit will perform a leak test procedure before engine starts operating on gas. This is a safety precaution to ensure the tightness of valves and the proper function of components.

One GVU is required for each engine. The GVU has to be located as close the engine as possible to ensure engine response to transient conditions. The maximum length of fuel gas pipe between the GVU and the engine gas inlet is 10 m.

Inert gas and compressed air are to be dry and clean. Inert gas pressure max 1.5 MPa (15 bar). The requirements for compressed air quality are presented in chapter "Compressed air system".

Figure 6.4 Gas valve unit P&I diagram (DAAF0038982D)

<table>
<thead>
<tr>
<th>Unit components:</th>
<th>B01</th>
<th>Gas filter</th>
<th>V03</th>
<th>First block valve</th>
<th>V08</th>
<th>Shut off valve</th>
</tr>
</thead>
<tbody>
<tr>
<td>B02</td>
<td></td>
<td>Control air filter</td>
<td>V04</td>
<td>Vent valve</td>
<td>V09</td>
<td>Shut off valve</td>
</tr>
<tr>
<td>B03</td>
<td></td>
<td>Inert gas filter</td>
<td>V05</td>
<td>Second block valve</td>
<td>V10</td>
<td>Pressure regulator</td>
</tr>
</tbody>
</table>

* Valve is operated from outside of enclosure area
* Gas inlet from A1
Unit components:

| V01 | Manual shut off valve |
| V02 | Vent valve |
| V06 | Gas control valve |
| V07 | Inerting valve |
| CV-V0# | Solenoid valve |

Sensors and indicators:

| P01 | Pressure transmitter, gas inlet |
| P02 | Pressure manometer, gas inlet |
| P03 | Pressure transmitter |
| P04 | Pressure transmitter, gas outlet |
| P05 | Pressure transmitter, inert gas |
| P06 | Pressure transmitter, control air |
| P07 | Pressure transmitter |
| T01 | Temperature sensor, gas inlet |

Pipe connections:

| A1 | Gas inlet [5-10 bar(g)] |
| A1' | Optional gas inlet / Air inlet |
| B1 | Gas outlet |
| B2 | Inert gas [max 15 bar(g)] |
| D1 | Gas venting |
| X1 | Instrument air [6-8 bar(g)] |

<table>
<thead>
<tr>
<th>Size</th>
<th>Pressure class</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>DN80 / DN125</td>
<td>DN16</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>DN80 / DN125</td>
<td>DN16</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>DN80 / DN125</td>
<td>DN16</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>G1/2 ' '</td>
<td>DN16</td>
<td>DIN 2353</td>
</tr>
<tr>
<td>DN16</td>
<td></td>
<td>DIN 2353</td>
</tr>
<tr>
<td>G1/2 ' '</td>
<td></td>
<td>DIN 2353</td>
</tr>
</tbody>
</table>

Figure 6.5 Main dimensions of the GVU for W50DF (DAAF020519A)

Master fuel gas valve

For LNG carriers, IMO IGC code requires a master gas fuel valve to be installed in the fuel gas feed system. At least one master gas fuel valve is required, but it is recommended to apply one valve for each engine compartment using fuel gas to enable independent operation.

It is always recommended to have one main shut-off valve directly outside the engine room and valve room in any kind of installation.
Fuel gas venting

In certain situations during normal operation of a DF-engine, as well as due to possible faults, there is a need to safely ventilate the fuel gas piping. During a stop sequence of a DF-engine gas operation the GVU and DF-engine gas venting valves performs a ventilation sequence to relieve pressure from gas piping. Additionally in emergency stop V02 will relief pressure from gas piping upstream from the GVU.

This small amount of gas can be ventilated outside into the atmosphere, to a place where there are no sources of ignition.

Alternatively to ventilating outside into the atmosphere, other means of disposal (e.g. a suitable furnace) can also be considered. However, this kind of arrangement has to be accepted by classification society on a case by case basis.

NOTE! All breathing and ventilation pipes that may contain fuel gas must always be built sloping upwards, so that there is no possibility of fuel gas accumulating inside the piping.

In case the DF-engine is stopped in gas operating mode, the ventilation valves will open automatically and quickly reduce the gas pipe pressure to atmospheric pressure.

The pressure drop in the venting lines are to be kept at a minimum.

To prevent gas ventilation to another engine during maintenance vent lines from gas supply or GVU of different engines cannot be interconnected. However, vent lines from the same engine can be interconnected to a common header.

Purging by inert gas

Before beginning maintenance work, the fuel gas piping system has to be de-pressurized and inerted with an inert gas. If maintenance work is done after GVU and the enclosure of the GVU doesn’t need to be opened it is enough to inert gas pipe between GVU and engine. If the maintenance work is done on GVU and the enclosure of the GVU need to open the fuel gas piping upstream from GVU double-block-and-bleed-valves need to be inerted from gas storage system. The piping of the Wärtsilä 50DF engine and the gas valve unit is equipped with inerting connections for inert gas (Nitrogen).

There might be a need for inerting the fuel gas piping as a normal procedure during engine operation. This arrangement has to be considered on a case by case basis. A connection for inerting purposes has been installed on the GVU to be able to inert piping between the GVU and the engine.

Gas feed pressure

The required fuel gas feed pressure depends on the expected minimum lower heating value (LHV) of the fuel gas, as well as the pressure losses in the feed system to the engine. The LHV of the fuel gas has to be above 28 MJ/m³ at 0°C and 101.3 kPa.

- A fuel gas with a lower heating value of 28 MJ/m³ at 0°C and 101.3 kPa correspond to a required fuel gas pressure of 537 kPa (gauge pressure) at the GVU inlet at 100% engine load.
- Fuel gas LHV of 36 MJ/m³ at 0°C and 101.3 kPa correspond to 492 kPa (gauge pressure) at the GVU inlet. The required fuel gas pressure do not change at higher LHV at 100% engine load.
- For fuel gas with LHV between 28 and 36 MJ/m³ at 0°C and 101.3 kPa, the required gas pressure can be interpolated.
- The pressure losses in the gas feed system to engine has to be added to get the required gas pressure.
- A pressure drop of 120 kPa over the GVU is a typical value that can be used as guidance.
- The required gas pressure to the engine depends on the engine load. This is regulated by the GVU.
6.4 Fuel oil system

6.4.1 Internal fuel oil system

Figure 6.6 Internal fuel oil system, in-line engines (3V69E8745-1i)

System components:
- 01 Injection pump
- 02 Injection valve with pilot solenoid and nozzle
- 03 Pressure control valve
- 04 Pilot fuel filter
- 05 Pilot fuel pump
- 06 Pilot fuel safety valve
- 07 Fuel leakage collector
- 08 Water separator

Sensors and indicators:
- PT101 Fuel oil inlet pressure
- TE101 Fuel oil inlet temperature
- PT112 Pilot fuel oil inlet pressure
- TE112 Pilot fuel oil inlet temperature
- LS103 Clean fuel oil leakage level
- LS108 Dirty fuel oil leakage level
- CV124 Pilot fuel pressure control valve
- PT125 Pilot fuel pressure
- PDS129 Pilot fuel diff. pressure over filter

Pipe connections:

<table>
<thead>
<tr>
<th>Pipe connection</th>
<th>Size</th>
<th>Pressure class</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>101 Fuel inlet</td>
<td>DN32</td>
<td>PN40</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>102 Fuel outlet</td>
<td>DN32</td>
<td>PN40</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>103 Leak fuel drain, clean fuel</td>
<td>OD28</td>
<td>PN40</td>
<td>DIN 2353</td>
</tr>
<tr>
<td>104 Leak fuel drain, dirty fuel</td>
<td>OD48</td>
<td>PN40</td>
<td>DIN 2353</td>
</tr>
<tr>
<td>112 Pilot fuel inlet</td>
<td>DN15</td>
<td>PN40</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>117 Pilot fuel outlet</td>
<td>DN15</td>
<td>PN40</td>
<td>ISO 7005-1</td>
</tr>
</tbody>
</table>
Figure 6.7 Internal fuel oil system, V-engines (3V69E8746-1h)

System components:

01 Injection pump  
02 Injection valve with pilot solenoid and nozzle  
03 Pressure control valve  
04 Pilot fuel filter  
05 Pilot fuel pump  
06 Pilot fuel safety valve  
07 Fuel leakage collector  
08 Water separator

Sensors and indicators:

PT101 Fuel oil inlet pressure  
TE101 Fuel oil inlet temperature  
PT112 Pilot fuel oil inlet pressure  
TE112 Pilot fuel oil inlet temperature  
LS103A Clean fuel oil leakage level, A-bank  
LS103B Clean fuel oil leakage level, B-bank  
LS108A Dirty fuel oil leakage level, A-bank  
LS108B Dirty fuel oil leakage level, B-bank  
CV124 Pilot fuel pressure control valve  
PT125 Pilot fuel pressure  
PDS129 Pilot fuel diff.pressure over filter

Pipe connections:

<table>
<thead>
<tr>
<th>Pipe connection</th>
<th>Size</th>
<th>Pressure class</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>101 Fuel inlet</td>
<td>DN32</td>
<td>PN40</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>102 Fuel outlet</td>
<td>DN32</td>
<td>PN40</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>103 Leak fuel drain, clean fuel</td>
<td>OD28</td>
<td>PN40</td>
<td>DIN 2353</td>
</tr>
<tr>
<td>104 Leak fuel drain, dirty fuel</td>
<td>OD48</td>
<td>PN40</td>
<td>DIN 2353</td>
</tr>
<tr>
<td>112 Pilot fuel inlet</td>
<td>DN15</td>
<td>PN40</td>
<td>ISO 7005-1</td>
</tr>
<tr>
<td>117 Pilot fuel outlet</td>
<td>DN15</td>
<td>PN40</td>
<td>ISO 7005-1</td>
</tr>
</tbody>
</table>
There are separate pipe connections for the main fuel oil and pilot fuel oil. Main fuel oil can be Marine Diesel Fuel (MDF) or Heavy Fuel Oil (HFO). Pilot fuel oil is always MDF and the pilot fuel system is in operation in both gas- and diesel mode operation.

A pressure control valve in the main fuel oil return line on the engine maintains desired pressure before the injection pumps.

**Leak fuel system**

Clean leak fuel from the injection valves and the injection pumps is collected on the engine and drained by gravity through a clean leak fuel connection. The clean leak fuel can be re-used without separation. The quantity of clean leak fuel is given in chapter *Technical data*.

Other possible leak fuel and spilled water and oil is separately drained from the hot-box through dirty fuel oil connections and it shall be led to a sludge tank.

### 6.4.2 External fuel oil system

The design of the external fuel system may vary from ship to ship, but every system should provide well cleaned fuel of correct viscosity and pressure to each engine. Temperature control is required to maintain stable and correct viscosity of the fuel before the injection pumps (see *Technical data*). Sufficient circulation through every engine connected to the same circuit must be ensured in all operating conditions.

The fuel treatment system should comprise at least one settling tank and two separators. Correct dimensioning of HFO separators is of greatest importance, and therefore the recommendations of the separator manufacturer must be closely followed. Poorly centrifuged fuel is harmful to the engine and a high content of water may also damage the fuel feed system.

Injection pumps generate pressure pulses into the fuel feed and return piping. The fuel pipes between the feed unit and the engine must be properly clamped to rigid structures. The distance between the fixing points should be at close distance next to the engine. See chapter *Piping design, treatment and installation*.

A connection for compressed air should be provided before the engine, together with a drain from the fuel return line to the clean leakage fuel or overflow tank. With this arrangement it is possible to blow out fuel from the engine prior to maintenance work, to avoid spilling.

**NOTE!** In multiple engine installations, where several engines are connected to the same fuel feed circuit, it must be possible to close the fuel supply and return lines connected to the engine individually. This is a SOLAS requirement. It is further stipulated that the means of isolation shall not affect the operation of the other engines, and it shall be possible to close the fuel lines from a position that is not rendered inaccessible due to fire on any of the engines.

**Fuel heating requirements HFO**

Heating is required for:

- Bunker tanks, settling tanks, day tanks
- Pipes (trace heating)
- Separators
- Fuel feeder/booster units

To enable pumping the temperature of bunker tanks must always be maintained 5...10°C above the pour point, typically at 40...50°C. The heating coils can be designed for a temperature of 60°C.

The tank heating capacity is determined by the heat loss from the bunker tank and the desired temperature increase rate.
Example 1: A fuel oil with a viscosity of 380 cSt (A) at 50°C (B) or 80 cSt at 80°C (C) must be pre-heated to 115 - 130°C (D-E) before the fuel injection pumps, to 98°C (F) at the separator and to minimum 40°C (G) in the storage tanks. The fuel oil may not be pumpable below 36°C (H).

To obtain temperatures for intermediate viscosities, draw a line from the known viscosity/temperature point in parallel to the nearest viscosity/temperature line in the diagram.

Example 2: Known viscosity 60 cSt at 50°C (K). The following can be read along the dotted line: viscosity at 80°C = 20 cSt, temperature at fuel injection pumps 74 - 87°C, separating temperature 86°C, minimum storage tank temperature 28°C.

Fuel tanks

The fuel oil is first transferred from the bunker tanks to settling tanks for initial separation of sludge and water. After centrifuging the fuel oil is transferred to day tanks, from which fuel is supplied to the engines.
**Settling tank, HFO (1T02) and MDF (1T10)**

Separate settling tanks for HFO and MDF are recommended. To ensure sufficient time for settling (water and sediment separation), the capacity of each tank should be sufficient for min. 24 hours operation at maximum fuel consumption. The tanks should be provided with internal baffles to achieve efficient settling and have a sloped bottom for proper draining.

The temperature in HFO settling tanks should be maintained between 50°C and 70°C, which requires heating coils and insulation of the tank. Usually MDF settling tanks do not need heating or insulation, but the tank temperature should be in the range 20...40°C.

**Day tank, HFO (1T03) and MDF (1T06)**

Two day tanks for HFO are to be provided, each with a capacity sufficient for at least 8 hours operation at maximum fuel consumption. A separate tank is to be provided for MDF. The capacity of the MDF tank should ensure fuel supply for 8 hours. Settling tanks may not be used instead of day tanks.

HFO day tanks shall be provided with heating coils and insulation. It is recommended that the viscosity is kept below 140 cSt in the day tanks. Due to risk of wax formation, fuels with a viscosity lower than 50 cSt at 50°C must be kept at a temperature higher than the viscosity would require. Continuous separation is nowadays common practice, which means that the HFO day tank temperature normally remains above 90°C.

The temperature in the MDF day tank should be in the range 20...40°C. The level of the tank must ensure a positive static pressure on the suction side of the fuel feed pumps. If black-out starting with MDF from a gravity tank is foreseen, then the tank must be located at least 15 m above the engine crankshaft.

**Leak fuel tank, clean fuel (1T04)**

Clean leak fuel is drained by gravity from the engine. The fuel should be collected in a separate clean leak fuel tank, from where it can be pumped to the day tank and reused without separation. The pipes from the engine to the clean leak fuel tank should be arranged continuously sloping. The tank and the pipes must be heated and insulated, unless the installation is designed for operation on MDF only.

In HFO installations the change over valve for leak fuel (1V13) is needed to avoid mixing of the MDF and HFO clean leak fuel. When operating the engines in gas mode and MDF is circulating in the system, the clean MDF leak fuel shall be directed to the MDF clean leak fuel tank. Thereby the MDF can be pumped back to the MDF day tank (1T06).

When switching over from HFO to MDF the valve 1V13 shall direct the fuel to the HFO leak fuel tank long time enough to ensure that no HFO is entering the MDF clean leak fuel tank. Refer to section "Fuel feed system - HFO installations" for an example of the external HFO fuel oil system.

The leak fuel piping should be fully closed to prevent dirt from entering the system.

**Leak fuel tank, dirty fuel (1T07)**

In normal operation no fuel should leak out from the components of the fuel system. In connection with maintenance, or due to unforeseen leaks, fuel or water may spill in the hot box of the engine. The spilled liquids are collected and drained by gravity from the engine through the dirty fuel connection. Dirty leak fuel shall be led to a sludge tank. The tank and the pipes must be heated and insulated, unless the installation is designed for operation exclusively on MDF.

**Fuel treatment**

**Separation**

Heavy fuel (residual, and mixtures of residuals and distillates) must be cleaned in an efficient centrifugal separator before it is transferred to the day tank.
Classification rules require the separator arrangement to be redundant so that required capacity is maintained with any one unit out of operation.

All recommendations from the separator manufacturer must be closely followed.

Centrifugal disc stack separators are recommended also for installations operating on MDF only, to remove water and possible contaminants. The capacity of MDF separators should be sufficient to ensure the fuel supply at maximum fuel consumption. Would a centrifugal separator be considered too expensive for a MDF installation, then it can be accepted to use coalescing type filters instead. A coalescing filter is usually installed on the suction side of the circulation pump in the fuel feed system. The filter must have a low pressure drop to avoid pump cavitation.

**Separator mode of operation**

The best separation efficiency is achieved when also the stand-by separator is in operation all the time, and the throughput is reduced according to actual consumption.

Separators with monitoring of cleaned fuel (without gravity disc) operating on a continuous basis can handle fuels with densities exceeding 991 kg/m³ at 15°C. In this case the main and stand-by separators should be run in parallel.

When separators with gravity disc are used, then each stand-by separator should be operated in series with another separator, so that the first separator acts as a purifier and the second as clarifier. This arrangement can be used for fuels with a density of max. 991 kg/m³ at 15°C. The separators must be of the same size.

**Separation efficiency**

The term Certified Flow Rate (CFR) has been introduced to express the performance of separators according to a common standard. CFR is defined as the flow rate in l/h, 30 minutes after sludge discharge, at which the separation efficiency of the separator is 85%, when using defined test oils and test particles. CFR is defined for equivalent fuel oil viscosities of 380 cSt and 700 cSt at 50°C. More information can be found in the CEN (European Committee for Standardisation) document CWA 15375:2005 (E).

The separation efficiency is measure of the separator’s capability to remove specified test particles. The separation efficiency is defined as follows:

\[
n = 100 \times \left(1 - \frac{C_{out}}{C_{in}}\right)
\]

where:

- \( n \) = separation efficiency [%]
- \( C_{out} \) = number of test particles in cleaned test oil
- \( C_{in} \) = number of test particles in test oil before separator

**Separator unit (1N02/1N05)**

Separators are usually supplied as pre-assembled units designed by the separator manufacturer. Typically separator modules are equipped with:

- Suction strainer (1F02)
- Feed pump (1P02)
- Pre-heater (1E01)
- Sludge tank (1T05)
- Separator (1S01/1S02)
- Sludge pump
- Control cabinets including motor starters and monitoring
Figure 6.9 Fuel transfer and separating system (3V76F6626d)

Separator feed pumps (1P02)
Feed pumps should be dimensioned for the actual fuel quality and recommended throughput of the separator. The pump should be protected by a suction strainer (mesh size about 0.5 mm)
An approved system for control of the fuel feed rate to the separator is required.

Design data:

<table>
<thead>
<tr>
<th></th>
<th>HFO</th>
<th>MDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design pressure</td>
<td>0.5 MPa (5 bar)</td>
<td>0.5 MPa (5 bar)</td>
</tr>
<tr>
<td>Design temperature</td>
<td>100°C</td>
<td>50°C</td>
</tr>
<tr>
<td>Viscosity for dimensioning electric motor</td>
<td>1000 cSt</td>
<td>100 cSt</td>
</tr>
</tbody>
</table>

Separator pre-heater (1E01)
The pre-heater is dimensioned according to the feed pump capacity and a given settling tank temperature. The surface temperature in the heater must not be too high in order to avoid cracking of the fuel. The temperature control must be able to maintain the fuel temperature within ± 2°C.
Recommended fuel temperature after the heater depends on the viscosity, but it is typically 98°C for HFO and 20...40°C for MDF. The optimum operating temperature is defined by the separator manufacturer. The required minimum capacity of the heater is:
where:
\[ P = \frac{Q \times \Delta T}{1700} \]

\[ P = \text{heater capacity [kW]} \]
\[ Q = \text{capacity of the separator feed pump [l/h]} \]
\[ \Delta T = \text{temperature rise in heater [°C]} \]

For heavy fuels \( \Delta T = 48°C \) can be used, i.e. a settling tank temperature of 50°C. Fuels having a viscosity higher than 5 cSt at 50°C require pre-heating before the separator.

The heaters to be provided with safety valves and drain pipes to a leakage tank (so that the possible leakage can be detected).

**Separator (1S01/1S02)**

Based on a separation time of 23 or 23.5 h/day, the service throughput \( Q \ [l/h] \) of the separator can be estimated with the formula:

\[ Q = \frac{P \times b \times 24[h]}{\rho \times t} \]

where:
\[ P = \text{max. continuous rating of the diesel engine(s) [kW]} \]
\[ b = \text{specific fuel consumption } + 15\% \text{ safety margin [g/kWh]} \]
\[ \rho = \text{density of the fuel [kg/m}^3\text{]} \]
\[ t = \text{daily separating time for self cleaning separator [h] (usually } = 23 \text{ h or } 23.5 \text{ h)} \]

The flow rates recommended for the separator and the grade of fuel must not be exceeded. The lower the flow rate the better the separation efficiency.

Sample valves must be placed before and after the separator.

**MDF separator in HFO installations (1S02)**

A separator for MDF is recommended also for installations operating primarily on HFO. The MDF separator can be a smaller size dedicated MDF separator, or a stand-by HFO separator used for MDF.

**Sludge tank (1T05)**

The sludge tank should be located directly beneath the separators, or as close as possible below the separators, unless it is integrated in the separator unit. The sludge pipe must be continuously falling.
Fuel feed system - MDF installations

Figure 6.10 Example of fuel feed system (DAAE015150d)

System components:

- 1E04 Cooler (MDF)
- 1F05 Fine filter (MDF)
- 1F07 Suction strainer (MDF)
- 1103 Flowmeter (MDF)
- 1P03 Circulation pump (MDF)
- 1T06 Day tank (MDF)
- 1T11 Mixing tank, min. 200 l
- 1V02 Pressure control valve (MDF)

Pipe connections:

- 101 Fuel inlet
- 102 Fuel outlet
- 103 Leak fuel drain, clean fuel
- 104 Leak fuel drain, dirty fuel
- 112 Pilot fuel inlet
- 117 Pilot fuel outlet

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>Fuel inlet</td>
</tr>
<tr>
<td>102</td>
<td>Fuel outlet</td>
</tr>
<tr>
<td>103</td>
<td>Leak fuel drain, clean fuel</td>
</tr>
<tr>
<td>104</td>
<td>Leak fuel drain, dirty fuel</td>
</tr>
<tr>
<td>112</td>
<td>Pilot fuel inlet</td>
</tr>
<tr>
<td>117</td>
<td>Pilot fuel outlet</td>
</tr>
</tbody>
</table>
If the engines are to be operated on MDF only, heating of the fuel is normally not necessary. In such case it is sufficient to install the equipment listed below. Some of the equipment listed below is also to be installed in the MDF part of a HFO fuel oil system.

**Circulation pump, MDF (1P03)**

The circulation pump maintains the pressure at the injection pumps and circulates the fuel in the system. It is recommended to use a screw pump as circulation pump. A suction strainer with a fineness of 0.5 mm should be installed before each pump. There must be a positive static pressure of about 30 kPa on the suction side of the pump.

**Design data:**
- **Capacity:** 4 x the total consumption of the connected engines and the flush quantity of a possible automatic filter
- **Design pressure:** 1.6 MPa (16 bar)
- **Max. total pressure (safety valve):** 1.0 MPa (10 bar)
- **Nominal pressure:** see chapter "Technical Data"
- **Design temperature:** 50°C
- **Viscosity for dimensioning of electric motor:** 90 cSt

**Flow meter, MDF (1I03)**

If the return fuel from the engine is conducted to a return fuel tank instead of the day tank, one consumption meter is sufficient for monitoring of the fuel consumption, provided that the meter is installed in the feed line from the day tank (before the return fuel tank). A fuel oil cooler is usually required with a return fuel tank. The total resistance of the flow meter and the suction strainer must be small enough to ensure a positive static pressure of about 30 kPa on the suction side of the circulation pump.

There should be a by-pass line around the consumption meter, which opens automatically in case of excessive pressure drop.

**Fine filter, MDF (1F05)**

The fuel oil fine filter is a full flow duplex type filter with steel net. This filter must be installed as near the engine as possible.

The diameter of the pipe between the fine filter and the engine should be the same as the diameter before the filters.

**Design data:**
- **Fuel viscosity:** according to fuel specifications
- **Design temperature:** 50°C
- **Design flow:** Equal to feed/circulation pump capacity
- **Design pressure:** 1.6 MPa (16 bar)
- **Fineness:** 37 μm (absolute mesh size)

**Maximum permitted pressure drops at 14 cSt:**
- clean filter: 20 kPa (0.2 bar)
- alarm: 80 kPa (0.8 bar)

**MDF cooler (1E04)**

The fuel viscosity may not drop below the minimum value stated in Technical data. When operating on MDF, the practical consequence is that the fuel oil inlet temperature must be kept below 45°C. Very light fuel grades may require even lower temperature.

Sustained operation on MDF usually requires a fuel oil cooler. The cooler is to be installed in the return line after the engine(s). LT-water is normally used as cooling medium.
Design data:

- Heat to be dissipated: 4 kW/cyl at full load and 0.5 kW/cyl at idle
- Max. pressure drop, fuel oil: 80 kPa (0.8 bar)
- Max. pressure drop, water: 60 kPa (0.6 bar)
- Margin (heat rate, fouling): min. 15%
- Design temperature MDF/HFO installation: 50/150°C

**Return fuel tank (1T13)**

The return fuel tank shall be equipped with a vent valve needed for the vent pipe to the MDF day tank. The volume of the return fuel tank should be at least 100 l.

**Black out start**

Diesel generators serving as the main source of electrical power must be able to resume their operation in a black out situation by means of stored energy. Depending on system design and classification regulations, it may in some cases be permissible to use the emergency generator. HFO engines without engine driven fuel feed pump can reach sufficient fuel pressure to enable black out start by means of:

- A gravity tank located min. 15 m above the crankshaft
- A pneumatically driven fuel feed pump (1P11)
- An electrically driven fuel feed pump (1P11) powered by an emergency power source
Fuel feed system - HFO installations

Figure 6.11 Example of fuel oil system (HFO), multiple engine installation (DAAE010197f)

System components:

1E02 Heater (booster unit) 1P06 Circulation pump (booster unit)
1E03 Cooler (booster unit) 1P12 Circulation pump (HFO/MDF)
1E04 Cooler (MDF) 1P13 Pilot fuel feed pump (MDF)
1F03 Safety filter (HFO) 1T03 Day tank (HFO)
1F05 Fine filter (MDF) 1T06 Day tank (MDF)
1F06 Suction filter (booster unit) 1T08 De-aeration tank (booster unit)
1F07 Suction strainer (MDF) 1V01 Changeover valve
1F08 Automatic filter (booster unit) 1V02 Pressure control valve (MDF)
1I01 Flow meter (booster unit) 1V03 Pressure control valve (booster unit)
1I02 Viscosity meter (booster unit) 1V05 Overflow valve (HFO/MDF)
1N01 Feeder/booster unit 1V07 Venting valve (booster unit)
1N03 Pump and filter unit (HFO/MDF) 1V13 Change over valve for leak fuel
1P04 Fuel feed pump (booster unit)

Pipe connections:

101 Fuel inlet 104 Leak fuel drain, dirty fuel
102 Fuel outlet 112 Pilot fuel inlet
103 Leak fuel drain, clean fuel 117 Pilot fuel outlet

HFO pipes shall be properly insulated. If the viscosity of the fuel is 180 cSt/50°C or higher, the pipes must be equipped with trace heating. It shall be possible to shut off the heating of the pipes when operating on MDF (trace heating to be grouped logically).
**Starting and stopping**

In diesel mode operation, the engine can be started and stopped on HFO provided that the engine and the fuel system are pre-heated to operating temperature. The fuel must be continuously circulated also through a stopped engine in order to maintain the operating temperature. Changeover to MDF for start and stop is not required.

Prior to overhaul or shutdown of the external system the engine fuel system shall be flushed and filled with MDF.

**Changeover from HFO to MDF**

The control sequence and the equipment for changing fuel during operation must ensure a smooth change in fuel temperature and viscosity. When MDF is fed through the HFO feeder/booster unit, the volume in the system is sufficient to ensure a reasonably smooth transfer.

When there are separate circulating pumps for MDF, then the fuel change should be performed with the HFO feeder/booster unit before switching over to the MDF circulating pumps. As mentioned earlier, sustained operation on MDF usually requires a fuel oil cooler. The viscosity at the engine shall not drop below the minimum limit stated in chapter *Technical data*.

**Number of engines in the same system**

When the fuel feed unit serves Wärtsilä 50DF engines only, maximum two engines should be connected to the same fuel feed circuit, unless individual circulating pumps before each engine are installed.

Main engines and auxiliary engines should preferably have separate fuel feed units. Individual circulating pumps or other special arrangements are often required to have main engines and auxiliary engines in the same fuel feed circuit. Regardless of special arrangements it is not recommended to supply more than maximum two main engines and two auxiliary engines, or one main engine and three auxiliary engines from the same fuel feed unit.

In addition the following guidelines apply:

- Twin screw vessels with two engines should have a separate fuel feed circuit for each propeller shaft.
- Twin screw vessels with four engines should have the engines on the same shaft connected to different fuel feed circuits. One engine from each shaft can be connected to the same circuit.

**Feeder/booster unit (1N01)**

A completely assembled feeder/booster unit can be supplied. This unit comprises the following equipment:

- Two suction strainers
- Two fuel feed pumps of screw type, equipped with built-on safety valves and electric motors
- One pressure control/overflow valve
- One pressurized de-aeration tank, equipped with a level switch operated vent valve
- Two circulating pumps, same type as the fuel feed pumps
- Two heaters, steam, electric or thermal oil (one heater in operation, the other as spare)
- One automatic back-flushing filter with by-pass filter
- One viscosimeter for control of the heaters
- One control valve for steam or thermal oil heaters, a control cabinet for electric heaters
- One thermostatic valve for emergency control of the heaters
- One control cabinet including starters for pumps
- One alarm panel

The above equipment is built on a steel frame, which can be welded or bolted to its foundation in the ship. The unit has all internal wiring and piping fully assembled. All HFO pipes are insulated and provided with trace heating.
Fuel feed pump, booster unit (1P04)

The feed pump maintains the pressure in the fuel feed system. It is recommended to use a screw pump as feed pump. The capacity of the feed pump must be sufficient to prevent pressure drop during flushing of the automatic filter.

A suction strainer with a fineness of 0.5 mm should be installed before each pump. There must be a positive static pressure of about 30 kPa on the suction side of the pump.

**Design data:**

- **Capacity:** Total consumption of the connected engines added with the flush quantity of the automatic filter (1F08)
- **Design pressure:** 1.6 MPa (16 bar)
- **Max. total pressure (safety valve):** 0.7 MPa (7 bar)
- **Design temperature:** 100°C
- **Viscosity for dimensioning of electric motor:** 1000 cSt
Pressure control valve, booster unit (1V03)
The pressure control valve in the feeder/booster unit maintains the pressure in the de-aeration tank by directing the surplus flow to the suction side of the feed pump.

Design data:
- Capacity: Equal to feed pump
- Design pressure: 1.6 MPa (16 bar)
- Design temperature: 100°C
- Set-point: 0.3...0.5 MPa (3...5 bar)

Automatic filter, booster unit (1F08)
It is recommended to select an automatic filter with a manually cleaned filter in the bypass line. The automatic filter must be installed before the heater, between the feed pump and the de-aeration tank, and it should be equipped with a heating jacket. Overheating (temperature exceeding 100°C) is however to be prevented, and it must be possible to switch off the heating for operation on MDF.

Design data:
- Fuel viscosity: According to fuel specification
- Design temperature: 100°C
- Preheating: If fuel viscosity is higher than 25 cSt/100°C
- Design flow: Equal to feed pump capacity
- Design pressure: 1.6 MPa (16 bar)
- Fineness:
  - automatic filter: 35 μm (absolute mesh size)
  - by-pass filter: 35 μm (absolute mesh size)
- Maximum permitted pressure drops at 14 cSt:
  - clean filter: 20 kPa (0.2 bar)
  - alarm: 80 kPa (0.8 bar)

Flow meter, booster unit (1I01)
If a fuel consumption meter is required, it should be fitted between the feed pumps and the de-aeration tank. When it is desired to monitor the fuel consumption of individual engines in a multiple engine installation, two flow meters per engine are to be installed: one in the feed line and one in the return line of each engine. There should be a by-pass line around the consumption meter, which opens automatically in case of excessive pressure drop. If the consumption meter is provided with a prefilter, an alarm for high pressure difference across the filter is recommended.

De-aeration tank, booster unit (1T08)
It shall be equipped with a low level alarm switch and a vent valve. The vent pipe should, if possible, be led downwards, e.g. to the overflow tank. The tank must be insulated and equipped with a heating coil. The volume of the tank should be at least 100 l.

Circulation pump, booster unit (1P06)
The purpose of this pump is to circulate the fuel in the system and to maintain the required pressure at the injection pumps, which is stated in the chapter Technical data. By circulating the fuel in the system it also maintains correct viscosity, and keeps the piping and the injection pumps at operating temperature.

Design data:
- Capacity:
  - without circulation pumps (1P12): 4 x the total consumption of the connected engines
  - with circulation pumps (1P12): 15% more than total capacity of all circulation pumps
Design data:
Design pressure: 1.6 MPa (16 bar)
Max. total pressure (safety valve): 1.0 MPa (10 bar)
Design temperature: 150°C
Viscosity for dimensioning of electric motor: 500 cSt

Heater, booster unit (1E02)
The heater must be able to maintain a fuel viscosity of 14 cSt at maximum fuel consumption, with fuel of the specified grade and a given day tank temperature (required viscosity at injection pumps stated in Technical data). When operating on high viscosity fuels, the fuel temperature at the engine inlet may not exceed 135°C however.
The power of the heater is to be controlled by a viscosimeter. The set-point of the viscosimeter shall be somewhat lower than the required viscosity at the injection pumps to compensate for heat losses in the pipes. A thermostat should be fitted as a backup to the viscosity control.
To avoid cracking of the fuel the surface temperature in the heater must not be too high. The heat transfer rate in relation to the surface area must not exceed 1.5 W/cm².
The required heater capacity can be estimated with the following formula:

\[ P = \frac{Q \times \Delta T}{1700} \]

where:
- \( P \) = heater capacity (kW)
- \( Q \) = total fuel consumption at full output + 15% margin [l/h]
- \( \Delta T \) = temperature rise in heater [°C]

Viscosimeter, booster unit (1I02)
The heater is to be controlled by a viscosimeter. The viscosimeter should be of a design that can withstand the pressure peaks caused by the injection pumps of the diesel engine.

Pump and filter unit (1N03)
When more than two engine are connected to the same feeder/booster unit, a circulation pump (1P12) must be installed before each engine. The circulation pump (1P12) and the safety filter (1F03) can be combined in a pump and filter unit (1N03). A safety filter is always required.
There must be a by-pass line over the pump to permit circulation of fuel through the engine also in case the pump is stopped. The diameter of the pipe between the filter and the engine should be the same size as between the feeder/booster unit and the pump and filter unit.

Circulation pump (1P12)
The purpose of the circulation pump is to ensure equal circulation through all engines. With a common circulation pump for several engines, the fuel flow will be divided according to the pressure distribution in the system (which also tends to change over time) and the control valve on the engine has a very flat pressure versus flow curve.
In installations where MDF is fed directly from the MDF tank (1T06) to the circulation pump, a suction strainer (1F07) with a fineness of 0.5 mm shall be installed to protect the circulation pump. The suction strainer can be common for all circulation pumps.
Design data:
Capacity: 4 x the fuel consumption of the engine
Design pressure: 1.6 MPa (16 bar)
Max. total pressure (safety valve): 1.0 MPa (10 bar)
Design temperature: 150°C
Pressure for dimensioning of electric motor (ΔP):
- if MDF is fed directly from day tank: 0.7 MPa (7 bar)
- if all fuel is fed through feeder/booster unit: 0.3 MPa (3 bar)
Viscosity for dimensioning of electric motor: 500 cSt

Safety filter (1F03)
The safety filter is a full flow duplex type filter with steel net. The filter should be equipped with a heating jacket. The safety filter or pump and filter unit shall be installed as close as possible to the engine.

Design data:
Fuel viscosity: according to fuel specification
Design temperature: 150°C
Design flow: Equal to circulation pump capacity
Design pressure: 1.6 MPa (16 bar)
Filter fineness: 37 μm (absolute mesh size)
Maximum permitted pressure drops at 14 cSt:
- clean filter: 20 kPa (0.2 bar)
- alarm: 80 kPa (0.8 bar)

Overflow valve, HFO (1V05)
When several engines are connected to the same feeder/booster unit an overflow valve is needed between the feed line and the return line. The overflow valve limits the maximum pressure in the feed line, when the fuel lines to a parallel engine are closed for maintenance purposes.
The overflow valve should be dimensioned to secure a stable pressure over the whole operating range.

Design data:
Capacity: Equal to circulation pump (1P06)
Design pressure: 1.6 MPa (16 bar)
Design temperature: 150°C

Pilot fuel feed pump, MDF (1P13)
The pilot fuel feed pump is needed in HFO installations. The pump feed the engine with MDF fuel to the pilot fuel system. No HFO is allowed to enter the pilot fuel system.
It is recommended to use a screw pump as circulation pump. A suction strainer with a fineness of 0.5 mm should be installed before each pump. There must be a positive static pressure of about 30 kPa on the suction side of the pump.

Design data:
Capacity: 1 m³/h per engine
Design pressure: 1.6 MPa (16 bar)
Max. total pressure (safety valve): 1.0 MPa (10 bar)
Nominal pressure: see chapter "Technical Data"
Design temperature: 50°C
Viscosity for dimensioning of electric motor: 90 cSt
Flushing

The external piping system must be thoroughly flushed before the engines are connected and fuel is circulated through the engines. The piping system must have provisions for installation of a temporary flushing filter. The fuel pipes at the engine (connections 101 and 102) are disconnected and the supply and return lines are connected with a temporary pipe or hose on the installation side. All filter inserts are removed, except in the flushing filter of course. The automatic filter and the viscosimeter should be bypassed to prevent damage. The fineness of the flushing filter should be 35 µm or finer.