WÄRTSILÄ

WÄRTSILÄ Environmental Technologies

# Environmental

PRODUCT GUIDE

# Introduction

This Product Guide provides data and system proposals for the early design phase of marine installations. For contracted projects specific instructions for planning the installation are always delivered. Any data and information herein is subject to revision without notice. This 1/2017 issue replaces all previous issues of the Wärtsilä Environmental Systems Product Guides.

| Issue | Published | Updates |
|---|---|---|
| 1/2017 | 26.4.2017 | NOx and SOx emissions control chapters updated.<br>Emission monitoring system chapter updated.<br>Other general updates. |

Wärtsilä, Marine Solutions

Vaasa, April 2017

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# 1. International Maritime Organisation

The International Maritime Organisation (IMO) is an agency of the United Nations which has been formed to promote maritime safety. The increasing concern of air pollution has resulted in the introduction of exhaust gas emission controls to the marine industry; IMO ship pollution rules are contained in the "International Convention on the Prevention of Pollution from Ships", which represents the first set of regulations on marine exhaust emissions, known as MARPOL 73/78, 1973 as modified by the Protocol of 1978. Marpol 73/78 is the most important international marine environmental convention. It was designed to minimise pollution of the seas, including dumping, and oil and exhaust pollution. Its stated object is to preserve the marine environment through the complete elimination of pollution by oil and other harmful substances and the minimization of accidental discharge of such substances.

The original MARPOL Convention was signed on 17 February 1973, but did not come into force. The current Convention is a combination of 1973 Convention and the 1978 Protocol. It entered into force on 2 October 1983. Marpol contains 6 annexes, concerned with preventing different forms of marine pollution from ships:

Annex I - Oil

Annex II - Noxious Liquid Substances carried in Bulk

Annex III - Harmful Substances carried in Packaged Form

Annex IV - Sewage

Annex V - Garbage

Annex VI - Air Pollution

## 1.1 MARPOL Annex VI - Air Pollution

The MARPOL 73/78 Annex VI entered into force 19 May 2005. The Annex VI sets limits on Nitrogen Oxides, Sulphur Oxides and Volatile Organic Compounds emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances.

### 1.1.1 Nitrogen Oxides, $NO_x$ Emissions

The MARPOL 73/78 Annex VI regulation 13, Nitrogen Oxides, applies to diesel engines over 130 kW installed on ships built (defined as date of keel laying or similar stage of construction) on or after January 1, 2000 and different levels (Tiers) of NOx control apply based on the ship construction date. The $NO_x$ emissions limit is expressed as dependent on engine speed. IMO has developed a detailed $NO_x$ Technical Code which regulates the enforcement of these rules.

#### EIAPP Certification

An EIAPP (Engine International Air Pollution Prevention) Certificate is issued for each engine showing that the engine complies with the $NO_x$ regulations set by the IMO.

When testing the engine for $NO_x$ emissions, the reference fuel is Marine Diesel Oil (distillate) and the test is performed according to ISO 8178 test cycles. Subsequently, the $NO_x$ value has to be calculated using different weighting factors for different loads that have been corrected to ISO 8178 conditions. The used ISO 8178 test cycles are presented in the following table.

**Table 1-1 ISO 8178 test cycles**

| | | | | | | |
|---|---|---|---|---|---|---|
| D2: Constant-speed auxiliary engine application | Speed (%) | 100 | 100 | 100 | 100 | 100 |
| | Power (%) | 100 | 75 | 50 | 25 | 10 |
| | Weighting factor | 0.05 | 0.25 | 0.3 | 0.3 | 0.1 |

| E2: Constant-speed main propulsion application including diesel-electric drive and all controllable-pitch propeller installations | Speed (%) | 100 | 100 | 100 | 100 |
|---|---|---|---|---|---|
| | Power (%) | 100 | 75 | 50 | 25 |
| | Weighting factor | 0.2 | 0.5 | 0.15 | 0.15 |

| E3: Propeller-law operated main and propeller-law operated auxiliary engine application (Fixed-pitch propeller) | Speed (%) | 100 | 91 | 80 | 63 |
|---|---|---|---|---|---|
| | Power (%) | 100 | 75 | 50 | 25 |
| | Weighting factor | 0.2 | 0.5 | 0.15 | 0.15 |

| C1: Variable -speed and -load auxiliary engine application | Speed | Rated | | | | Intermediate | | | Idle |
|---|---|---|---|---|---|---|---|---|---|
| | Torque (%) | 100 | 75 | 50 | 10 | 100 | 75 | 50 | 0 |
| | Weighting factor | 0.15 | 0.15 | 0.15 | 0.1 | 0.1 | 0.1 | 0.1 | 0.15 |

### Engine family/group

As engine manufacturers have a variety of engines ranging in size and application, the $NO_x$ Technical Code allows the organising of engines into families or groups. By definition, an engine family is a manufacturer's grouping, which through their design, are expected to have similar exhaust emissions characteristics i.e., their basic design parameters are common. When testing an engine family, the engine which is expected to develop the worst emissions is selected for testing. The engine family is represented by the parent engine, and the certification emission testing is only necessary for the parent engine. Further engines can be certified by checking document, component, setting etc., which have to show correspondence with those of the parent engine.

### Technical file

According to the IMO regulations, a Technical File shall be made for each engine. The Technical File contains information about the components affecting $NO_x$ emissions, and each critical component is marked with a special IMO number. The allowable setting values and parameters for running the engine are also specified in the Technical File. The EIAPP certificate is part of the IAPP (International Air Pollution Prevention) Certificate for the whole ship.

## IMO NOx emission standards

The first IMO Tier 1 NOx emission standard entered into force in 2005 and applies to marine diesel engines installed in ships constructed on or after 1.1.2000 and prior to 1.1.2011.

The Marpol Annex VI and the $NO_x$ Technical Code were later undertaken a review with the intention to further reduce emissions from ships and a final adoption for IMO Tier 2 and Tier 3 standards were taken in October 2008.

The IMO Tier 2 NOx standard entered into force 1.1.2011 and replaced the IMO Tier 1 NOx emission standard globally. The Tier 2 NOx standard applies for marine diesel engines installed in ships constructed on or after 1.1.2011.

The IMO Tier 3 $NO_x$ emission standard effective date started from year 2016. The Tier 3 standard apply in designated emission control areas (ECA). The ECAs are to be defined by the IMO. The North American ECA and the US Caribbean Sea ECA were defined and came effective for marine diesel engines installed in ships constructed on or after 1.1.2016. The North Sea and Baltic Sea have also been defined as NOx ECA and will enter into force for marine diesel engines installed in ships constructed on or after 1.1.2021. For other ECAs which might be designated in the future for Tier 3 NOx control, the entry into force date would apply to ships constructed on or after the date of adoption by the MEPC of such an ECA, or a later date as may be specified separately. The IMO Tier 2 $NO_x$ emission standard will apply outside the Tier 3 designated areas.

The $NO_x$ emissions limits in the IMO standards are expressed as dependent on engine speed. These are shown in the following figure.

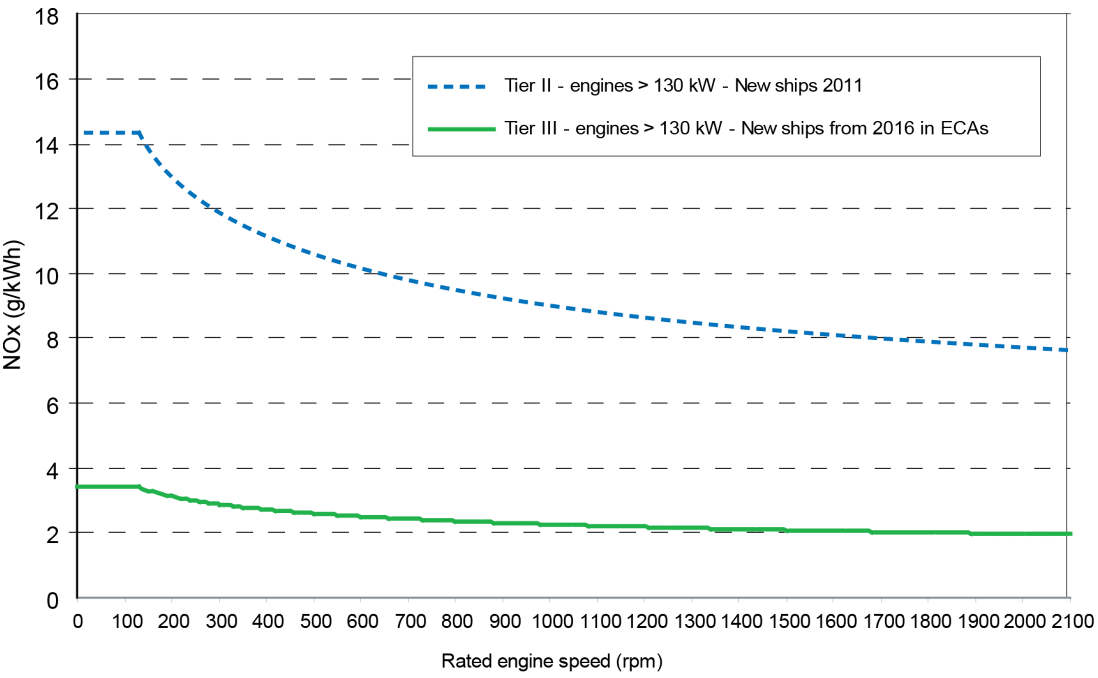


**Fig 1-1 IMO $NO_x$ emission limits**

## IMO Tier 2 $NO_x$ emission standard (new ships 2011)

The IMO Tier 2 $NO_x$ emission standard entered into force in 1.1.2011 and applies globally for new marine diesel engines > 130 kW installed in ships which keel laying date is 1.1.2011 or later.

**The IMO Tier 2 $NO_x$ limit is defined as follows:**

$NO_x$ [g/kWh] $= 44 \times rpm^{-0.23}$ when $130 < rpm < 2000$

The $NO_x$ level is a weighted average of $NO_x$ emissions at different loads, and the test cycle is based on the engine operating profile according to ISO 8178 test cycles. The IMO Tier 2 NOx level is met by engine internal methods.

## IMO Tier 3 $NO_x$ emission standard (new ships from 2016 in ECAs)

The IMO Tier 3 $NO_x$ emission standard entered into force in 1.1.2016. It applies for new marine diesel engines > 130 kW installed in ships which keel laying date is 1.1.2016 or later when operating inside the North American ECA and the US Caribbean Sea ECA and for new marine diesel engines > 130 kW installed in ships which keel laying date is 1.1.2021 or later inside North Sea and Baltic Sea ECA.

**The IMO Tier 3 $NO_x$ limit is defined as follows:**

$NO_x$ [g/kWh] $= 9 \times rpm^{-0.2}$ when $130 < rpm < 2000$

The IMO Tier 3 $NO_x$ emission level corresponds to an 80% reduction from the IMO Tier 1 NOx emission standard. The reduction can be reached by applying a secondary exhaust gas emission control system. A Selective Catalytic Reduction (SCR) system is an efficient way for diesel engines to reach the NOx reduction needed for the IMO Tier 3 standard.

If the Wärtsilä NOx Reducer SCR system is installed together with the engine, the engine + SCR installation complies with the maximum permissible NOx emission according to the IMO Tier 3 NOx emission standard and the Tier 3 EIAPP certificate will be delivered for the complete installation.

Refer to chapter 2 in this guide for information about the Wärtsilä NOx Reducer SCR system.

**NOTE**

The Dual Fuel engines fulfil the IMO Tier 3 NOx emission level as standard in gas mode operation without the need of a secondary exhaust gas emission control system.

## 1.1.2 Sulphur Oxides, $SO_x$ emissions

Marpol Annex VI has set a maximum global fuel sulphur limit of currently 3,5% (from 1.1.2012) in weight for any fuel used on board a ship. Annex VI also contains provisions allowing for special SOx Emission Control Areas (SECA) to be established with more stringent controls on sulphur emissions. In a SECA, which currently comprises the Baltic Sea, the North Sea, the English Channel, the US Caribbean Sea and the area outside North America (200 nautical miles), the sulphur content of fuel oil used onboard a ship must currently not exceed 0,1 % in weight.

The Marpol Annex VI has undertaken a review with the intention to further reduce emissions from ships. The current and upcoming limits for fuel oil sulphur contents are presented in the following table.

**Table 1-2 Fuel sulphur caps**

| Fuel sulphur cap | Area | Date of implementation |
|---|---|---|
| Max 3.5% S in fuel | Globally | 1 January 2012 |
| Max. 0.1% S in fuel | SECA Areas | 1 January 2015 |
| Max. 0.5% S in fuel | Globally | 1 January 2020 |

Abatement technologies including scrubbers are allowed as alternatives to low sulphur fuels. The exhaust gas system can be applied to reduce the total emissions of sulphur oxides from ships, including both auxiliary and main propulsion engines, calculated as the total weight of sulphur dioxide emissions.

Refer to chapter 3 in this guide for information about Wärtsilä SOx Scrubber systems.

## 1.2 Standards for Ballast Water Management

Ballast water regulations are introduced to prevent the spread of invasive species, which have been transported with the ballast water in ships.

### 1.2.1 IMO Regulation

The Ballast Water Convention (BWC) was introduced by the International Maritime Organisation in 2004 to address the Control and Management of Ships' Ballast Water and Sediments, and applies to all sea going ships greater than 400gt that use ballast water. The BWC will be considered ratified when a minimum of 30 IMO member states representing no less than 35% of world gross registered tonnage sign up to the convention. The BWC ultimately requires ships to fit a ballast water treatment system conforming to Regulation D2 discharge performance standard. As an interim measure the BWC requires ships to manage their ballast water in accordance with Regulation D1.

In the convention, the IMO has specified ballast water performance standards (D2 Discharge Standard) as follows:

| Organism Size / Indicator Microbes | Discharge Regulation |
|---|---|
| size ≥ 50 micrometres in minimum dimension | < 10 viable organisms per $m^3$ |
| 10 ≤ size < 50 micrometres in minimum dimension | < 10 viable organisms per milliliter |
| size < 10 micrometres in minimum dimension | No limit |
| Toxicogenic Vibrio cholera (O1 and O139) | < 1 cfu * / 100 millilitres, or<br>< 1 cfu * / gram (wet weight) zooplankton samples |
| Escherichia coli | < 250 cfu * / 100 millilitres |
| Intestinal Enterococci | < 100 cfu / 100 millilitres |

### 1.2.2 United States Coast Guard

The United States Coast Guard have set their own rules for Ballast Water Management. The USCG final rule addressing “Standards for Living Organisms in Ship's Ballast Water Discharged in US Water” (BWDS) was published in the US Federal Register on 23 March 2012. The new USCG Regulations (33 CFR Part 151 and 46 CFR Part 162) entered into force on 21 June 2012 and apply to all new ships constructed on or after December 2013 as well as to existing ships from 2014 onwards. The rule performance standard is numerically equal to the IMO D2 standard. The US Coast Guard Rule affect vessels, US and foreign, which operate in the US waters, are bound for ports or places in the US, and are equipped with ballast tanks. These vessels are required to install and operate a USCG approved BWMS before discharging ballast water into US waters. As an interim measure, vessel with Alternate management system (AMS) accepted system on board are allowed.

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# 2. NOx Emissions Control

## 2.1 The Wärtsilä NOx Reducer (NOR)

### 2.1.1 Solution for meeting NOx reduction requirements

The Wärtsilä NOx Reducer (NOR) system is an emission after-treatment system compliant with various NOx emission reduction needs, such as IMO Tier 3. It can also be optimised for Norwegian NOx fund operation or other NOx emission limits as per customer requirements.

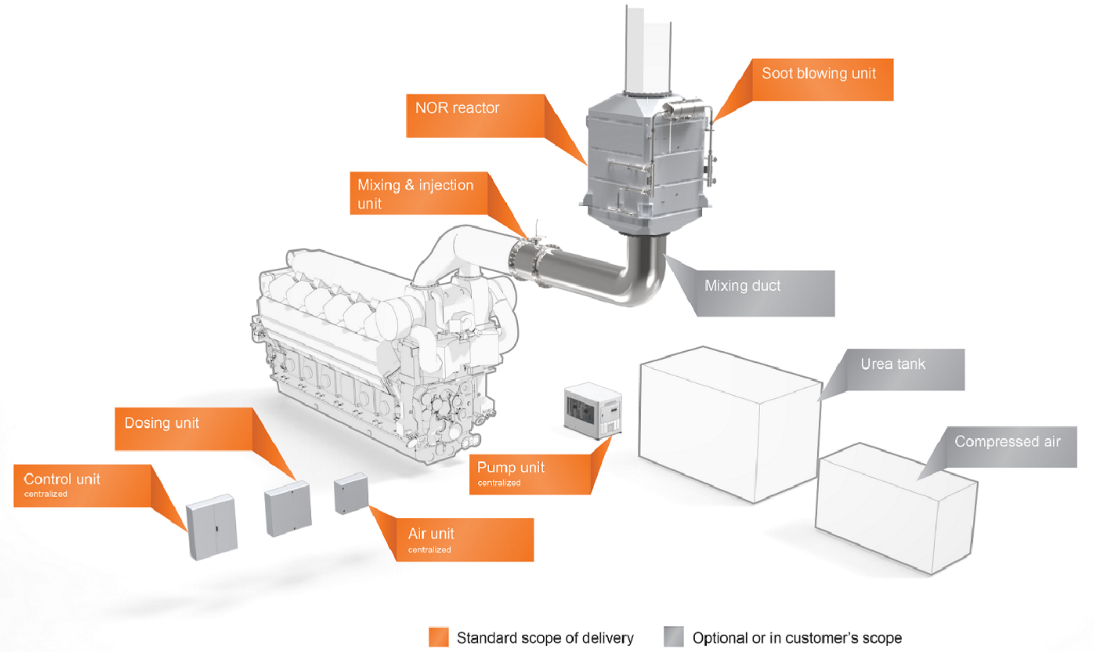


**Fig 2-1 NOR system overview**

### 2.1.2 Selective catalytic reduction

The Wärtsilä NOx Reducer is based on the Selective Catalytic Reduction (SCR) technology for Nitrogen Oxide ($NO_x$) reduction. The SCR system reduces the level of nitrogen oxide in the exhaust gas from the engine by means of catalyst elements and a reducing agent. In the process a reducing agent of a urea water solution is added to the exhaust gas stream. The water in the urea solution is evaporated as the solution is injected into the hot exhaust gas. The high temperature also induces thermal decomposition of the urea ($(NH_2)2CO$) into ammonia ($NH_3$) and carbon dioxide ($CO_2$):

$(NH_2)2CO + H_2O \rightarrow 2NH_3 + CO_2$

Exhaust gas NOx emissions are thereafter transformed into molecular nitrogen ($N_2$) and water ($H_2O$), as they react with the ammonia at a catalytic surface:

$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6H_2O$

$6NO_2 + 8NH_3 \rightarrow 7N_2 + 12H_2O$.

The catalytic elements are located inside a metallic reactor structure located in the exhaust gas line. The end products of the reaction are pure nitrogen and water, i.e. major constituents of ambient air. No liquid or solid by-products are produced.

### 2.1.3 System overview

The Wärtsilä NOx Reducer is as standard available in several different sizes and shapes to cover, in a flexible way, the 4-stroke engine portfolio for both MDF and HFO installations.

The main components that are included in the standard scope of supply are:

- Reactor housing
- Catalyst elements
- Soot blowing unit
- Urea injection and mixing unit
- Urea dosing unit
- Control and automation unit
- Urea pump unit
- Air unit
- Humidity sensor

The standard scope of supply may also be extended with the following:

- NOx analyser
- NOx sensor system
- Mixing duct
- Compressor station (compressed air for urea injection and soot blowing system)

Other components that are essential for the system are:

- Urea tank
- Insulation
- Expansion bellows incl. counter flanges
- Support for ducting and reactor
- Piping and valves between the NOR units

A pump unit transfers urea from the storage tank to the dosing unit, which regulates the flow of urea solution to the injection system based on the operation of the engine and humidity of ambient air. The humidity sensor based urea control adjustment ensures Tier 3 emission compliance in all ambient conditions. The dosing unit also controls the compressed air flow to the urea injector.

The urea injector sprays the urea solution into the exhaust gas duct. After the urea injection, the exhaust gas flows through the mixing pipe to the reactor, where the NOx reduction take place over catalyst elements. The reactor is equipped with a soot blowing system for keeping the catalyst elements clean. Figure 2-2 presents an overview of the system.

The components are described more in detail in following chapters. Guidelines and recommendations for the components not included in the Wärtsilä supply can be found in chapter 2.1.6.

The SCR process is shown in the following figure, *Overview of the SCR system*.

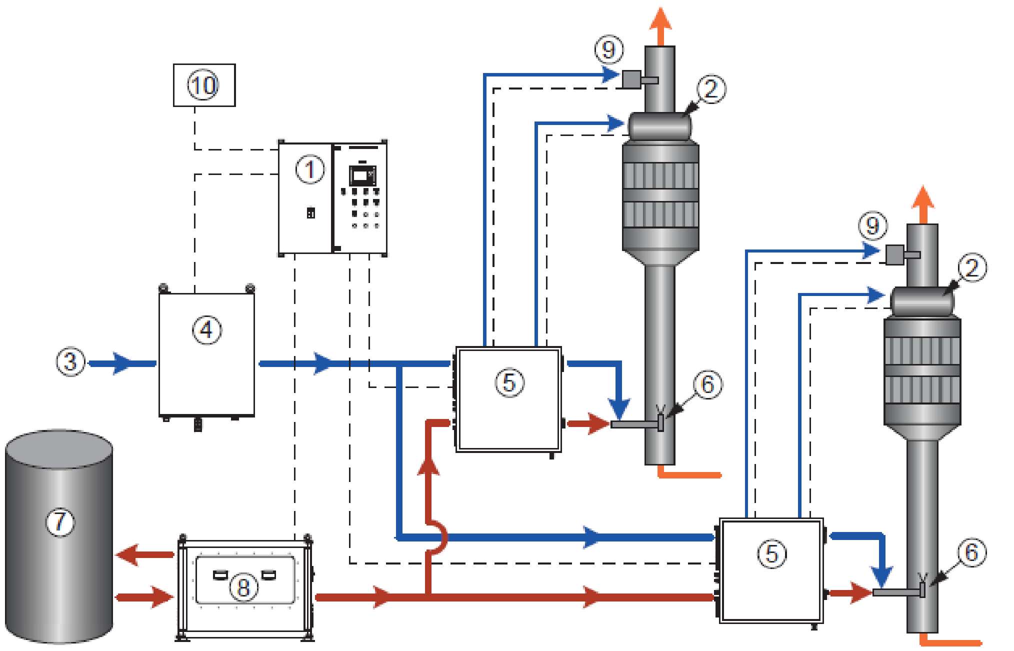


**Fig 2-2** **Overview of the SCR system**

| System components | | | |
|---|---|---|---|
| 1 | Control cabinet | 6 | Injector |
| 2 | Soot blowing | 7 | Urea tank |
| 3 | Compressed air supply | 8 | Pump unit |
| 4 | Air unit | 9 | NOx sensor (optional) |
| 5 | Dosing unit | 10 | Humidity sensor |

## SCR Reactor

One SCR Reactor is installed per engine and exhaust gas pipe. The reactor is a steel casing consisting of an inlet and an outlet cone, catalyst layers, a steel structure for supporting the catalyst layers and a soot blowing unit. Compressed air connections for soot blowing are installed at each catalyst layer. The reactor is equipped with a differential pressure transmitter for monitoring the condition of the catalyst elements as well as upstream and downstream temperature transmitters for monitoring the exhaust gas temperature. The reactor is also equipped with manhole(s) for the inspection of ducts and maintenance doors for service/replacement of the catalytic elements.

The standard reactor is designed in a flexible way for the initial loading of two or three catalyst layers depending on the ship structure, and it can be installed either vertically or horizontally onboard the ship. The following figures shows the two different standardized reactor shapes and the needed maintenance space onboard. Examples of the standard reactors main dimensions are shown in table 2-1 and 2-2 (the reactor dimensions are presented with 150 mm insulation). Should there be any specific space restrictions, the SCR reactor and mixing duct design can be tailor made upon request. The SCR reactor can also be integrated with silencer and used together with Wärtsilä Compact Silencer System (CSS) in order to further optimise the use of space onboard. For exhaust gas noise attenuation the following options for Wärtsilä SCR system are available:

Compact NOR: SCR reactor with integrated silencer (absorbtive type)

Mixing silencer: Urea injection and mixing unit with integrated silencer (reactive type)

Examples of dimensions of the Compact NOR and Mixing silencer are presented in table 2-3. Following figure shows an overview of the Compact NOR and Mixing duct silencer arrangement.

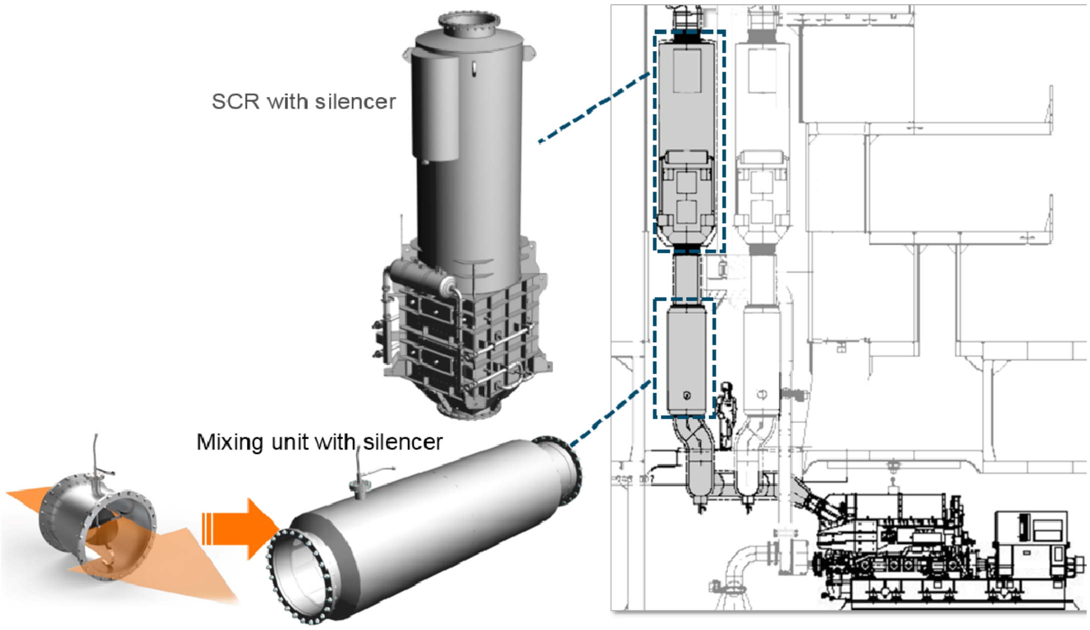


**Fig 2-3** **Compact NOR and Mixing duct silencer**

The following figure presents the main aspects to be considered when combining the SCR reactor with other exhaust gas equipment in the exhaust gas line. The figure shows how silencing features can be combined as a part of the SCR reactor (Compact NOR) and the mixing duct (mixing silencer including urea injection unit) to save space.

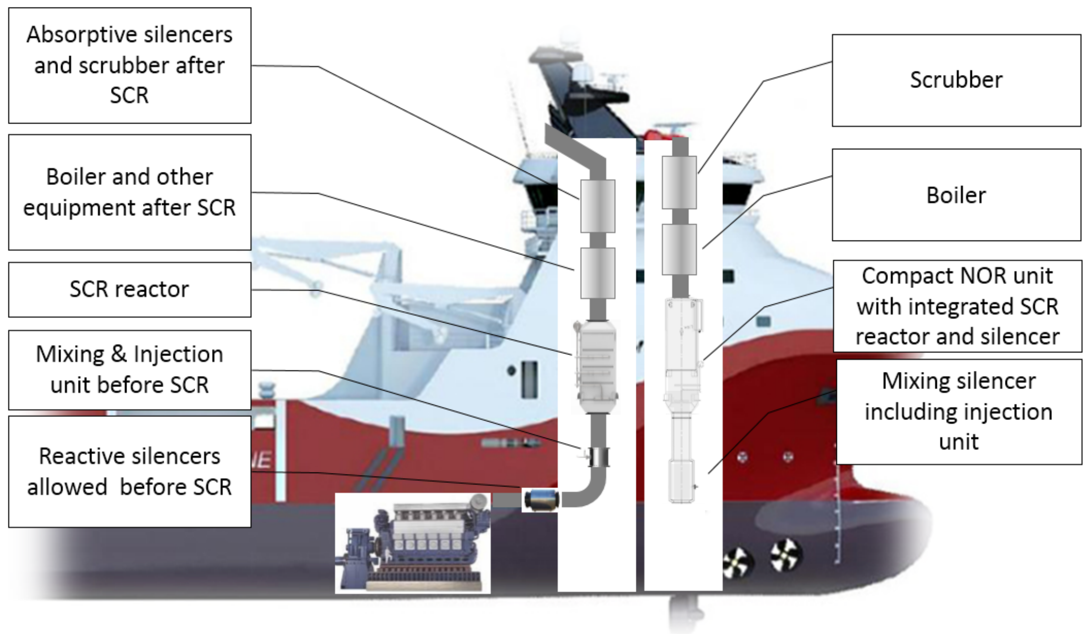


**Fig 2-4** **Wärtsilä NOx Reducer arrangement**

The standard reactor is dimensioned for a NOx reduction level from the IMO Tier 2 to the IMO Tier 3 NOx level and can be used for both MDF and HFO installations. For installations with other NOx reduction requirements, the SCR reactor and mixing duct design can be tailor made upon request.

## Catalyst elements

The catalyst elements are located in steel frames inside the reactor. The brick-shaped catalyst elements have a honeycomb structure to increase the catalytic surface. Vanadium pentoxide ($V_2O_5$) is used as the catalytic material. Althought the catalyst elements are cleaned by regular soot blowing to prevent deposit formation and clogging, the efficiency of the catalyst decreases with time, mainly due to thermal load and small amounts of catalyst poisons. When the catalytic activity has decreased too much, the catalyst elements must be changed. The typical lifetime is 4 - 6 years.

### Soot blowing system

Each reactor is provided with an automatically operated soot blowing unit. The soot blowing system removes soot deposits from the catalyst elements, to prevent clogging of the elements installed. The catalyst elements are cleaned by blowing air into the reactor through large rapid reaction solenoid valves. The soot blowing system also comprises a pressure vessel, a relief valve and a pressure transmitter. The air supply has to be in operation at all times while the engines are running, to prevent reduced efficiency.

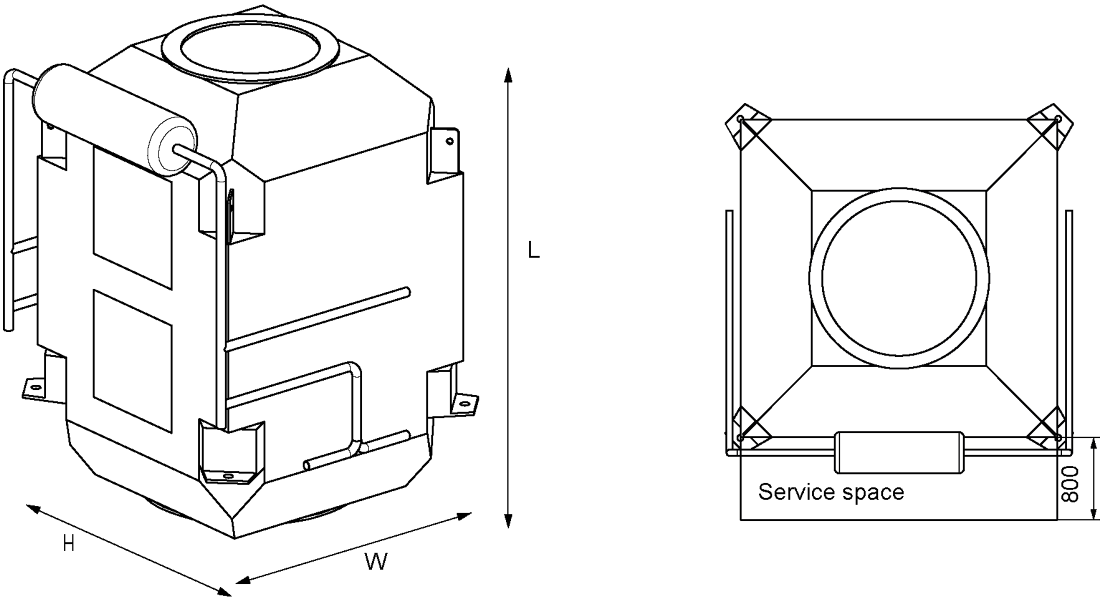


**Fig 2-5 Reactor, 2 catalyst layers**

**Table 2-1 Example of typical dimensions, 2 catalyst layers reactor**

| Engine size | MDF Fuel | | | HFO Fuel | | |
|---|---|---|---|---|---|---|
| Engine type | L (mm) (incl. cones) | H (mm) (incl. 150 mm insulation) | W (mm) (incl. 150 mm insulation) | L (mm) (incl. cones) | H (mm) (incl. 150 mm insulation) | W (mm) (incl. 150 mm insulation) |
| Wärtsilä 6L20 | 2350 | 1160 | 1160 | 2600 | 1480 | 1480 |
| Wärtsilä 8L20 | 2500 | 1320 | 1160 | 2700 | 1640 | 1640 |
| Wärtsilä 6L32 | 3000 | 1800 | 1640 | 3200 | 1960 | 2120 |
| Wärtsilä 8L32 | 3000 | 1960 | 1800 | 3200 | 2280 | 2280 |
| Wärtsilä 9L32 | 3000 | 1960 | 1960 | 3300 | 2440 | 2280 |
| Wärtsilä 8L46F | 3300 | 2440 | 2440 | 3600 | 2920 | 2920 |
| Wärtsilä 12V46F | 3600 | 2920 | 2920 | 3900 | 3560 | 3560 |

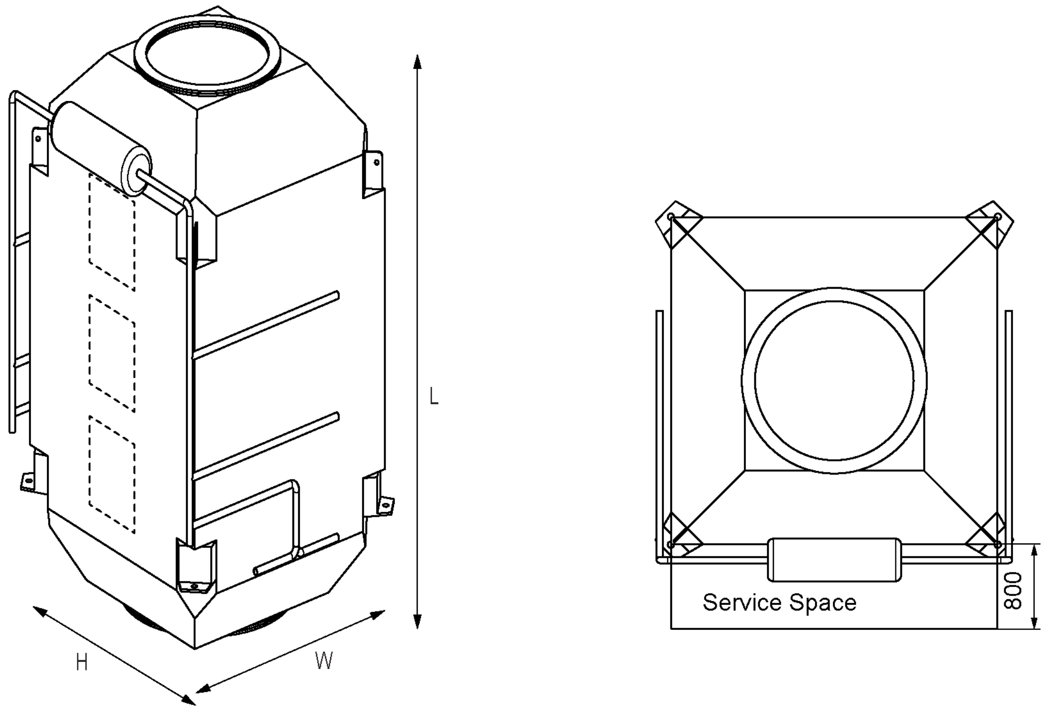


**Fig 2-6** **Reactor, 3 catalyst layers**

**Table 2-2** **Example of typical dimensions, 3 catalyst layers reactor**

| **Engine size** | **MDF Fuel** | | | **HFO Fuel** | | |
|---|---|---|---|---|---|---|
| Engine Type | L (mm) (incl. cones) | H (mm) (incl. 150 mm insulation) | W (mm) (incl. 150 mm insulation) | L (mm) (incl. cones) | H (mm) (incl. 150 mm insulation) | W (mm) (incl. 150 mm insulation) |
| Wärtsilä 6L20 | 3150 | 1160 | 1000 | 3300 | 1320 | 1160 |
| Wärtsilä 8L20 | 3150 | 1160 | 1160 | 3400 | 1480 | 1320 |
| Wärtsilä 6L32 | 3500 | 1640 | 1480 | 4000 | 1800 | 1640 |
| Wärtsilä 8L32 | 3500 | 1640 | 1640 | 4000 | 1960 | 1800 |
| Wärtsilä 9L32 | 4000 | 1800 | 1800 | 4200 | 2120 | 1960 |
| Wärtsilä 8L46F | 4200 | 2280 | 2120 | 4300 | 2600 | 2440 |
| Wärtsilä 12V46F | 4400 | 2600 | 2600 | 4600 | 2920 | 2920 |

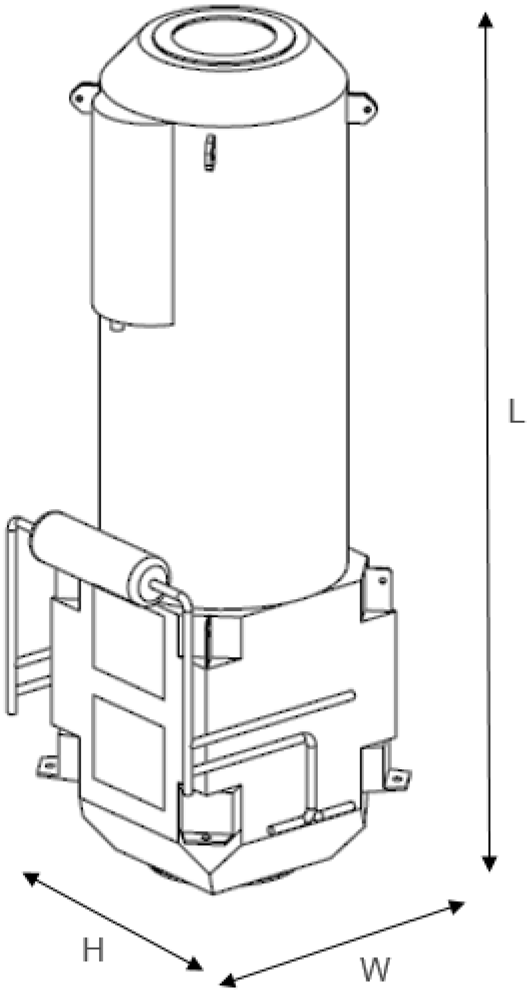


**Fig 2-7** **Compact NOR, Reactor with integrated silencer**

**Table 2-3** **Example of typical dimensions, Compact NOR**

| Engine size | MDF Fuel | | | HFO Fuel | | |
|---|---|---|---|---|---|---|
| Engine type | L (mm) (incl. cones) | H (mm) (incl. 150 mm insulation) | W (mm) (incl. 150 mm insulation) | L (mm) (incl. cones) | H (mm) (incl. 150 mm insulation) | W (mm) (incl. 150 mm insulation) |
| Wärtsilä 6L20 | 5080 | 1160 | 1160 | 5230 | 1480 | 1480 |
| Wärtsilä 8L20 | 5130 | 1320 | 1160 | 5230 | 1640 | 1640 |
| Wärtsilä 6L32 | 6300 | 1800 | 1640 | 6400 | 1960 | 2120 |
| Wärtsilä 8L32 | 6500 | 1960 | 1800 | 6600 | 2280 | 2280 |
| Wärtsilä 9L32 | 6500 | 1960 | 1960 | 6700 | 2440 | 2280 |
| Wärtsilä 8L46F | 8650 | 2440 | 2440 | 8750 | 2920 | 2920 |
| Wärtsilä 12V46F | 10050 | 2920 | 2920 | 10150 | 3560 | 3560 |

## Urea pump unit

The urea pump unit transfers urea from the tank to the dosing system and maintains a sufficient pressure in the urea lines. The unit has full redundancy so that failure of one pump will not stop the SCR system operation. The main components of the unit are two electrically driven screw pumps, which are mounted on a frame together with the necessary accessories. Suction filters protect the pumps and the downstream equipment from impurities. Non-return valves for preventing backflow of the urea are installed after each pump. For pump protection, the unit also provides stator temperature monitoring as well as suction and discharge pressure monitoring. The design includes an overflow valve, which protects the pump and other parts of the system from excessive pressure. Excess urea returns to the storage tank through an overflow line.The pump unit is connected to the SCR control unit via a connection box. The connection box includes safety switches for the pumps. One pump unit can be used for several SCR reactors.

## Urea dosing unit

The dosing unit defines the correct urea dosing rate for the injection system and adjusts the urea flow accordingly by an automatic control valve. The dosing unit also supplies air to the soot blowing unit. One dosing unit is installed for each SCR reactor and should be installed close to the urea injection point, for instance in the engine room.

## Air unit

The air unit is the connection point for compressed air supply to the SCR system. The unit distributes air to the dosing units. The unit includes a filter element, pressure regulators and an outlet pressure transmitter. It has built-in redundancy so that service work can be made on the unit during operation of the SCR system. The pressure set on the air unit specifies the inlet pressure of the dosing units and the pressure for the soot blowing unit.

## Control unit

The SCR control unit is a common control system for the complete SCR system. Each module is connected to this control system either via field bus connections or hardwired connections. In the control system, all functionality and control is automatically processed and executed depending on the engine running status and the SCR system status. Alarms, process values and system status information are sent over the field bus (Modbus TCP or Modbus RTU) to the vessel automation system. If the SCR control system is not connected to the ship systems via the recommended serial or Ethernet Modbus link, the hardwired digital group alarms and status indication are the mandatory minimum connection between the SCR and the ship alarm and monitoring systems.

The urea injection is based on the operation of the engine. The control unit receives the engine load and speed signal, and adjusts the urea dosing accordingly. When the engine load increases, the urea dosing is also increased to maintain an efficient nitrogen oxide abatement. The urea dosing may also be controlled by a feedback signal from the optional NOx sensor, emission analyser or external emission analyser.

The soot blowers are operated automatically at a preset interval. The control system initiates the soot blowing by opening the solenoid valves in the compressed air lines. During the soot blowing sequence, the soot blowing valves are operated by turns, to clean one catalyst layer at a time.

An operator terminal with a display and control keys is installed in the front panel of the cabinet. The operator terminal is used for monitoring the process values and reading alarms.

If the system is in standby mode, the urea injection is automatically activated when the engine has started and the minimum reactor temperature is reached. Correspondingly, when the engine stops, the urea dosing is shut off. The injection system is automatically purged of urea after a stop. The SCR system will automatically stop urea injection when turbine washing is started. The urea injection is stopped according to SCR inlet temperature sensor reading indicating too low exhaust gas temperature. This is a safety feature to avoid urea injection to too cold exhaust gas. As turbine washing is activated manually, it is recommended to check that there are no alarms related to SCR inlet sensor failue. If sensor failyre is active, a manual stopping of SCR system is required to stop the urea dosing and the faulty sensor needs to be replaced. The SCR control system layout is illustrated in the figure here below.

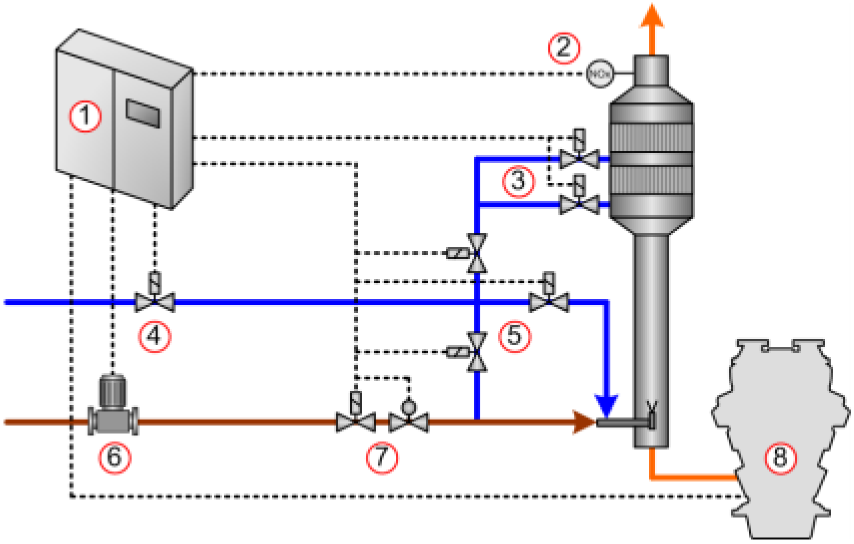


**Fig 2-8 Control system layout**

| System components | | | |
|---|---|---|---|
| 1 | Control unit | 5 | Compressed air control valves |
| 2 | NOx sensor (optional) | 6 | Pump unit |
| 3 | Soot blowing valves | 7 | Urea dosing control valves |
| 4 | Air unit | 8 | Engine |

## Urea injection and mixing unit

The reducing agent is sprayed into the exhaust gas duct and mixed with the exhaust gas before it enters the reactor. The urea injection is performed using compressed air. An injector lance is mounted on the exhaust gas duct, and it extends to the middle of the duct. The lance consists of two coaxial pipes, of which the inner one is used for urea solution and the outer one for compressed air. The urea and the compressed air are mixed in an injection nozzle at the end of the lance, causing injection of urea solution into the exhaust gas as a fine spray.

A mixing plate is installed in the exhaust gas duct before the urea injector. The static mixer ensures that the reducing agent is uniformly mixed with the exhaust gas. After the injection of reducing agent, the exhaust gas flow passes through a mixing duct where the urea transforms into ammonia and mix homogeneously before it reaches the reactor with the catalyst elements. The following figure illustrates the urea injection and mixing duct arrangement.

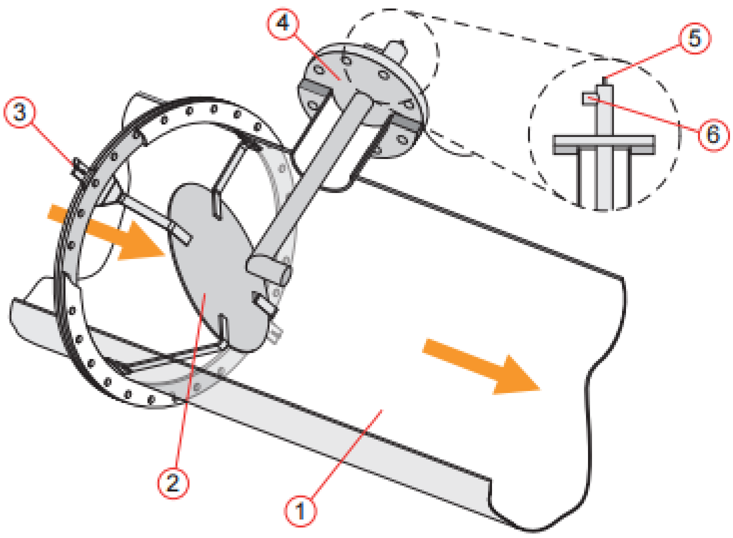


**Fig 2-9 Urea injection and mixing unit**

| System components | | | |
|---|---|---|---|
| 1 | Injection duct | 4 | Injector flange |
| 2 | Mixing plate | 5 | Urea connection |
| 3 | Mixing plate orientation indicator | 6 | Air connection |

## 2.1.4 Operating conditions and limitations

### Pressure drop over the SCR reactor

Pressure is measured continuously before and after the reactor. The pressure drop over the SCR system is normally designed to be below 15mbar at 100% engine load.

### Exhaust gas temperature control

Wärtsilä has developed a standard solution for how to integrate temperature control where the engine is delivered together with an SCR system. The temperature control can be configured to adjust the temperature set-point depending on the operating condition, such as SCR on/off or fuel used. Exhaust gas temperature compatibility with SCR shall be analyzed for all relevant conditions. As an example, clogging and blue haze formation as phenomena are independent from urea injection on/off. Therefore, in many projects, engine and SCR integration need to ensure compatibility also when the urea dosing is turned off, such as when outside and ECA. The table below illustrates how different design aspects need to be considered in example project operating on LFO when using SCR and rest of the time operating on HFO.

| | Operation inside SECA & NECA | Operation outside SECA & NECA |
|---|---|---|
| Fuel | Low Sulphur LFO | HFO |
| SCR on/off | On | Off |
| Exhaust gas temperatures | Ensure SCR operation | High enough to avoid clogging. Low enough to avoid blue haze. |
| Catalyst design | SCR dimensioning | HFO operation sets boundaries for catalyst type choice. |

Considering the complexity, close coordination is needed between engine and SCR configuration during all phases of a project. Changes in operation profile, fuel spec, etc may influence the optimal configuration of the engine and SCR.

## 2.1.5 System design data

### Urea solution quality

Wärtsilä recommends the use of 40 weight % aqueous urea solution as the reducing agent in the SCR unit, but other solutions such as 32,5 % may also be used. The urea solution concentration is taken into account when designing the urea tank and selecting the urea pump and dosing units. No blending between different concentrations is allowed. If a change between the two urea solutions is done, the urea tank has to be emptied before filling it with the new solution. This will also require adjustments to the dosing amounts set during the commissioning. The urea solution quality requirements are specified in following tables, see ISO18611-1:2014 for reference. It is not allowed to use agricultural or fertilizer urea.

**Table 2-4 Quality requirements for 40% urea solution**

| Characteristics | Unit | Min. limit | Max. limit | Typical value |
|---|---|---|---|---|
| Urea content | % (m/m) | 39.0 | 41.0 | 40.0 |
| Density | kg/m3 | 1105.0 | 1177.0 | |
| Refractive index at 20 °C | | 1.3947 | 1.3982 | |
| Alkalinity as NH3 | % (m/m) | | 05 | |
| Biuret | % (m/m) | | 0.8 | |
| Aldehydes | mg/kg | | 100.0 | |
| Insolubles | mg/kg | | 50.0 | |
| Phosphates (PO4) | mg/kg | | 1.0 | |
| Calcium | mg/kg | | 1.0 | |
| Iron | mg/kg | | 1.0 | |
| Magnesium | mg/kg | | 1.0 | |
| Sodium | mg/kg | | 1.0 | |
| Potassium | mg/kg | | 1.0 | |

**Table 2-5 Quality requirements for 32,5% urea solution**

| Characteristics | Unit | Min. limit | Max. limit | Typical value |
|---|---|---|---|---|
| Urea content | % (m/m) | 31.8 | 33.2 | 32.5 |
| Density | kg/m3 | 1087.0 | 1093.0 | |
| Biuret | % (m/m) | | 0.3 | |
| Aldehydes | mg/kg | | 5.0 | |
| Insolubles | mg/kg | | 20.0 | |
| Phosphate (PO4) | mg/kg | | 0.5 | |
| Calcium | mg/kg | | 0.5 | |
| Iron | mg/kg | | 0.5 | |
| Copper | mg/kg | | 0.2 | |
| Zinc | mg/kg | | 0.2 | |
| Chromium | mg/kg | | 0.2 | |
| Nickel | mg/kg | | 0.2 | |

| Characteristics | Unit | Min. limit | Max. limit | Typical value |
|---|---|---|---|---|
| Aluminium | mg/kg | | 0.5 | |
| Magnesium | mg/kg | | 0.5 | |
| Sodium | mg/kg | | 0.5 | |
| Potassium | mg/kg | | 0.5 | |

## Urea consumption

Urea consumption is directly proportional to the NOx reduction amount over the SCR catalysts. The NOx from the engine deviates due to the ambient air conditions and engine related issues. During the commissioning of the Wärtsilä NOx reducer system, the NOx deviations are taken into account in the urea dosing tuning. The typical urea consumption for reducing the NOx emissions from the IMO Tier 2 to the IMO Tier 3 NOx level is 15l/MWh at 100% engine load.

## Compressed air quality

The compressed air used for the reducing agent injection and the soot blowing must be clean and dry. The air should be of purity class 2 with respect to oil, purity class 3 with respect to particles, and purity class 4 with respect to water, according to the specifications in ISO 8573–1. The quality requirements are presented in following table.

**Table 2-6 Quality requirements for the compressed air**

| Particle size d [µm] | Maximum number per m3 |
|---|---|
| $0.5 < d \leq 1.0$ | 90 000 |
| $1.0 < d \leq 5.0$ | 1000 |

| Characteristics | Value |
|---|---|
| Pressure dew point | max. +3 °C |
| Total oil concentration (aerosol, liquid and vapour) | max. 0.1 mg/m3 |

## Compressed air consumption

Compressed air is required for urea injection, soot blowing operation and soot blowing valves cooling.

The total maximum compressed air consumption for urea feeding and soot blowing systems per vessel is calculated as follows:

$$\dot{V}_{AIR} = 0.007 \cdot P + n \cdot 15$$

**Fig 2-10 Formula for SCR Compressed air consumption**

where:

$V_{AIR}$ = Total compressed air consumption of the SCR systems per vessel [Nm3/h]

$P$ = Total power of the engines equipped with SCR per vessel [kW]

$n$ = Total number of engines equipped with SCR per vessel

*Nm3/h is defined at 0 °C and 101,325 Pa*

The compressed air pressure for urea feeding is 4 bar(g), and for the soot blowing system 8 bar(g). The part of the soot blowing system air consumption (operation + valve cooling) is as a standard 6 Nm3/h.

The maximum air consumption occurs only during urea injector purging. The air consumption during operation on 85% engine load is typically >20% lower than the max consumption.

### Electrical consumption

Electrical power is used by the SCR auxilliary units mainly for running the pumps and the control system. Typical power consumption for an operational dosing unit including control system is 0.5 kW. For the pump unit the typical power consumption is installation dependant, but in between 0.4... 3,0 kW each. The system is designed for supply voltages 400V/50 Hz or 440V/60 Hz as standard. The design can be tailor made for other voltages upon request.

## 2.1.6 Recommendations

### - Mixing duct

The recommended material for the mixing duct is stainless steel. A minimum mixing duct lenght of 3-5 meters is normally needed in order to give sufficient time for the urea to transform into ammonia and mix homogeneously before it reaches the catalyst elements. The minimum mixing duct lenght requirement is case specific.

### - Piping

The recommended material for piping is stainless steel (AISI 316) and for seals EDPM. Copper and its alloys must be avoided.

### - Urea tank

The SCR system requires a continuous supply of reducing agent to reduce the nitrogen oxide emissions. The capacity of the main urea tank should be calculated for proper and defined duration considering the maximum urea solution consumption and the filling interval.

The urea tank must be made of a material that meets the requirements for storing urea (e.g. stainless steel), please refer to ISO18611-1:2014. The recommended storage temperature for the urea solution is +5 to +35 degrees C. Therefore insulation and heating might be needed in some installations.

If the urea injection point is very far from the main tank, the installation of a transfer pump and of a day tank is needed to avoid cavitation. The transfer pump should be located close to the main tank, while the day tank should be placed in the engine room. The capacity of the urea day tank should be sufficient for 10 hours operation at maximum urea solution consumption.

### - Compressed air

The operation of the SCR system requires a continuous and reliable supply of compressed air. Compressed air is required for urea injection and for the soot blowing system. The air compressors must always be in operation when the SCR system is running, as a lack of compressed air inhibits the urea injection and the soot blowing. To prevent equipment damage and catalyst clogging, the air supply to the soot blowers must never be stopped when the engine is running, even if the urea injection is temporarily disabled. The capacity of the compressed air should be calculated for proper and defined duration considering the maximum air consumption.

### - Insulation

The insulation thickness should be in accordance with the applicable safety requirements, for instance SOLAS (Safety Of Life at Sea). A thickness of 150 mm is usually recommended.

### - NOx analyser

A NOx analyser is an optional device and provides NOx emission measurement after the SCR reactor. The analyser can be a stationary analyser based on continuous emission measurements or alternatively a portable emission analyser for spot check measurements.

See chapter 4 in this product guide for more information about NOx analysers.

### - NOx sensor system

The NOx sensor based emission monitoring and control system is designed to employ the measurement signal from the NOx sensors as a source for the reducing agent feedback control. The system allows an improved accuracy on the control of the NOx emission level after the SCR reactor. The NOx sensor system is designed for low sulphur fuel applications, LFO < 0.3 % S, since fuel quality affects the lifetime of the sensor.

The NOx sensor based monitoring and control system contains following components per engine:

- Sampling pipe, flange and mounting plate

- NOx sensor and cabinet

## 2.1.7 Service and maintenance

Table 2.1.7.1 gives a guideline for the calendar based maintenance schedule for the NOR system. The maintenance intervals often depend on the operating conditions.

**Table 2-7 Maintenance intervals**

| Interval | Unit | Maintenance needed |
|---|---|---|
| 2 months | Reactor soot blowing system | Checking the soot blower valve operation |
| 3 months | Air unit | Inspecting the air unit |
| 6 months | Urea pump unit | Inspecting the pumps |
| | Urea pump unit | Maintaining the urea filter |
| | Urea dosing unit | Inspecting the dosing unit |
| | Reactor | Cleaning and inspecting the catalyst |
| | Reactor | Inspecting the differential pressure transmitter |
| 1 year | Urea injection | Maintaining the atomizing lance |
| | Reactor | Cleaning and inspecting the catalyst |
| 2 years | Urea pump unit | Lubricate the urea pump drives |
| | Urea pump unit | Overhauling the urea pump |

# 3. SOx Emissions Control

## 3.1 The Wärtsilä SOx Scrubber

### 3.1.1 Solution for meeting SOx emission requirements

Wärtsilä has developed the scrubber products available today with the help of long experience and practical testing of exhaust gas cleaning. This has resulted in Wärtsilä having an extensive reference list, the first installation dating back to 2005, and in a highly effective scrubber system optimized for sea conditions.

The scrubbing technology is based on the fact that sulphur oxides dissolve in water. This means that when the exhaust gas is sprayed with the alkaline water in the scrubber, the SOx will dissolve in the scrubbing water and be cleaned from the exhaust gas. The alkalinity in the scrubbing water will neutralize the SOx emissions, as to not burden the environment when let out into the sea with the scrubbing water. The scrubbing water will be cleaned of particulate matter and other contaminants before being discharged.

#### SOx Scrubber types

Wärtsilä has a full wet scrubber portfolio, including an open loop, a closed loop and a hybrid scrubber system. Each of these systems will be described in this guide separately. All of the Wärtsilä scrubber technologies are certified in accordance with IMO Resolution MEPC.259(68), Guidelines for Exhaust Gas Cleaning Systems. They are fit for both newbuilding and retrofit, for any engine or boiler brand. All scrubbers can also be made in main stream (one inlet) or integrated (several inlets) solutions, but the best alternative should always be discussed with both the customer and a technical expert.

#### SOx Scrubber configurations

There are basically four types of configurations: Main Stream system, Integrated System, Single Venturi systems and Multiple Venturi systems. All these configurations can work as open loop, closed loop or hybrid systems, and all can be fitted to both newbuildings and retrofit installations.

##### Main stream system

Main Stream systems are designed to be installed in the main exhaust gas stream of an individual diesel engine or boiler. The solution is advantageous for a range of machinery configurations, for example single main engines in ships where generator engines and oil fired boilers use compliant fuel. Also generator engines can be equipped with main stream scrubbers.

##### Integrated system

Integrated Systems are designed to clean the exhaust gases of several combustion units with one scrubber unit. This can be applied for several engines or oil fired boilers. If needed, an exhaust gas fan can be provided to eliminate any exhaust gas back pressure. The integrated scrubber is suitable for all ship types, and in particular ships with several main engines, ships with single main engines and heavy fuel oil generator engines, and diesel-electric ships. Engines and boilers can be added to the same scrubber unit, but certain precautions must be taken to ensure safe operation. The integration of boiler requires sufficient arrangements/fans on the boiler according to the manufacturer's advice in order to prevent any risk of back pressure issues.

##### Single inlet with venturi

Single inlet V-SOx systems have one exhaust gas entry from an individual combustion unit and provides the most flexible solution for most machinery arrangements. For very large engine power output where the power rating exceeds the maximum scrubber size currently available, multiple scrubbers can be utilized to share the exhaust gas output from such machinery.

Fig 3-1 Single inlet with venturi

### Multi inlet with venturi

Multi-inlet systems with a maximum of four exhaust gas connections can be used to clean the exhaust gas of multiple fuel oil combustion units. If required, this type of scrubber can be fitted with a fan to assist in controlling the exhaust gas back pressure on non-running connected machinery and in particular to control the exhaust gas back pressure of any connected oil fired boiler.

The multi-inlet V-SOx scrubber is of particular advantage when used to clean the exhaust gas from a number of similar sized fuel oil combustion units. These scrubbers can be utilized for both retrofits and new building projects.

Fig 3-2 Multi inlet with venturi

### Single inlet without venturi

Wärtsilä has developed the I-SOx scrubber to get a smaller footprint, and thus give the opportunity for smaller size vessels to install a scrubbing system. The Wärtsilä I-SOx scrubber does not have a venturi, which will save space, but also remove less particles from the exhaust gas. The scrubber unit has a smaller diameter and is slightly higher than the conventional V-SOx scrubber unit. The smaller size allows easier installation and will often allow installation in retrofits without adjustments to the exhaust gas funnel. This scrubber type has following capability in SOx reduction:

| Sulphur in fuel (%) | SOx reduced in scrubber to correspond to Sulphur in fuel (%) |
|---|---|
| 2.5 | 0.1 |
| 3.5 | 0.5 |
| 3.5 | 0.1 with alkali injection |

The I-SOx scrubber is ideal for retrofits and vessels where space is an issue. The I-SOx scrubber can be made as an open loop, closed loop or hybrid system.

**Fig 3-3 Inline scrubber**

## Performance

As a default the scrubber system is designed for maximum sulphur content in the fuel of 3.5%. The SOx reduction efficiency corresponds to a reduction of fuel sulphur content from 3.5% to 0.1%. This is typical guaranteed performance of the system. Other alternatives can be offered following discussion with Wärtsilä Moss AS. The Wärtsilä I-SOx scrubber can be installed with several engines combined into one scrubber unit. This is done using a connection box.

The scrubber will also remove some particulate matter (PM) from the exhaust gas, which will be trapped in the wash water treatment unit after the scrubber. The amount of PM removed depends on different variables, but tests have shown a possible removal of up to 85% particulate matter.

## Combustion units

Combustion units can be diesel engines of any make, type or application, 2-stroke or 4-stroke. In the case of main stream scrubbers, also flue gases from oil-fired boilers can be cleaned. Boilers can be scrubbed in both multi-inlet and mainstream scrubbers.

Combustion unit gas flow and temperature throughout the load range are needed to determine appropriate scrubber configuration. Also exhaust gas back pressure measurement information is needed especially in main stream scrubber retrofit installations. Wärtsilä can provide assistance in back pressure measurement.

## Alkalinity

The main difference between the different types of scrubbers is the way alkalinity is added in the scrubbing water. In an open loop scrubber the natural alkalinity found in seawater is utilised while an alkali (NaOH) is added to recirculated seawater in a closed loop scrubber, to get the same effect. In a hybrid scrubber seawater is used in open loop mode, and when the system run in closed loop mode caustic soda (NaOH) is added to maintain the alkalinity level.

To determine which system should be selected for a specific project, one has to look at the vessels' operating route. The alkalinity level in the sea varies from place to place. Generally the alkalinity level is high in the great oceans, while inland waterways and lakes have lower levels. For an open loop scrubbing system to be efficient, Wärtsilä has set a recommendation of 2000 umol/l for V-SOx and 2200 umol/l for I-SOx.

## Rules and regulations

The system is designed and certified in accordance with IMO Resolution MEPC.259(68), Guidelines for Exhaust Gas Cleaning Systems. Scrubber design criteria can be agreed upon on a project specific basis, and may include permitted SOx-emissions equivalent to 0.1 % or 0.5% sulphur in the fuel as per:

- EU regulations for EU ports 1.1.2010.

- IMO and EU regulations for SOx ECAs with entry into force 2015 as per IMO Marpol Annex VI.

- IMO and EU global regulations for SOx outside ECAs with entry into force in 2020.

### Dimensioning of Integrated and Multi-inlet Scrubbers for highest gas flow

Integrated Scrubbers and Multi-inlet scrubbers can be dimensioned for a smaller gas flow than the total exhaust gas of the combustion units, still without limiting engine operation in any way. This could be the case when all generator engines are connected to the scrubber, as all generator engines are not fully loaded simultaneously in sea-going conditions.

### Dimensioning of scrubbers for less than highest gas flow

Subject to confirmation from the classification society, a scrubber can be dimensioned for a smaller gas flow than the exhaust gas of the combustion unit at full load, provided that such a compliance principle is based on a realistic operating mode. In such cases the SECP should specify operating modes when the ship is compliant by fuel and when by scrubbing. Any engine load exceeding the scrubber capacity would automatically open the exhaust gas bypass line, and the ship is responsible for compliance.

## Sludge

Impurities separated from the bleed-off form sludge in the treatment unit, sludge amount depending on fuel oil quality.

The composition of the sludge is mainly water, hydrocarbons, soot and metals. The amount of water is aimed to be kept as minimal as possible, without losing the pumpablility of the mixture.

The scrubber sludge can be stored in the same tank as other engine room sludge. However, the current DNV regulation specifically requires separate tanks to be used for both scrubber sludge and engine room sludge. Scrubber sludge is not permitted to be incinerated on board.

As an option, Wärtsilä can offer a de-watering unit for sludge. This unit separates the excess water from the sludge by filtration, thus reducing the amount of sludge to be stored on board. The compact contaminants are stored in a bag which can be disposed of at port.

## Maintenance

As a general rule, maintenance and inspections can be carried out during normal ship operation, including port calls. Maintenance of the scrubber system is composed of generic maintenance tasks of individual pieces of equipment, such as valves and actuators, pumps, electric motors, heat exchangers, tanks, water treatment units, instruments etc.

These components should be inspected regularly for leaks etc, and maintenance work carried out as recommended by the individual component manufacturers, which is summarized into one scheduled maintenance table for the whole scrubber system in the scrubber User's Manual.

In the scrubber unit the need for maintenance is minimal. There are no parts to be greased or oiled periodically. Visual internal inspections of scrubber housing, packed bed, spray nozzles, droplet separator and mechanical condition generally should be performed annually. Maintenance openings (hatches) with flange are provided in the scrubber unit as standard solution.

Detailed maintenance instructions are given in the User's Manual, and they should be followed in conjunction with general good housekeeping.

## 3.1.2 Wärtsilä Open Loop Scrubber system

### General

The Wärtsilä Open Loop Scrubber is designed to utilize the natural alkalinity found in seawater to neutralize the Sulphur Oxides in the exhaust gas from the engine or oil-fired boiler. Open loop means that the water is taken from the sea, run through the scrubber and then discharged back to the sea after cleaning. The scrubbing water is not re-circulated. This solution requires no chemicals to work.

This solution is optimal for vessels sailing in high alkalinity areas (seawater alkalinity ≥ 2000 µmol /l).

The main components in an open loop scrubber system include: a scrubber unit, scrubbing water pumps, washwater pumps, hydrocyclones, a scrubbing water monitoring module, a continuous emission monitoring system, a residence tank and a settling tank. An exhaust gas fan and a de-plume system can be included if needed.

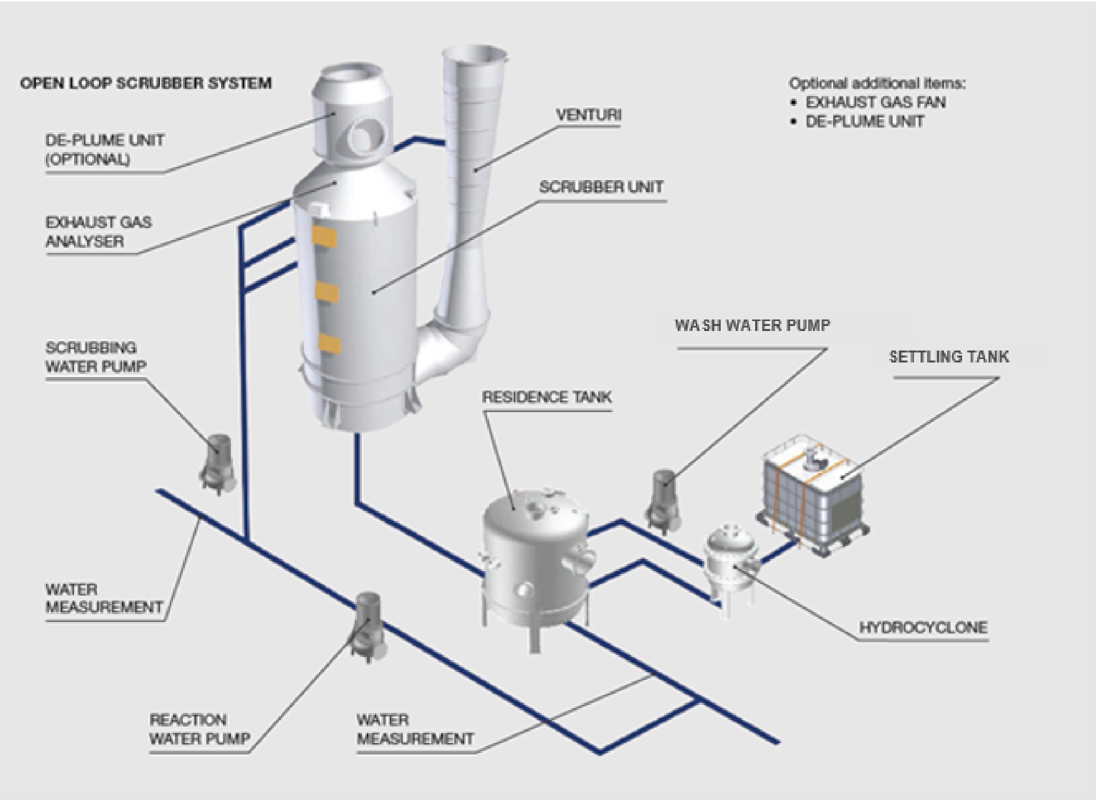


**Fig 3-4 Wärtsilä Open Loop Scrubber system overview**

### Scrubbing unit

The scrubber unit is as a standard made out of high grade alloy steel to resist corrosion, and should be suitable for the life of the ship. The main body is cylindrical which provides for a rigid structure. The exhaust gas will enter the main body via one or several venturies. In a V-SOx scrubber the exhaust gas flow is regulated, so that it will be the optimal speed in the scrubber unit. Most of the particulate matter will also be removed in the venturi, as this is where the exhaust gas first comes into contact with scrubbing water.

Inside the scrubber unit there are two rings of spraying nozzles, complete with two separate layers of packed beds. These layers help the exhaust gas to come into contact with the scrubbing water sprayed from the nozzles.

In the I-SOx scrubber, the exhaust gas enters the scrubber from below. A water trap is installed at the bottom of the scrubber to avoid water going back down the exhaust gas line. In the tower several layers of spray nozzles are installed to spray the exhaust gas.

## Scrubbing water pumps

Scrubbing water pumps are installed to transport seawater from the sea chest into the scrubber. In the open loop scrubber the water flow is 45 m3/MWh (for a SOx reduction corresponding to 3,5% S down to 0,1% S). The I-SOx scrubber has a slightly higher water flow of 55 m3/MWh.

## Scrubbing water monitoring module

Scrubbing water monitoring modules are positioned both at inlet and outlet in an open loop scrubber. This enables one to see the difference in the seawater taken in and the water let out after the scrubbing process. The system monitors pH, PAH, turbidity and temperature.

## Wash water treatment system

The open loop scrubber includes a wash water treatment system. The system includes a residence tank, hydrocyclones, wash water pumps and a settling tanks.

### Residence tank

Incorporated into the open loop system is a residence tank, this tank is to be coated internally in order to resist the corrosion effects of low pH warn return (wash) water from the scrubber. The main purpose of this tank is to provide a residence period for the wash water to allow gas and air to separate out from the water to aid the recovery in the hydrocyclones of the products of combustion that are held in the gas/air stream(s). This separation allows the particulate matter to settle out where it can then be captured in the hydro-cyclones and subsequently collected in sludge holding tank(s).

### Hydrocyclone

Hydrocyclones are utilised to clean the wash water from the scrubber in an open loop system. The contaminants are separated into a settling tank and the cleaned water can be discharged overboard. The efficiency of the cleaning is monitored before discharge.

### Wash water return pump

In order to provide the necessary differential pressure across the hydrocyclones and in some cases to aid over board discharge, wash water pumps are provided to fulfil this function. These pumps are provided with internal components manufactured in Super Duplex or similar material in order to withstand the corrosion effects of the ward low pH water returning from the scrubbing process.

### Settlings tanks

Settling tanks generally are in the form of a standard IBC container of 1 m3 capacity. Positioning of these tanks should be arranged to allow tank exchange when full. The contents of the full tank(s) are to be disposed of ashore and cannot be incinerated on board or disposed of to the sea, MEPC 259(68) section10.4. The tanks are arranged such that all services are provided in the lid of the tank in order to facilitate easy replacement of tanks when full without the need for extensive disconnection and reconnection. The sludge collected in these tanks from de-sludging the hydrocyclones (normally once a day) is allowed to settle and the separate water is then pumped back into the wash water stream in order to pass it through the hydro clones again before discharge with the wash water to overboard.

## Deplume system

A deplume system can be installed as an option for the scrubber system. The deplume system eliminates water vapour from the exhaust gas after the scrubber unit. This means that white smoke is eliminated and corrosion is avoided on the top of the exhaust gas funnel (if the scrubber is installed inside the funnel).

## Exhaust gas fan

If required due to back pressure limitations, an exhaust gas fan can be installed to suck the exhaust gases from the scrubber unit.

### CEMS

A continuous emission monitoring system (CEMS) is installed to measure the SO2/CO2-ratio, to guarantee that the SOx removal in the scrubber is meeting the requirements set by emission legislation. The results measured are recorded in accordance with IMO resolution MEPC.259(68) to enable the ship operator to prove compliance upon inspection on board.

## 3.1.3 Wärtsilä Hybrid Scrubber system

### General

The Wärtsilä Hybrid scrubber is designed to work in both open loop and closed loop mode. The hybrid scrubber will utilise the natural alkalinity in seawater in areas where the alkalinity is sufficient (seawater alkalinity ≥ 2000 µmol /l). When entering low alkalinity areas, the hybrid scrubber can switch operation into closed loop mode so that the exhaust gas cleaning can work independently of sea water alkalinity levels. In closed loop mode (hybrid mode) NaOH will be added to the re-circulating water, to maintain the needed alkalinity levels needed in the scrubbing water.

The Wärtsilä hybrid scrubber enables flexibility for vessels operating both in high and low alkalinity areas. Dimensioning of the system should be calculated according to customer needs (time in low alkalinity areas, bunkering intervals etc.).

The main components in a hybrid scrubber system include: a scrubber unit, scrubbing water pumps, washwater pumps, hydrocyclones, a scrubbing water monitoring module, a continuous emission monitoring system, a residence tank, a process tank, an alkali feed module, a bleed-off treatment unit, a make-up water pump, a heat exchanger, seawater cooling pumps and settling and sludge tanks. An exhaust gas fan, a de-plume system and a holding tank can be included if needed.

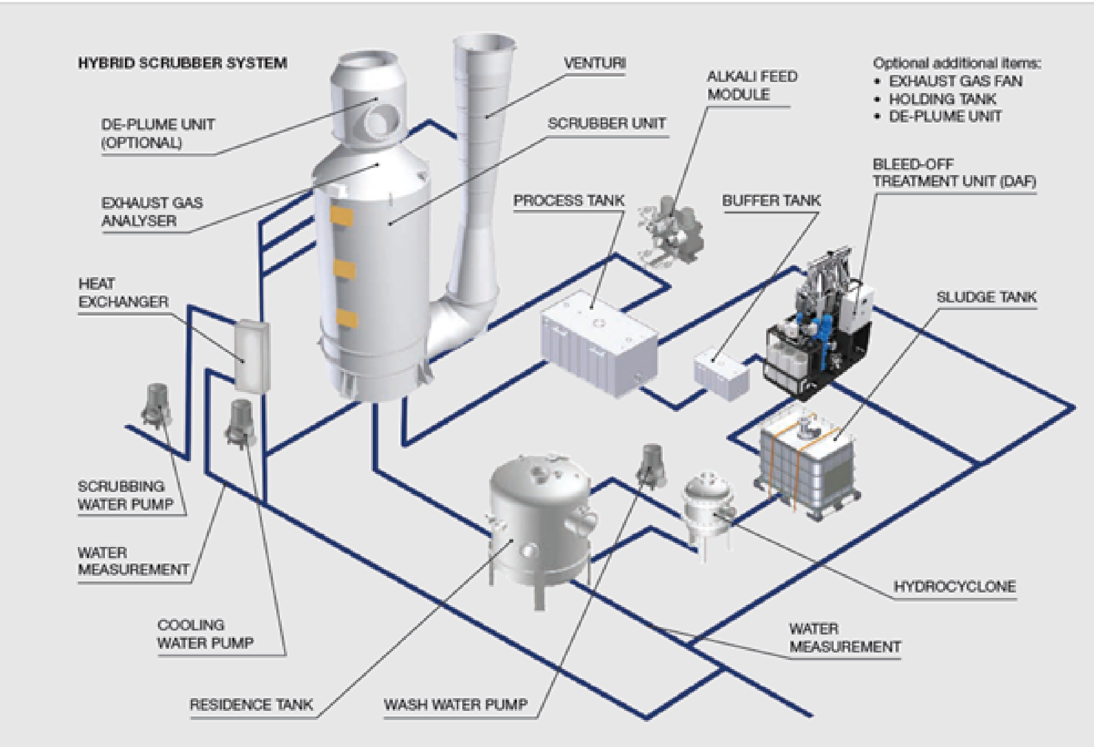


**Fig 3-5 Wärtsilä Hybrid Scrubber system overview**

### Process tank

Water from some types of EGC units (scrubbers) running in a closed loop mode (or in some scrubber types in the hybrid mode) flows into the process tank by gravity, and pumped back to the scrubber.

## Holding tank

In operational situations where effluent discharge is avoided, the effluent can be diverted from the effluent monitoring module (EMM) to a holding tank for later scheduled and periodical discharge. The volume of such a storage tank should be dimensioned according to the time the scrubber system is to be operated without discharge.

In normal operation the tank is empty, except a small amount of water always present in the tank to form a water lock to prevent ingress of exhaust gas from the scrubber through the overflow pipe. The content in the buffer tank can be pumped through the EMM (clean water) for direct overboard discharge or to the BOTUs (unclean water) for further cleaning.

## Alkali feed module

Alkali is automatically added to the scrubbing water circulation to maintain the process pH and consequently the SOX removal efficiency. Typically 50% NaOH (Sodium Hydroxide), also known as Caustic Soda or Lye, solution is used as alkali. In some cases 20% NaOH solution can be considered due to its low freezing point.

Main components in alkali system are alkali feed module, alkali transfer pump and alkali storage tank. The alkali feed module consists of two chemical dosing pumps. One pump is normally in operation and the other as stand-by.

Alkali consumption depends on the concentration of the solution, engine operating power, engine specific fuel oil consumption and fuel sulphur content. The alkali supply is automatically controlled based on these parameters.

Indication of the alkali consumption can be seen in the figure below. It also indicates the relations of the affecting parameters.

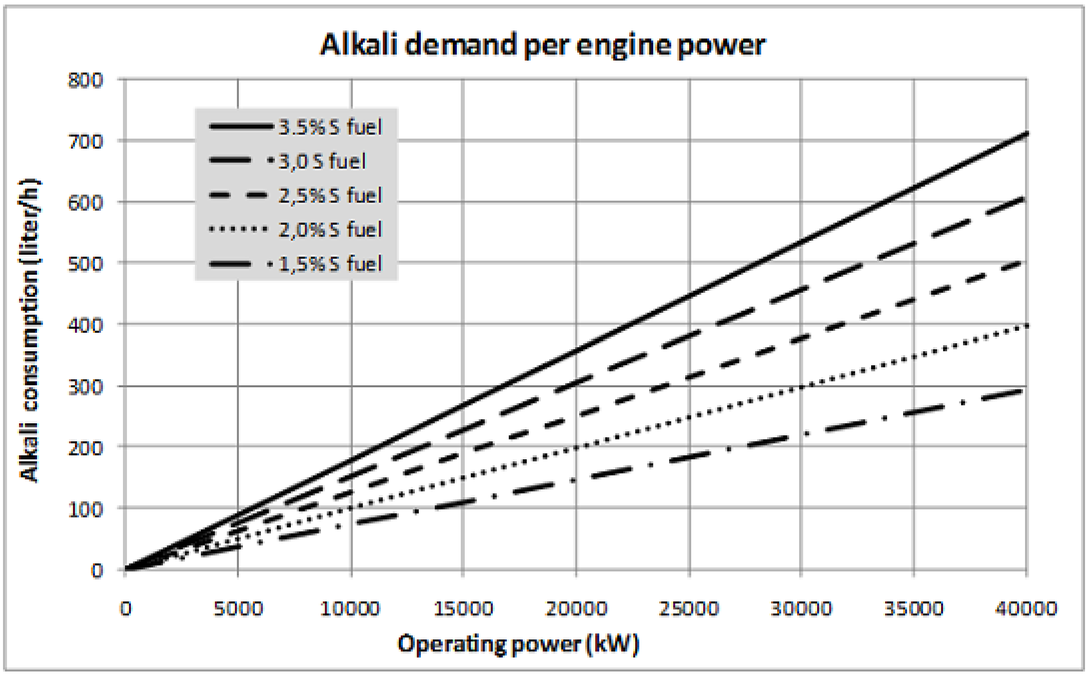


**Fig 3-6** **Alkali demand per engine power**

### Alkali storage tank

Onboard storage capacity is dictated by the following parameters: vessel autonomy, alkali consumption and vessels operation profile and area.

For vessels that are operating in regular routes or in specific areas, the storage capacity could be equal to the fuel bunkering interval. To minimize the transportation costs and ease the bunkering arrangement, tank capacity should be adequate to receive the total volume from one delivery truck. The ideal storage capacity should be at least 1.5 times the volume of the truck.

It is recommended that two separate, preferably adjacent, structural tanks are provided for alkali. This configuration would allow continuous scrubber operation during the tank surveys, inspections and cleaning.

Internal tank coating is recommended to avoid corrosion that may occur particularly on tank upper parts. Major suppliers have epoxy resins that are suitable for this purpose. Suppliers' recommendation is to be followed concerning intended use, surface preparation and application.

## Heat exchanger

Exhaust gas heat is transferred to scrubbing water and is removed in the seawater heat exchanger. The purpose of the cooling is to minimize the water content in the cleaned exhaust gas after the scrubber, thereby minimizing plume opacity and water consumption. The cooling has negligible effect on sulphur removal efficiency from the exhaust gases.

The system is typically designed for sea water temperature maximum of 32 °C. Alternatively, a different temperature can be specified if requested. In cold environment minimum sea water temperature is ensured by a thermostatic valve and a recirculation line to avoid crystallization of the sulphates in scrubbing water. A sufficient sea water flow is needed to ensure the scrubbing water cooling.

The location of the heat exchanger onboard the ship should be below the water line. The ideal location minimizes the length of sea water and scrubbing water circuits onboard the ship.

### Seawater cooling pump

A seawater cooling pump is needed to supply the heat exchanger with seawater. The position of the cooling water pump depends on the location of the heat exchanger and ship sea chest arrangement. The cooling water pump should be installed below sea water level in all operating conditions of the ship to ensure adequate water flow to pump.

## Make-up water pump

Make-up water is needed to compensate scrubbing water evaporation losses and extracted bleed-off. In other words, the needed make-up water equals the humidity lost to the atmosphere plus the bleed-off, minus the water content of the exhaust gas from the combustion units. The water content in the exhaust gas is typically around 5 % in diesel engines and clearly higher in oil-fired boilers. The water balance is determined on project specific basis.

The make-up water consumption depends somewhat on prevailing ambient conditions. Scrubbing water and consequently also seawater cooling temperature affect the make-up water consumption.

Make-up water needed is generally 0,14 m3/MWh. A make-up water pump is needed to supply the make-up water for the scrubber system.

## 3.1.4 Wärtsilä Closed Loop Scrubber system

### General

The Wärtsilä closed loop scrubber is a water and alkali (NaOH) based exhaust gas scrubber. As the name indicates, it is a closed loop system, which means that the scrubbing water is recirculated, instead of using a continuous water flow (unlike in an open loop scrubber system). Fresh water or seawater can be used as scrubbing water, and caustic soda (NaOH) is added to get the required alkalinity to neutralize the SOx. This means that the scrubber performance is not affected by the alkalinity in the seawater. The Wärtsilä closed loop scrubber is recommended for vessels operating full time in low alkalinity areas, e.g. the Great Lakes.

The main components in a closed loop scrubber system include: a scrubber unit, scrubbing water pumps, a scrubbing water monitoring module, a continuous emission monitoring system, a residence tank, an alkali feed module, a bleed-off treatment unit, a make-up water pump, a bleed-off treatment unit, a heat exchanger, seawater cooling pumps and sludge tanks. An exhaust gas fan, a de-plume system and a holding tank can be included if needed.

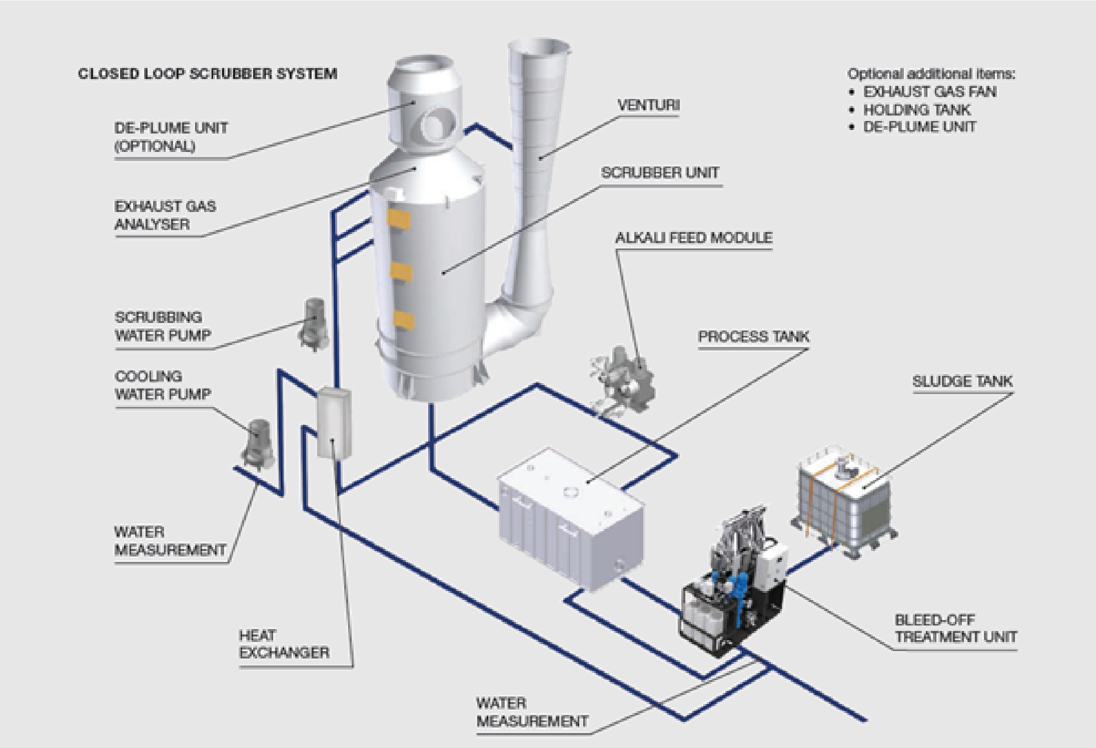


**Fig 3-7 Wärtsilä Closed Loop Scrubber system overview**

## 3.1.5 Wärtsilä EGC Scrubber for 2020

The IMO will introduce the global sulphur cap of 0.5% in 2020. Wärtsilä has developed an optimized scrubber solution for vessels operating mostly outside ECAs, that still need to comply with the global cap. The solution is available for all Wärtsilä scrubber types and systems, and will save both space and money.

The water flow is reduced to 38 m3/h (from 45 m3/h) in open loop operation, which means smaller equipment installed (nozzles, pumps, tanks, hydrocyclones etc). Smaller equipment means a smaller investment cost, and the total footprint of the system will also be reduced. Smaller pumps means that the energy consumption will go down and hence one gets a smaller OPEX.

The 2020 scrubber system will reach the equivalent of 0.5% sulphur in fuel. If the vessel enters an Emission Control Area where 0.1% rules apply, the operator can choose between running on low sulphur fuel, switching to closed loop mode (hybrid system) or adding alkali injection to the open loop system.

# 4. Emission Monitoring System

Exhaust gas emission monitoring can be done for the purpose of self-surveillance or for verification of compliance with specific emission requirements. It can also be used for reporting for emission trading or taxation schemes or for process feedback for control purposes when an exhaust gas aftertreatment device is installed.

## 4.1 CEMS, Continuous Emission Monitoring System

One of the systems used for emission monitoring is based on continuous emission monitoring system (CEMS) technology with a stationary analyser for continuous measurements. The system is continuously measuring the concentration of specific components in the exhaust gas. Typically NOx, CO and SOx emissions are measured, but it can also be used for CO2, CH4, H2O and O2 measurements. The analyser system is certified for compliance with the IMO NOx Technical code.

### 4.1.1 System overview

The CEMS system is an extractive system, which means that the exhaust gas sample is taken from the exhaust gas stack with a sampling probe and conveyed in heated sampling lines to a gas analyser via sample conditioning.

A data logging/ handling system is needed for reporting purpose.

The main components are:

- sample probe(s)
- Sample line(s)
- Emission analyser and measurement cabinet

#### Datalogging

The CEMS might need a data collection tool to store and report measured emission data. In some cases ship control system might be enough. This need to be chosen according to the need and requirements for the installation. The measured signals are available over normal analogue 4…20 mA signals or Modbus TCP. Other protocols are available upon request.

#### Time sharing principle

The CEMS system can work with the time sharing principle where exhaust emissions from several engines are monitored by the same analyser, one at a time. This is suitable for multi-engine installations where up to 5 engines can be connected to one analyser.

The measurements can be performed on-demand or in a sequential manner. There are several benefits with time sharing of the analyser i.e. reduced maintenance, lower cost and lower own consumption. The diagram below show a typical CEMS installation with timesharing between several engines.

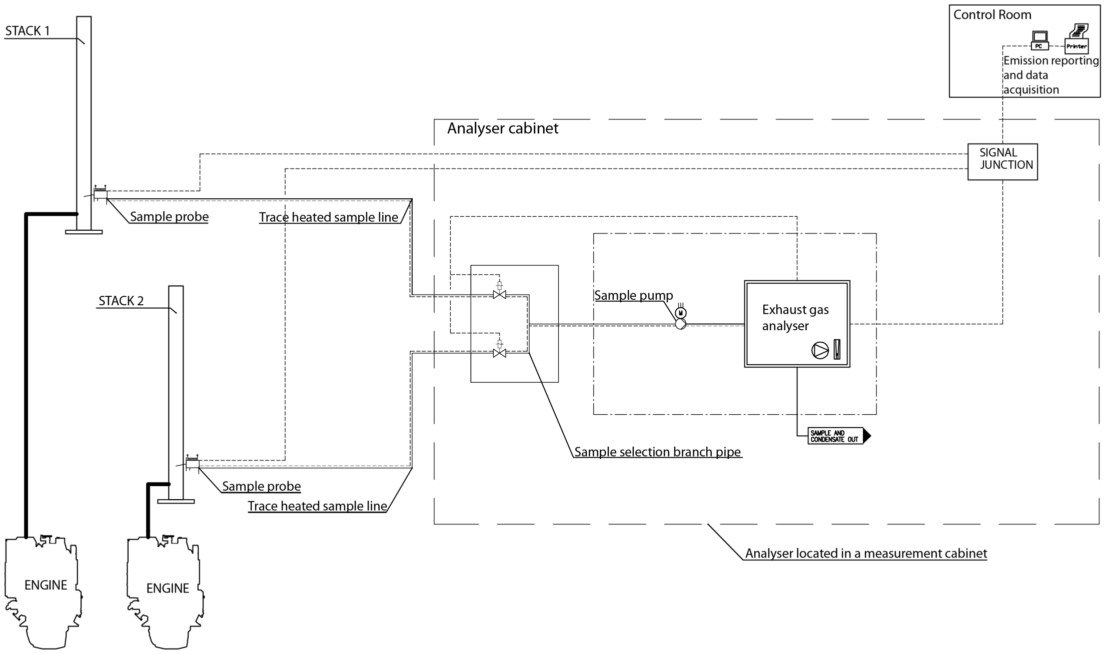


**Fig 4-1 Typical P&I diagram, CEMS with time sharing (DBAC208630)**

## Emission analyser and measurement cabinet

The analyser cabinet is designed for wall-mounting. The overall dimensions are presented in the next table.

| CEMS analyser cabinet dimensions and weights | | | | |
|---|---|---|---|---|
| Size (Number of engines connected to the CEMS analyser) | Width (mm) | Lenght (mm) | Height (mm) | Weight (Kg) |
| 1...5 | 600 | 440 | 1300 | 120 |

## Sample switch box

A sample switch box is required when the emission analyser is to be connected to more than 2 engines. The sample swich box is designed for wall mounting and is to be installed next to the analyser cabinet.

## Sample Probe

The sample probes are installed in the exhaust duct. The sample probe is heated and contains control valves for flushing the complete system with instrument air. The instrument air and electricity is fed directly from the monitoring cabinet trough the bundle of pipes. A sample line is then required to transport the sampled gas from the probe to the monitoring cabinet. Note that the probe needs about 1.5 meter free space behind connecting flange to allow installation.

## Heated sample lines

The operation and lifetime of the analyser is secured by keeping the exhaust gases hot as it prevent condensation of components in the exhaust gas. Heated sample lines are used for transport of the sampled gas from the probes to the monitoring cabinet. The sample lines are sensitive and should be carefully installed. A sample line may not touch another sample line (or itself) at any point, as too much heat might be accumulated and the sample line destroyed. The bending radius of the sample line is 30 cm and the routing should be planned between the probe and the analyser accordingly. Max. lenght for a sample line is 35 meters.

### Bundles of pipes

The bundle of pipes contains the necessary cabling for the monitoring cabinet to control the probe. It is installed beside the sample line.

## 4.1.2 System design data

### Fuel qualities

The analyser is tested on a variety of fuels. It is compatible for both MDF and HFO operations.

### Compressed air quality and consumption

The emission analyser uses instrument air to flush the system and calibrate the zero point. While the system does not consume instrument air in monitoring mode, it will use some amount for back flushing. It is mandatory that the instrument air is of good oil-free quality.

The instrument air requirements:

- Purity Class 2 (ISO 8573)
- Dewpoint max: -40 °C
- Oilfree: <0.1 mg/m3
- Pressure: 6-7 bar

### Electrical consumption

The electrical consumption of the CEMS is approximately 2 kW +95 W/ sample line meter.

## 4.1.3 Service and maintenance

The maintenance schedule contains monthly and quarterly checks and an annual change of filters and seals.

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# 5. Bilge Systems

## 5.1 Wärtsilä Oily Water Separator (OWS)

**Fig 5-1 Wärtsilä OWS unit**

### 5.1.1 System overview

The Wärtsilä OWS unit is an oily water separator used for bilge water treatment in marine installations. The Wärtsilä OWS separates oil and emulsions so that only treated clear water is discharged to the sea. The guaranteed amount of oil in the water after the treatment process is less than 5 ppm. The Wärtsilä OWS is certified according to USCG and the latest IMO regulations, where the max allowed oil content in the discharge water is 15 ppm at any time.

The Wärtsilä OWS main stages are:

- oil separation stage

- chemical mixing stage

- flotation stage

The unit is available in four different sizes and is built in modules for easy installation onboard ships.

| **Wärtsilä OWS units** | | |
|---|---|---|
| Type | Capacity [$m^3$/h] | Performance Oil & Grease |
| Wärtsilä OWS 500 | 0.5 | < 5 ppm |
| Wärtsilä OWS 1000 | 1.0 | < 5 ppm |
| Wärtsilä OWS 2500 | 2.5 | < 5 ppm |
| Wärtsilä OWS 5000 | 5.0 | < 15 ppm |

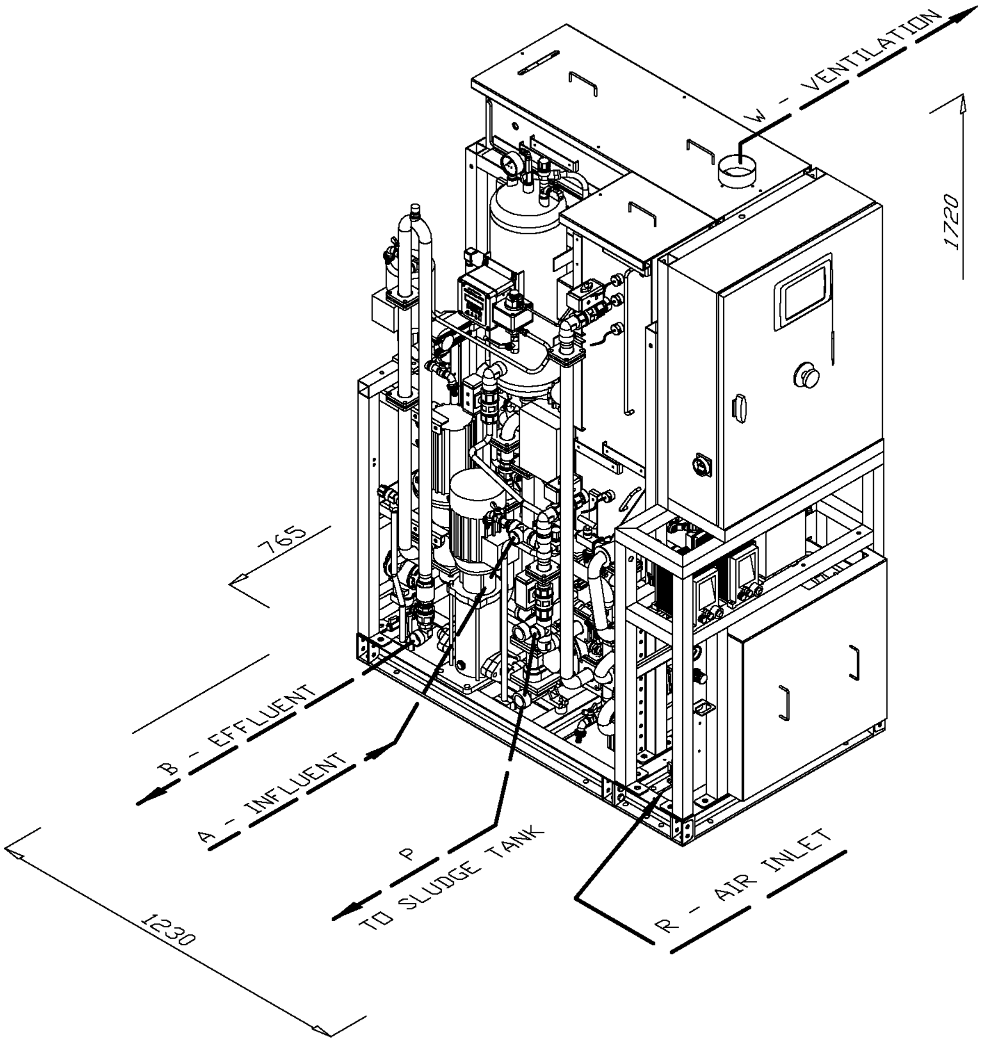


**Fig 5-2** **Wärtsilä OWS 500 (66651056_00)**

| Wärtsilä OWS 500 main dimensions and weights | | | | | |
|---|---|---|---|---|---|
| Type | Weight, dry [kg] | Weight, wet [kg] | H [mm] | L [mm] | W [mm] |
| Wärtsilä OWS 500 | 500 | 775 | 1720 | 1230 | 765 |

| Pipe connections Wärtsilä OWS 500 | | |
|---|---|---|
| A | Influent | DN 25 |
| B | Effluent | DN 25 |
| P | To sludge tank | DN 25 |
| R | Air inlet | DN 10 |
| W | Ventilation | |

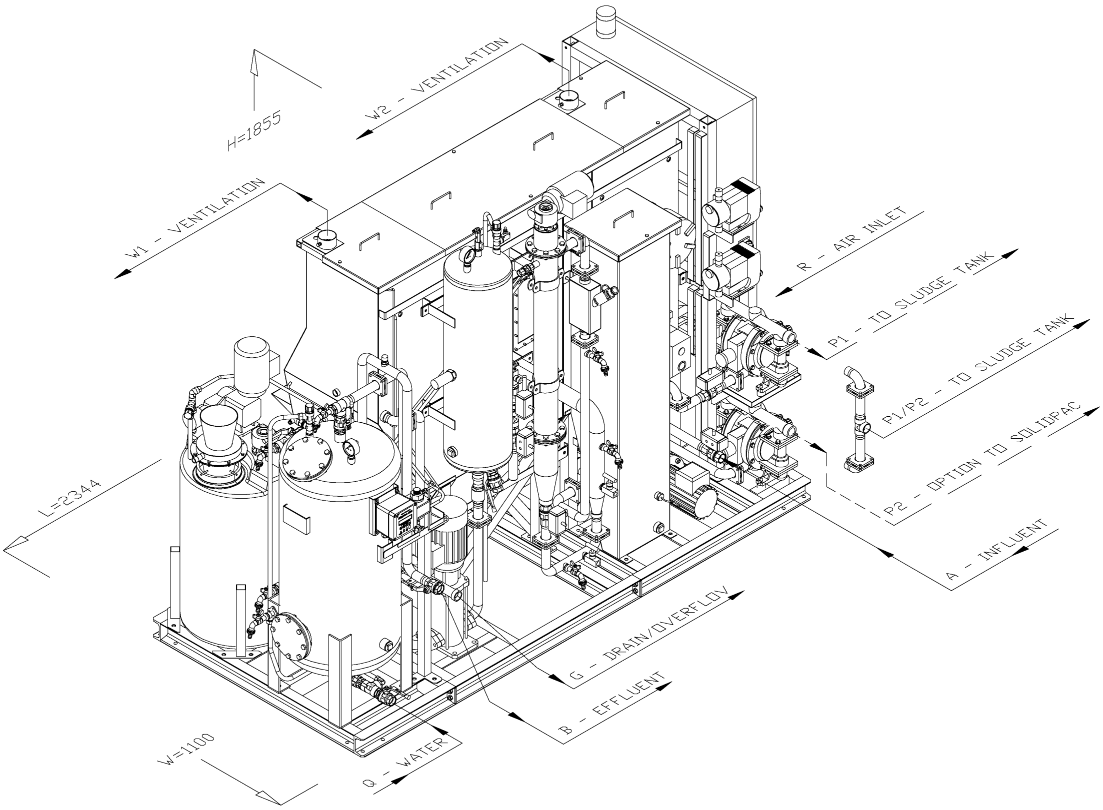


**Fig 5-3** **Wärtsilä OWS 1000 (DAAE054487b)**

| Wärtsilä OWS 1000 main dimensions and weights | | | | | |
|---|---|---|---|---|---|
| Type | Weight, dry [kg] | Weight, wet [kg] | H [mm] | L [mm] | W [mm] |
| Wärtsilä OWS 1000 | 650 | 1950 | 1855 | 2344 | 1100 |

| Pipe connections Wärtsilä OWS 1000 | | |
|---|---|---|
| Q | Water | DN 25 |
| G | Drain/ Overflow | DN 25 |
| B | Effluent | DN 25 |
| A | Influent | DN 25 |
| P1 | To sludge tank | DN 25 |
| P2 | To solid pack | DN 25 |
| P1/P2 | To sludge tank | DN 25 |
| R | Air inlet | DN 10 |
| W1 | Ventilation | |
| W2 | Ventilation | |

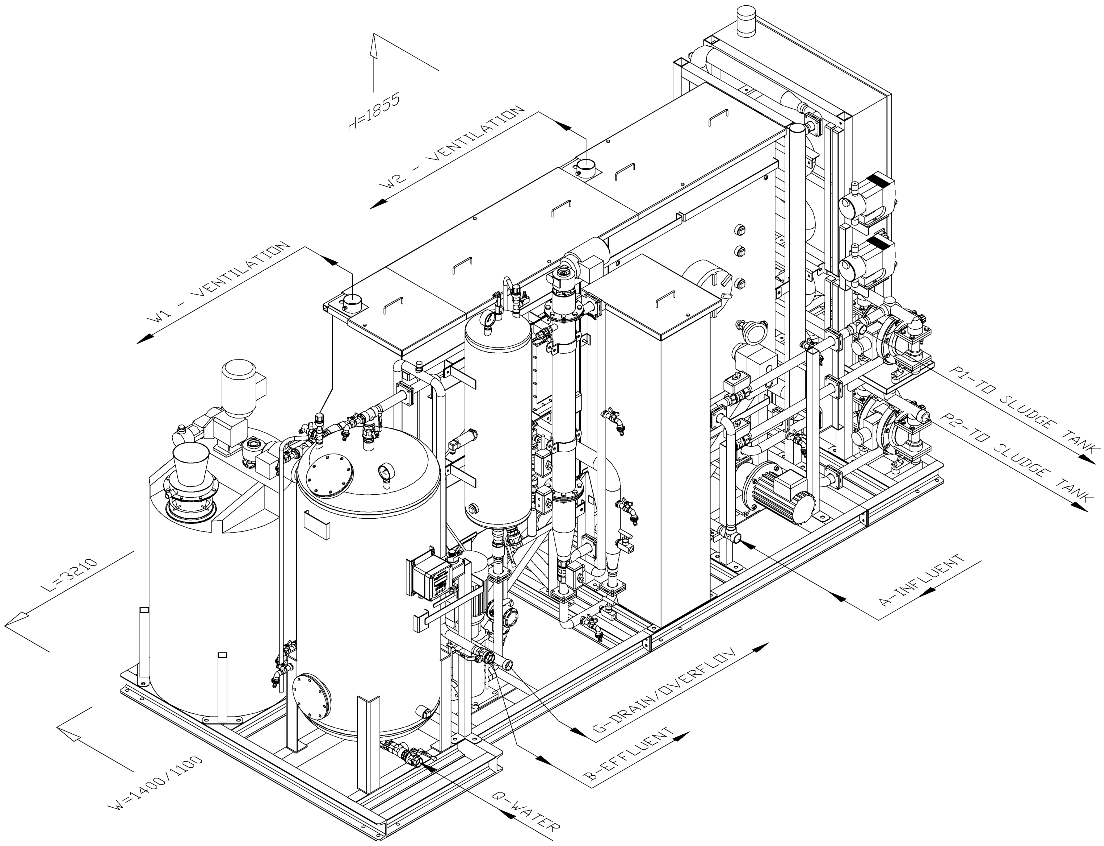


**Fig 5-4** **Wärtsilä OWS 2500 (DAAE076426)**

| Wärtsilä OWS 2500 main dimensions and weights | | | | | |
|---|---|---|---|---|---|
| Type | Weight, dry [kg] | Weight, wet [kg] | H [mm] | L [mm] | W [mm] |
| Wärtsilä OWS 2500 | 950 | 2700 | 1855 | 3210 | 1400 |

| Pipe connections Wärtsilä OWS 2500 | | |
|---|---|---|
| Q | Water | DN 25 |
| G | Drain/ Overflow | DN 25 |
| B | Effluent | DN 25 |
| A | Influent | DN 25 |
| P1 | To sludge tank | DN 25 |
| P2 | To sludge tank or solid pack | DN 25 |
| R | Air inlet | DN 10 |
| W1 | Ventilation | |
| W2 | Ventilation | |

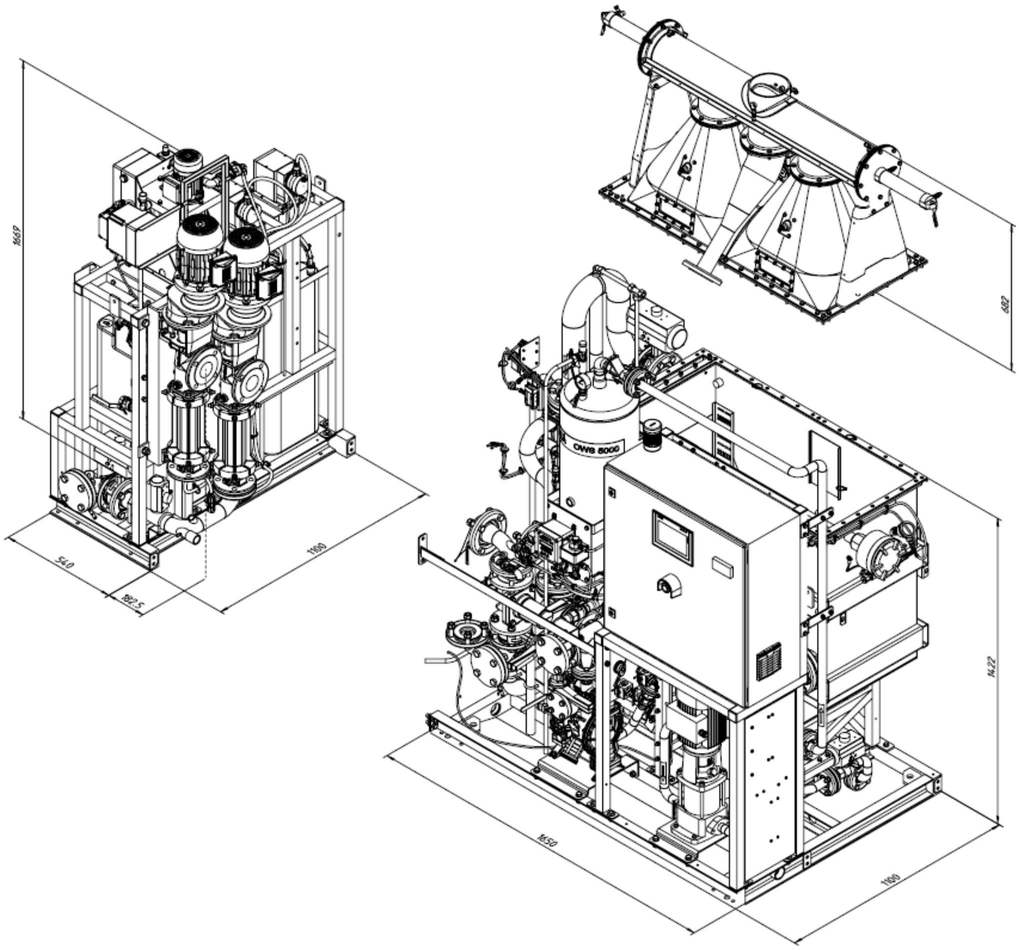


**Fig 5-5** **Wärtsilä OWS 5000 (DAAF291001)**

| Wärtsilä OWS 5000 main dimensions and weights | | | | | |
|---|---|---|---|---|---|
| Type | Weight, dry [kg] | Weight, wet [kg] | H [mm] | L [mm] | W [mm] |
| Wärtsilä OWS 5000 | 1200 | 2380 | 2109 | 2190 | 1100 |

## Process description

The Wärtsilä OWS treatment process is shown in the following diagram.

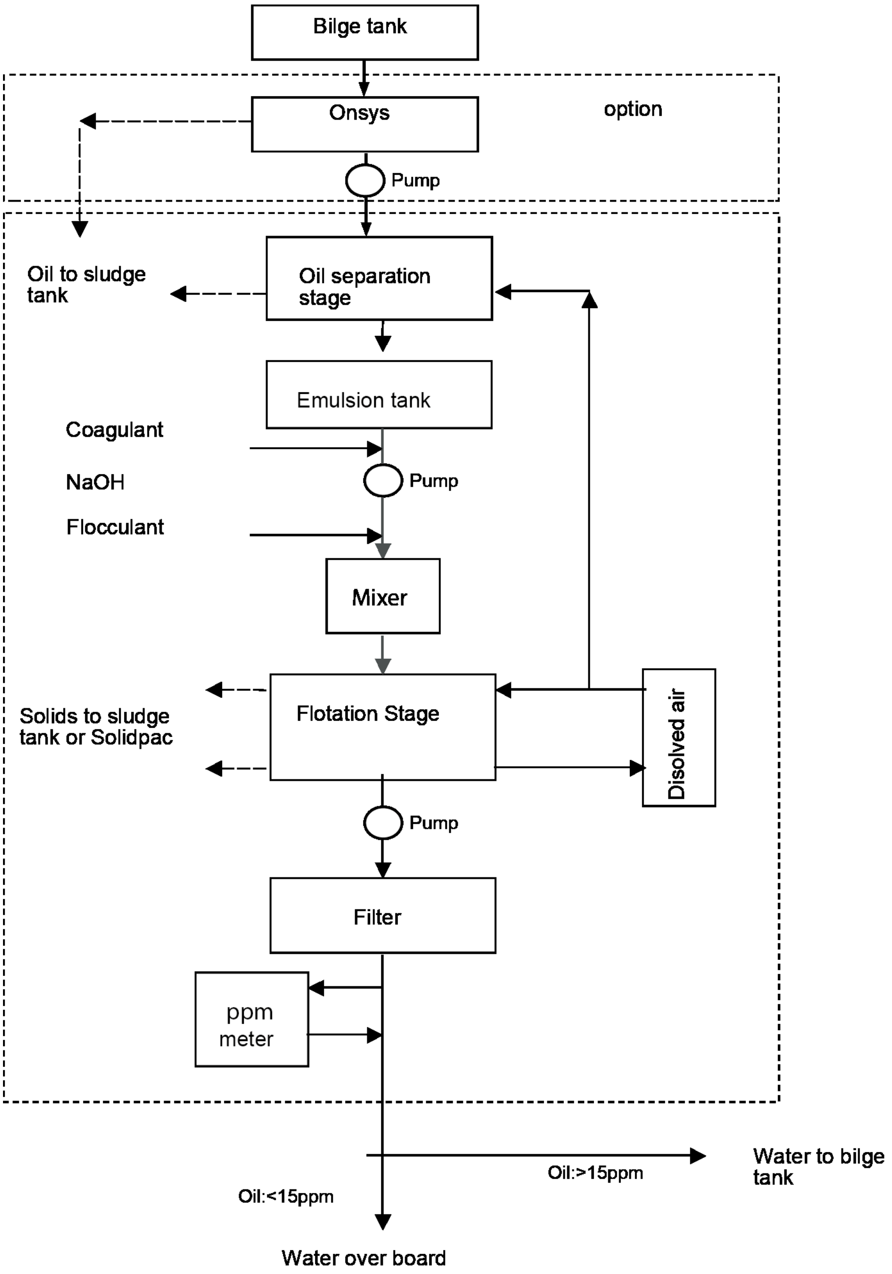


**Fig 5-6 OWS process diagram**

The first stage, known as the separation stage, is constructed for the separation of free oil from the wastewater. The water content in the separated oil depends on the quality of the oil. The oily emulsified water is pumped from the oily water buffer tank to the oil separation tank by a feed pump. In the bottom of the separation tank dispersion water (pressurized water saturated with air) is added to the oily water. The dispersion water is made by circulating treated water and adding compressed air into it in a separate tank. As the dispersion water is released to the lower pressure in the tank, micro bubbles are formed. In the tank the bubbles rise and help the oil rise to the surface, from where it is skimmed to an internal oil tank. From the internal oil tank the oil is pumped to the sludge tank. The water is collected into an integrated tank for further treatment in the flotation stage.

From the oil separation stage the emulsified water is lead through a series of mixers. Treatment chemicals are dosed with dosing pumps to the injection points on the mixers. The purpose of the chemical treatment is to break the emulsified oil in the water into particles and to make them into larger flocks that are easily separable by means of the flotation.

After the mixers the water enters the flotation stage. Again the dispersion water is injected to the bottom of the flotation tank. The micro bubbles produced are mixed with the suspended material. Gas bubbles attach to the solids forming solids/gas flocks, which are lighter than water and therefore rise to the surface and form a floating layer. The layer is removed by scraping and guided into the solids collecting tank unit. From there it is pumped to the Solidpac, solids tank or sludge tank.

The clear water passes a series of baffles and a parallel flock trap to separate the smallest particles before it is pumped to an activated carbon filter unit to clarify the water further. Before the filter, a part of the water is taken to be used as dispersion water in the dissolved air flotation. The water is discharged after the sand and/or activated carbon filter. The filter stage is included as standard delivery for Wärtsilä OWS 1000 and 2500 types. The filter stage is not included in the Wärtsilä OWS 500 and 5000 types.

The electric consumption of the Wärtsilä OWS unit is 10 kW.

### Chemicals

The chemicals used in the oily water separator process are; a coagulant, a flocculant and caustic soda (NaOH). The coagulating chemical is used for breaking the emulsified oil in the water into particles while the flocculant will collect the particles into bigger flocks for easier separation. Caustic soda is used for pH control. The unit is equipped with chemical storage and the consumption is 0.4 g/l of the coagulant, 0.4 g/l NaOH and 0.005 g/l of the flocculant. The flocculant is a powder that shall be mixed with water.

## 5.1.2 Options

The following options are available for the Wärtsilä OWS unit.

### Solidpac

A Solidpac module can be installed after the treatment unit for de-watering the solid waste from the separator. The Solidpac consists of a frame supporting two water-repellent filter sacks. 100 sacks with sealing wires are delivered as standard. The Solidpac is not available for the OWS 5000 unit.

### The Wärtsilä Bilge Water Guard

The Wärtsilä Bilge Water Guard is a bilge discharge monitoring system that constantly monitors and records the quantity of water being discharged overboard. It also monitors oil content and the time and location of the vessel. Should the effluent, for any reason, contain a level of oil exceeding the set limit, the flow is rerouted to the sludge tank. The system provides both a safety net, and a means of documenting what and where discharges have been made. According to the latest IMO regulations, the max allowed oil content in water is 15 ppm at any time.

The oily water enters the unit and a metering system measures the oil content. The information goes to a computer located in the unit. Downstream, a three way valve is located which directs the bilge water back to a bilge tank if the oil content is higher than 15 ppm (or a set limit). Further downstream a flow metering system measures the total effluent passing the Bilge Water Guard before it is discharged overboard. All this information is logged in the computer, including GPS position, ppm value and over board valve status. The Bilge Water Guard system can be connected to the ship´s automation system for easy surveillance. The Wärtsilä Bilge Water Guard has a capacity of max. 15 $m^3$/h. The installed power is 0.6 kW and the air consumption is less than 0.0001 $Nm^3$/min at 0.7 MPa (7 bar). The amount of water required for backflushing is 10 litres per flushing.

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# 6. Ballast Water Management Systems

The Wärtsilä Ballast Water Management Systems (BWMS) has been developed to comply with the Ballast Water requirements from both the IMO and the USCG.

## 6.1 Wärtsilä Aquarius® UV

### 6.1.1 System overview

Wärtsilä Aquarius® UV is a modular ballast water management system, providing a safe, flexible and economical process for the treatment of ballast water. Ballast water treatment with the Wärtsilä Aquarius® UV system is achieved through a simple and efficient two stage process. Upon uptake the sea water is first passed through a back washing filter (1st stage). The filtered sea water then passes through a UV chamber (2nd stage) where ultra-violet light is used to disinfect the water prior to entering the ballast tank. Upon discharge, water from the ballast tanks passes through the UV chamber only for a second time.

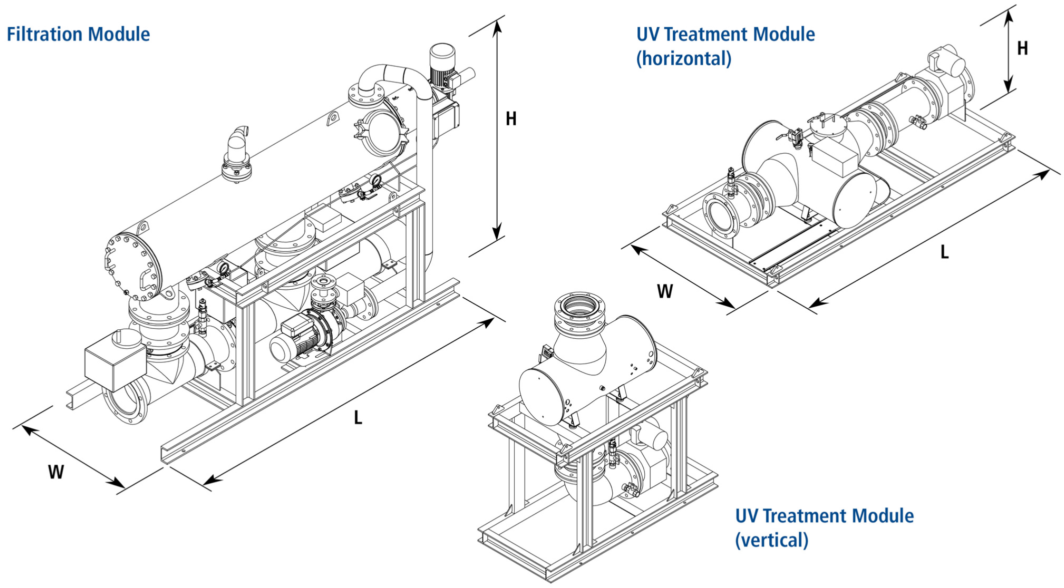


**Fig 6-1 Aquarius® UV Module**

**Table 6-1 UV Filtration Module**

| Aquarius® Module | Capacity (m3/h) | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) |
|---|---|---|---|---|---|
| AQ-50-UV | 0-50 | 2100 | 800 | 1200 | 470 |
| AQ-80-UV | 50-80 | 2400 | 800 | 1400 | 575 |
| AQ-125-UV | 80-125 | 2400 | 800 | 1500 | 700 |
| AQ-180-UV | 125-180 | 2400 | 800 | 1700 | 800 |
| AQ-250-UV | 180-250 | 3000 | 800 | 1600 | 960 |
| AQ-300-UV | 250-300 | 3000 | 800 | 1600 | 960 |
| AQ-375-UV | 300-375 | 2700 | 1100 | 2000 | 1460 |
| AQ-430-UV | 375-430 | 2700 | 1100 | 2000 | 1460 |
| AQ-500-UV | 430-500 | 3000 | 900 | 2100 | 1650 |

| Aquarius® Module | Capacity (m3/h) | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) |
|---|---|---|---|---|---|
| AQ-550-UV | 500-550 | 3000 | 900 | 2100 | 1650 |
| AQ-750-UV | 550-750 | 3700 | 1300 | 2500 | 3000 |
| AQ-850-UV | 750-850 | 3700 | 1300 | 2500 | 3000 |
| AQ-1000-UV | 850-1000 | 3700 | 1300 | 2600 | 3000 |

Capacities to 6000 m3/h achieved through a number of modular combinations.

**Table 6-2 UV Treatment Module, Horizontal**

| Aquarius® Module | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) | Total installed power (kW) |
|---|---|---|---|---|---|
| AQ-50-UV | 1500 | 900 | 700 | 265 | 19.0 |
| AQ-80-UV | 1500 | 900 | 700 | 265 | 19.0 |
| AQ-125-UV | 1500 | 900 | 700 | 265 | 19.0 |
| AQ-180-UV | 2200 | 1000 | 800 | 470 | 38.6 |
| AQ-250-UV | 2200 | 1000 | 800 | 470 | 40.1 |
| AQ-300-UV | 2200 | 1000 | 800 | 470 | 48.7 |
| AQ-375-UV | 2300 | 1000 | 800 | 540 | 47.3 |
| AQ-430-UV | 2400 | 1000 | 800 | 540 | 52.5 |
| AQ-500-UV | 2500 | 1000 | 800 | 575 | 62.6 |
| AQ-550-UV | 2600 | 1200 | 900 | 775 | 93.2 |
| AQ-750-UV | 2600 | 1200 | 900 | 775 | 93.2 |
| AQ-850-UV | 2600 | 1200 | 900 | 775 | 100.0 |
| AQ-1000-UV | 2600 | 1200 | 900 | 775 | 100.0 |

**Table 6-3 UV Treatment Module, Vertical**

| Aquarius® Module | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) | Total installed power (kW) |
|---|---|---|---|---|---|
| AQ-50-UV | 1100 | 900 | 1400 | 300 | 19.0 |
| AQ-80-UV | 1100 | 900 | 1400 | 300 | 19.0 |
| AQ-125-UV | 1100 | 900 | 1400 | 300 | 19.0 |
| AQ-180-UV | 1400 | 1000 | 2000 | 520 | 38.6 |
| AQ-250-UV | 1400 | 1000 | 2000 | 520 | 40.1 |
| AQ-300-UV | 1600 | 1000 | 2000 | 520 | 48.7 |
| AQ-375-UV | 1600 | 1000 | 2000 | 600 | 47.3 |
| AQ-430-UV | 1600 | 1000 | 2000 | 600 | 52.5 |
| AQ-500-UV | 1800 | 1000 | 2000 | 680 | 62.6 |
| AQ-550-UV | 2100 | 1200 | 2100 | 905 | 93.2 |
| AQ-750-UV | 2100 | 1200 | 2100 | 905 | 93.2 |
| AQ-850-UV | 2100 | 1200 | 2100 | 905 | 100.0 |

| Aquarius® Module | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) | Total installed power (kW) |
|---|---|---|---|---|---|
| AQ-1000-UV | 2100 | 1200 | 2100 | 905 | 100.0 |

**Table 6-4 UV Power Panel**

| Aquarius® Module | Length (mm) | Width (mm) | Height (mm) | Weight (kg) |
|---|---|---|---|---|
| AQ-50-UV | 1200 | 500 | 1300 | 200 |
| AQ-80-UV | 1200 | 500 | 1300 | 200 |
| AQ-125-UV | 1200 | 500 | 1300 | 200 |
| AQ-180-UV | 1200 | 500 | 1800 | 350 |
| AQ-250-UV | 1200 | 500 | 1800 | 350 |
| AQ-300-UV | 1200 | 500 | 1800 | 350 |
| AQ-375-UV | 1200 | 500 | 2000 | 450 |
| AQ-430-UV | 1200 | 500 | 2000 | 450 |
| AQ-500-UV | 1200 | 500 | 2000 | 450 |
| AQ-550-UV* | 1200 | 500 | 2000 | 400 |
| AQ-750-UV* | 1200 | 500 | 2000 | 400 |
| AQ-850-UV** | 1200 | 500 | 2000 | 450 |
| AQ-1000-UV** | 1200 | 500 | 2000 | 450 |

* Two UV power panels are supplied per system

** Three UV power panels are supplied per system

## 6.1.2 Operating principle

### Filtration

During uptake ballast water passes through an automatic back washing filter. The filter removes particulates, sediments, zooplankton and phytoplankton over 40 microns. Automatic filter cleaning ensures and maintains filtration efficiency.

### UV treatment

Filtered ballast water is directed into a disinfection chamber where ultraviolet lamps, set up in cross flow arrangement, deliver UV irradiation to achieve disinfection. Treated ballast water is then directed to the ballast tanks.

Lamps are fitted with an automatic wiper system which prevents bio-fouling and controls the accumulation of deposits on lamp sleeves ensuring maximum performance at all times.

UV light intensity is continuously monitored during system operation to ensure intensity is maintained and the desired dose for maximum treatment efficiency is achieved.

During discharge ballast water is pumped from the ballast tanks back through the UV disinfection chamber for final treatment before being discharged overboard. The filter is bypassed during discharge.

### Standard features

- Type approved system, compliant to IMO convention
- Accepted USCG Alternate Management System (AMS)

- Partnership program covering all stages from fleet evaluation to lifecycle support
- Turnkey solutions
- Broad environmental operating envelope
- No minimum retention time
- No active substances
- Integrated antifouling control system (No CIP)
- Filtration ensures optimum performance of the UV Chamber
- Modular construction
- Efficient use of space and power
- Easy integration with ship systems
- Flexible up-scaling
- Intelligent PLC control ensuring safe, automatic and economical operation

## 6.2 Wärtsilä Aquarius® EC

### 6.2.1 System overview

Wärtsilä Aquarius® EC is a modular ballast water management system, providing a safe, flexible and economical process for the treatment of ballast water. Ballast water treatment with a Wärtsilä Aquarius® EC system is achieved through a simple and efficient two stage process. Upon uptake the seawater is first passed through a back washing filter (1st stage) and then the filtered seawater passes through a static mixer, where the disinfectant generated from the side stream electrolysis unit (2nd stage) is injected to ensure a maximum level of 10ppm in the treated ballast water.

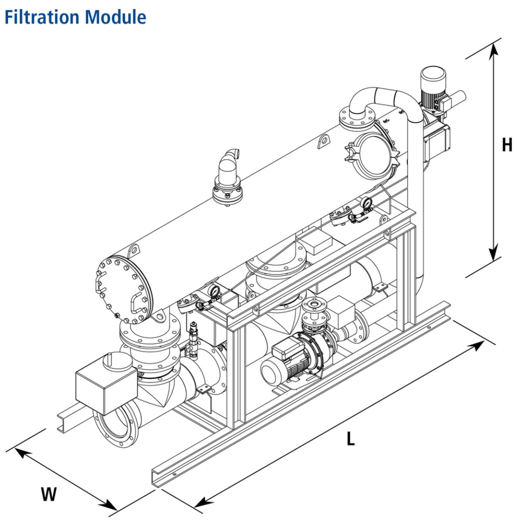


**Fig 6-2** **Aquarius® EC Module**

**Table 6-5** **EC Module**

| Aquarius® Module | Capacity (m3/h) | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) | Total installed power (kW) Installed/Nominal |
|---|---|---|---|---|---|---|
| AQ-250-EC | 0-250 | 3000 | 800 | 1600 | 960 | 24.3 / 22.1 |
| AQ-300-EC | 250-300 | 3000 | 800 | 1600 | 960 | 27.5 / 24.7 |
| AQ-375-EC | 300-375 | 2700 | 1100 | 2000 | 1460 | 31.8 / 28.2 |
| AQ-430-EC | 375-430 | 2700 | 1100 | 2000 | 1460 | 35.1 / 30.98 |
| AQ-500-EC | 430-500 | 3000 | 900 | 2100 | 1650 | 41.1 / 35.2 |
| AQ-550-EC | 500-550 | 3000 | 900 | 2100 | 1650 | 44.6 / 37.9 |
| AQ-750-EC | 550-750 | 3700 | 1300 | 2500 | 3000 | 57.6 / 47.9 |
| AQ-850-EC | 750-850 | 3700 | 1300 | 2500 | 3000 | 64.6 / 53.3 |
| AQ-1000-EC | 850-1000 | 3700 | 1300 | 2600 | 3050 | 76.6 / 62.0 |
| AQ-1200-EC | 1000-1200 | 3900 | 1300 | 2700 | 3490 | 89.3 / 71.3 |
| AQ-1500-EC | 1200-1500 | 1600 | 1700 | 3100 | 2896 | 110.0 / 88.2 |
| AQ-2000-EC | 1500-2000 | 1800 | 1800 | 3100 | 3341 | 153.6 / 120.0 |
| AQ-2400-EC | 2000-2400 | 1800 | 1800 | 3600 | 3341 | 202.2 / 148.6 |
| AQ-3000-EC | 2400-3000 | 1800 | 1800 | 3900 | 3700 | 270.2 / 197.5 |
| AQ-3300-EC | 3000-3300 | 1800 | 1800 | 3900 | 3953 | 328.6 / 237.8 |

Capacities to 13200 m3/h achieved through a number of modular combinations.

**Table 6-6 EC Sidestream Module**

| Aquarius® Module | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) |
|---|---|---|---|---|
| Aquarius® EC All sizes | 1100 | 400 | 700 | 120 |

Two sidesream modules per system.

**Table 6-7 EC Cell Module**

| Aquarius® Module | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) |
|---|---|---|---|---|
| AQ-250-EC | 2300 | 600 | 1450 | 375 |
| AQ-300-EC | 2300 | 600 | 1450 | 375 |
| AQ-375-EC | 2300 | 600 | 1700 | 490 |
| AQ-430-EC | 2300 | 600 | 1700 | 490 |
| AQ-500-EC | 2300 | 800 | 1700 | 475 |
| AQ-550-EC | 2300 | 800 | 1700 | 475 |
| AQ-750-EC | 2300 | 800 | 2000 | 525 |
| AQ-850-EC | 2300 | 800 | 2000 | 525 |
| AQ-1000-EC | 2500 | 800 | 1600 | 550 |
| AQ-1200-EC | 2500 | 800 | 1600 | 525 |
| AQ-1500-EC | 2500 | 800 | 2000 | 600 |
| AQ-2000-EC | 2500 | 1000 | 1800 | 560 |
| AQ-2400-EC | 2500 | 1000 | 1800 | 550 |
| AQ-3000-EC | 2400 | 1000 | 2400 | 650 |
| AQ-3300-EC | 2400 | 1000 | 2300 | 650 |

**Table 6-8 EC Neutralisation Module**

| Aquarius® Module | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) |
|---|---|---|---|---|
| Aquarius® EC All sizes | 1300 | 700 | 500 | 140 |

**Table 6-9 EC Dosing/Degassing Module**

| Aquarius® Module | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) |
|---|---|---|---|---|
| AQ-250-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-300-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-375-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-430-EC | 3000 | 1200 | 2000 | 1000 |

| Aquarius® Module | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) |
|---|---|---|---|---|
| AQ-500-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-550-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-750-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-850-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-1000-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-1200-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-1500-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-2000-EC | 3000 | 1200 | 2000 | 1000 |
| AQ-2400-EC | 3000 | 1600 | 2000 | 1200 |
| AQ-3000-EC | 3000 | 1600 | 2000 | 1200 |
| AQ-3300-EC | 3000 | 1600 | 2000 | 1200 |

**Table 6-10 EC Mixer Module**

| Aquarius® Module | Length (mm) | Width (mm) | Height (mm) | Dry weight (kg) |
|---|---|---|---|---|
| AQ-250-EC | 2000 | 550 | 1400 | 412 |
| AQ-300-EC | 2000 | 550 | 1400 | 412 |
| AQ-375-EC | 2400 | 650 | 1400 | 550 |
| AQ-430-EC | 2400 | 650 | 1400 | 550 |
| AQ-500-EC | 2700 | 700 | 1400 | 650 |
| AQ-550-EC | 2700 | 700 | 1400 | 650 |
| AQ-750-EC | 3000 | 800 | 1400 | 715 |
| AQ-850-EC | 3000 | 800 | 1400 | 715 |
| AQ-1000-EC | 3000 | 800 | 1400 | 715 |
| AQ-1200-EC | 3300 | 800 | 1400 | 975 |
| AQ-1500-EC | 3600 | 900 | 1500 | 1090 |
| AQ-2000-EC | 3700 | 900 | 1600 | 1245 |
| AQ-2400-EC | 4400 | 1000 | 1600 | 1600 |
| AQ-3000-EC | 4400 | 1000 | 1600 | 1600 |
| AQ-3300-EC | 4400 | 1000 | 1600 | 1600 |

## 6.2.2 Operating principle

### Filtration

During uptake ballast water passes through an automatic back washing filter. The filter removes particulates, sediments, zooplankton and phytoplankton over 40 microns. Automatic filter cleaning ensures and maintains filtration efficiency.

### Electro-chlorination

Disinfectant TRO (Total Residual Oxidant) is produced by an electrolysis module, comprising of electrolytic cells, specifically designed to generate sodium hypochlorite from sea water.

The sodium hypochlorite generated is pumped into the main ballast line, where it is mixed with filtered ballast water for efficient disinfection, and pumped into the ballast tanks. Ballast Water TRO concentration is monitored to ensure the correct hypochlorite dose.

During discharge the filter is bypassed and residual concentration of TRO in treated ballast water is monitored before being discharged overboard.

If required, treated ballast water is neutralized by injecting sodium bisulfate into the main ballast line during discharge. Neutralization effectiveness is continuously monitored to ensure compliance with MARPOL discharge limits.

### Standard features

- Type approved system, compliant with the IMO D2 Performance Discharge Standard
- Accepted USCG Alternate Management System (AMS)
- Flexible side stream electrolysis configuration
- Broad environmental operating envelope
- No salinity limits
- No temperature limits
- In situ safe, sustainable and economical disinfectant generation
- Efficient dosing controls
- Modular construction
- Efficient use of space and power
- Easy integration with ship systems
- Flexible up scaling
- Intelligent PLC control ensuring safe, automatic and economical operation

# 7. Crankcase Vent Systems

## 7.1 Oil Mist Separator Module

The combustion chamber of an engine cannot be completely sealed, a small part of the gas escapes as “blow-by” via the piston/cylinder liner gap and the piston rings into the crankcase. In turbo-charged engines there is also blow-by gas coming through the shaft sealing in the turbocharger. Since the crankcase is not designed for high pressures it requires a ventilation pipe to prevent pressure from building up inside.

As the gas pressure is very high during piston blow-by, it violently tears the lube oil off the walls breaking it into very small oil droplets forming a fine oil mist gas. These small oil droplets escape the crankcase via the crankcase ventilation which leads to oil pollution in the close surroundings and to increased lube oil consumption. By installing an oil mist separator module, the crankcase gas can be cleaned of oil droplets, even thogh the emissions from the crankcase ventilation are very low.

**System overview**

The basic function of the oil mist separator module can be seen in Figure 7.1.1. The oil mist separator is based on the centrifugal separation principle. Oily gas enters at the bottom of the separator and because of the centrifugal forces, the air is driven to the periphery of the disc stack separating the heavier oil droplets from the lighter gases by centrifugal separation. The cleaned air (the process abates odour and smoke emissions as well) exits the separator from the upper pipe connection.

The separated oil is collected through a specially designed draining system. This is carefully designed and tested to prevent already separated oil from re-entering the clean air outlet. The drained oil can be re-used by the engine and minimizes lube oil consumption. The oil mist separator module should be installed min. 10 meter from the engine. It has a cleaning efficiency of 98% and an electrical consumption of max. 1.5 kW. The oil mist separator is shown in the below picture. In addition to this, a control cabinet is also supplied.

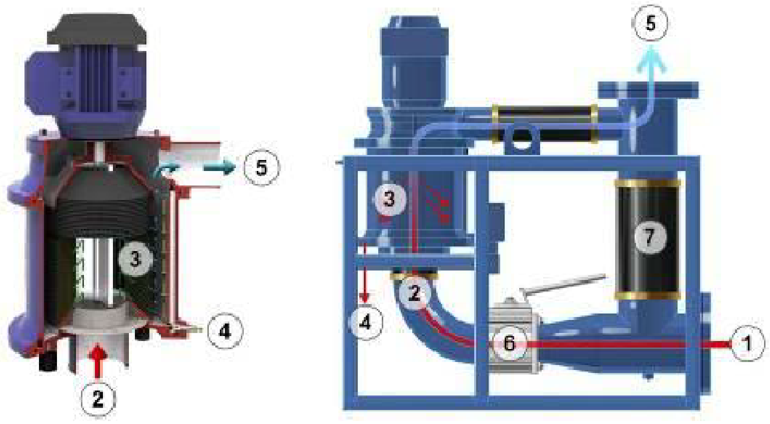


**Fig 7-1 Oil mist separator functional principle**

| Functional principle | | | |
|---|---|---|---|
| 1 | Crankcase gas from the engine | 5 | Cleaned air/gas to open air |
| 2 | Crankcase gas enters the separator | 6 | Restriction/thottle valve |
| 3 | Heavier oil droplets are separated from the lighter gases by centrifugal separation in the disc stack | 7 | Balancing pipe (by-pass line) |
| 4 | Drain oil outlet | | |

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# 8. Project guide attachments

This and other product guides can be accessed on the internet, from the Business Online Portal at www.wartsila.com. Product guides are available both in web and PDF format. Drawings are available in PDF and DXF format, and in near future also as 3D models. Consult your sales contact at Wärtsilä to get more information about the product guides on the Business Online Portal.

The attachments are not available in the printed version of the product guide.

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# 9. ANNEX

## 9.1 Unit conversion tables

The tables below will help you to convert units used in this product guide to other units. Where the conversion factor is not accurate a suitable number of decimals have been used.

*Length conversion factors*

| Convert from | To | Multiply by |
|---|---|---|
| mm | in | 0.0394 |
| mm | ft | 0.00328 |

*Mass conversion factors*

| Convert from | To | Multiply by |
|---|---|---|
| kg | lb | 2.205 |
| kg | oz | 35.274 |

*Pressure conversion factors*

| Convert from | To | Multiply by |
|---|---|---|
| kPa | psi (lbf/in$^2$) | 0.145 |
| kPa | lbf/ft$^2$ | 20.885 |
| kPa | inch $H_2O$ | 4.015 |
| kPa | foot $H_2O$ | 0.335 |
| kPa | mm $H_2O$ | 101.972 |
| kPa | bar | 0.01 |

*Volume conversion factors*

| Convert from | To | Multiply by |
|---|---|---|
| m$^3$ | in$^3$ | 61023.744 |
| m$^3$ | ft$^3$ | 35.315 |
| m$^3$ | Imperial gallon | 219.969 |
| m$^3$ | US gallon | 264.172 |
| m$^3$ | l (litre) | 1000 |

*Power conversion*

| Convert from | To | Multiply by |
|---|---|---|
| kW | hp (metric) | 1.360 |
| kW | US hp | 1.341 |

*Moment of inertia and torque conversion factors*

| Convert from | To | Multiply by |
|---|---|---|
| kgm$^2$ | lbft$^2$ | 23.730 |
| kNm | lbf ft | 737.562 |

*Fuel consumption conversion factors*

| Convert from | To | Multiply by |
|---|---|---|
| g/kWh | g/hph | 0.736 |
| g/kWh | lb/hph | 0.00162 |

*Flow conversion factors*

| Convert from | To | Multiply by |
|---|---|---|
| m$^3$/h (liquid) | US gallon/min | 4.403 |
| m$^3$/h (gas) | ft$^3$/min | 0.586 |

*Temperature conversion factors*

| Convert from | To | Multiply by |
|---|---|---|
| °C | F | F = 9/5 *C + 32 |
| °C | K | K = C + 273.15 |

*Density conversion factors*

| Convert from | To | Multiply by |
|---|---|---|
| kg/m$^3$ | lb/US gallon | 0.00834 |
| kg/m$^3$ | lb/Imperial gallon | 0.01002 |
| kg/m$^3$ | lb/ft$^3$ | 0.0624 |

### 9.1.1 Prefix

**Table 9-1 The most common prefix multipliers**

| Name | Symbol | Factor | Name | Symbol | Factor | Name | Symbol | Factor |
|---|---|---|---|---|---|---|---|---|
| tera | T | $10^{12}$ | kilo | k | $10^3$ | nano | n | $10^{-9}$ |
| giga | G | $10^9$ | milli | m | $10^{-3}$ | | | |
| mega | M | $10^6$ | micro | μ | $10^{-6}$ | | | |

## 9.2 Collection of drawing symbols used in drawings

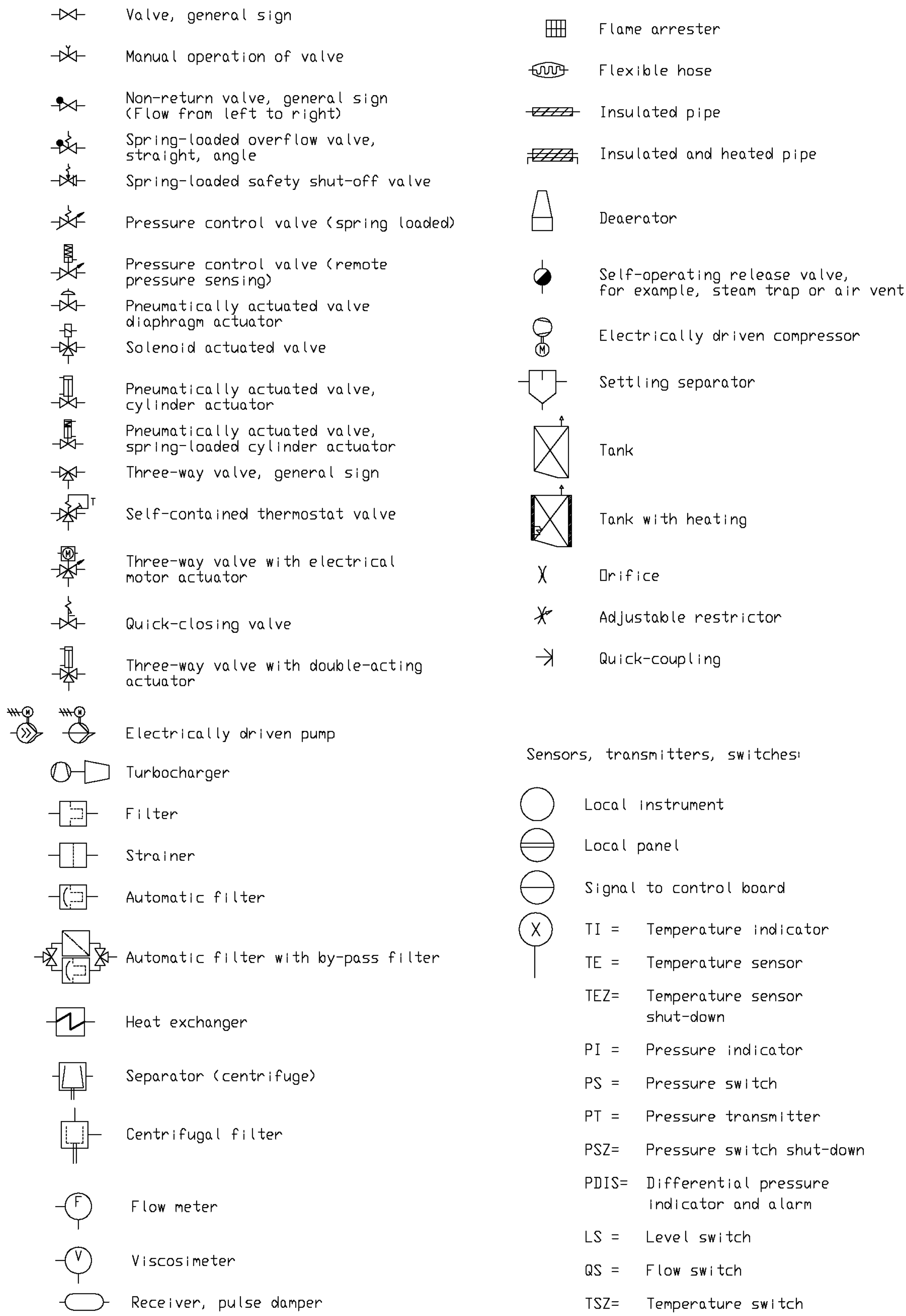


**Fig 9-1** **List of symbols (DAAE000806D)**

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