Everllence

Everllence B&W
two-stroke
marine engines



For Marpol Annex VI Regulations

Emission project guide

2026

Preface

Everllence B&W Two-stroke Marine Engines

Emission Project Guide

for Marpol Annex VI Regulations

The intention of the Emission Project Guide is to give sufficient information to decide and design solutions for emission reductions at the initial stage of a project involving Everllence B&W two-stroke marine engines.

The Emission Project Guide is divided in two parts:

Part 1 NO_x reduction – IMO Tier III solutions

Part 2 SO_x reduction – exhaust gas cleaning system

The information provides technical data needed for the **preliminary** design, including data for performance, layout, consumables, control and installation of the equipment. The information is to be considered as preliminary. It is intended for the project stage only and subject to modification in the interest of technical progress. The Emission Project Guide provides the general technical data available at the date of issue.

It should be noted that all figures, values, measurements or information about performance stated in this project guide are for **guidance only** and should not be used for detailed design purposes or as a substitute for specific drawings and instructions prepared for such purposes.

The latest, most current version of the Emission Project Guide is available on the Internet at: www.everllence.com → 'Marine' → 'Planning tools and downloads' → 'Project guides'.

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Depending on the subsequent specific individual projects, the relevant data may be subject to changes and will be assessed and determined individually for each project. This will depend on the particular characteristics of each individual project, especially specific site and operational conditions.

If this document is delivered in another language than English and doubts arise concerning the translation, the English text shall prevail.

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Abbreviations

ABS	Ammonium Bisulphate
AIG	Ammonia Injection Grid
CEAS	Computerised Engine Application System
CBV	Cylinder Bypass Valve
DCU	Decomposition Unit
ECA	Emission Control Area
EGB	Exhaust Gas Bypass
EGCS	Exhaust Gas Cleaning Systems
EGR	Exhaust Gas Recirculation
EMC	Electro Magnetic Compatibility
ERCS	Emission Reduction Control System
FW	Freshwater
HFO	Heavy Fuel Oil
HP	High Pressure
HS	High Sulphur
IMO	International Maritime Organisation
ISO	International Standard Organisation
LL	Low Load
LNG	Liquified Natural Gas
LP	Low Pressure
LS	Low Sulphur
MARPOL	International Convention for the Prevention of Pollution from Ships
ME-ECS	Engine Control System
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
MOP	Main Operating Panel
MPC	Multi Purpose Controller
NECA	NO_X Emission Control Area
NO_X	Nitrogen Oxides
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
QC	Quality Control
RH	Relative Humidity
RBV	Reactor Bypass Valve
RSV	Reactor Sealing Valve

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RTU	Receiving Tank Unit
RTV	Reactor Throttle Valve
S%	Sulphur content percentage in fuel oil
SCR	Selective Catalytic Reduction
SECA	SO_x Emission Control Area
SFOC	Specific Fuel Oil Consumption
SMCR	Specified Maximum Continuous Rating
SO_x	Sulphur Oxides
SU	Supply Unit
SW	Seawater
T/C or TC	Turbocharger
VAR	Valve After Reactor
VBR	Valve Before Reactor
WC	Water Column
WCU	Water Cleaning Unit
WHS	Water Handling System
WMC	Water Mist Catcher
WTS	Water Treatment System

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1 Introduction

1.1 NO_x and SO_x regulations

The international requirements on emissions of NO_X (nitrogen oxides), SO_X (sulphur oxides) and PM (particulate matter) are determined by the *MARPOL convention Annex VI – Regulations for the Prevention of Air Pollution from Ships.*

- NO_X

  According to the rules, the NO_X emission of any marine diesel engine installed in a ship constructed on or after 1st January 2016 shall meet the so-called Tier III level when operating inside a NO_X emission control area (NO_X ECA). In case a NO_X ECA is designated at a later date, the requirements only apply to ships constructed on or after this date. The ECA in North America is applicable for NO_X from January 2016 and the ECA in Northern Europe is applicable for NO_X from January 2021.

  Any abatement technology reducing the NO_X emission to the required level can be accepted. However, guidelines developed for this purpose must be followed.

- SO_X and PM

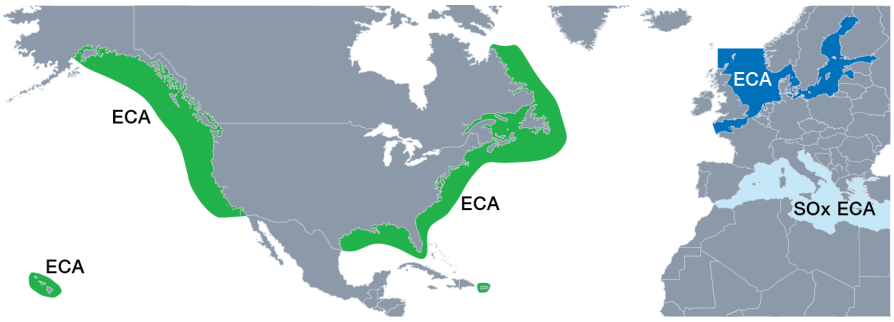
  Emissions of SO_X and PM are regulated by the sulphur content of any fuel used on board ships. The rules of SO_X and PM apply to all ships, no matter the date of ship construction.

  Any abatement technology reducing the emission of SO_X to a level equivalent to the emission level when using compliant fuels will be accepted, provided the relevant guidelines are followed.

  The global sulphur limit is 0.5% S. However, when sailing in SO_x emission control areas (SO_x ECA), which are defined in North America, Northern Europe and the Mediterranean Sea, the sulphur content of fuel oil must not exceed 0.1% S.

The ECA applicable today are shown in Fig.1, Page 8.

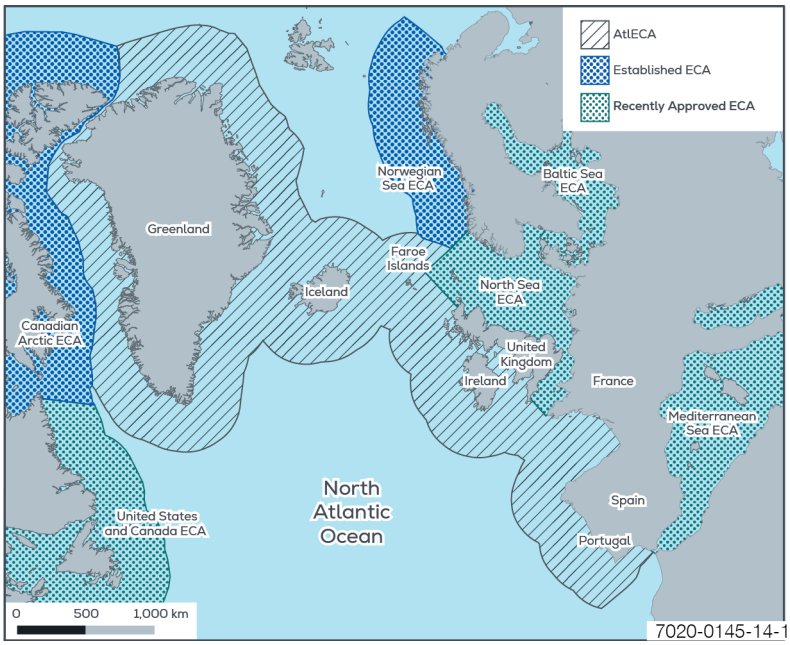
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Figure 1: Existing Emission Control Area – in North America and Europe

In addition to the existing ECA's it has been agreed to introduce a NO_x and SO_x ECA for the Norwegian Sea and the Canadian Artic Sea, taking effect from March 2026, and a North East Atlantic ECA, taking effect from March 2027.



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Figure 2: Agreed Emission Control Areas

2 NO_x reduction – Tier III solutions

2.1 NO_x limits

The international NO_X emission limits on marine diesel engines as determined by MARPOL Annex VI are shown in Fig. 3, Page 9, as a function of the rated engine speed, rpm.

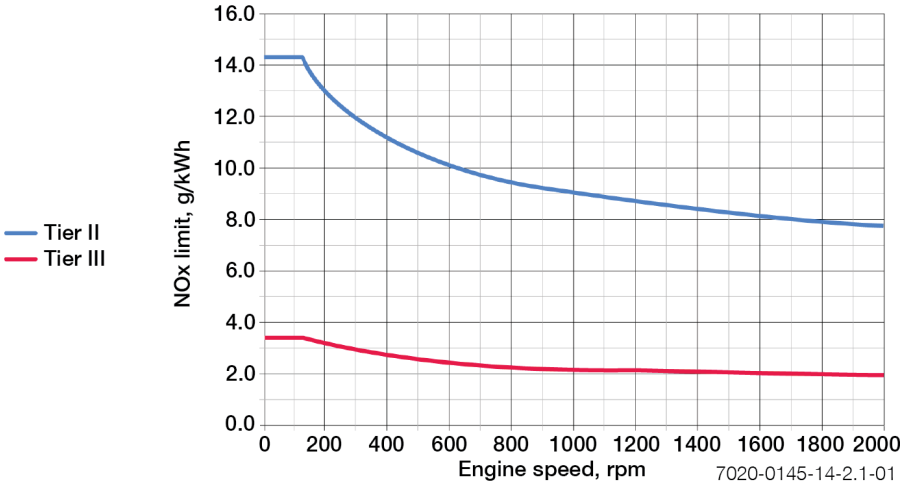


Figure 3: NO_x emission limits according to MARPOL Annex VI

The Tier II limits must be met globally by all ships constructed January 1st 2011 or later.

Tier III limits are local requirements to be met in designated NO_X Emission Control Area by ships which are constructed on or after the ECA designation date of the specific area. The present NO_X ECA and dates are listed in Table 1, Page 9.

NO_x Emission Control Area		NO_x ECA designation date
North America	US/Canada - 200 naut. mile	January 1st 2016
Northern Europe	Baltic sea, North sea and English channel	January 1st 2021
Norway	Norwegian Sea area	March 1st 2026
Canada	Canadian Arctic Sea area	March 1st 2026
North-East Atlantic	Europe, Iceland, Greenland	March 1 st 2027

Table 1: NO_x Emission Control Area

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2.2 Approach to NO_x reduction

Everllence offers more alternative methods to meet the Tier III NO_x requirement on two-stroke engines:

- Exhaust Gas Recirculation (EGR), is an internal engine process using recirculation of exhaust gas to prevent the formation of NO_x.
- Selective Catalytic Reduction (SCR), is an after-treatment method using a catalyst and an additive to reduce the NO_x generated in the combustion process. The SCR system is available in a high pressure system, SCR-HP, and a low pressure system, SCR-LP.
- Water in methanol (LGIM-W), is a method to obtain Tier III compliance on an engine operating on methanol by adding water in the methanol before injection.
- Low pressure gas engine (ME-GA) is a dual fuel engine where gas is admitted during the compression stroke. In this process the formation of NO_x is low, and the engine will meet the Tier III NO_x requirement when operating in dual-fuel mode. The ME-GA engine is configured as an EGR engine and presented in the EGR chapter.

Fig. 4, Page 10 shows examples on layout of EGR and SCR engines.

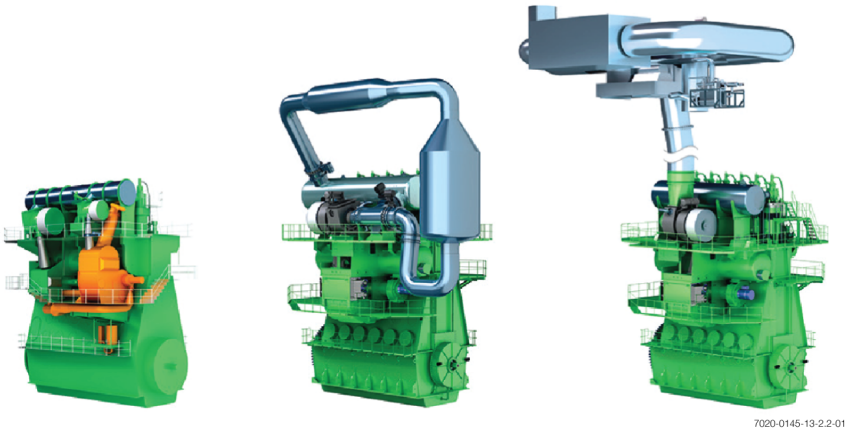


Figure 4: Examples of Tier III engine – EGR, HP SCR and LP SCR solutions

Influence of sulphur in fuel

In addition to meet the Tier III NO_X requirement, ships sailing in a combined NO_X and SO_X ECA must either run on low-sulphur fuel or run an exhaust gas cleaning process, i.e. a SO_X scrubber system. The SCR-HP system is the only system which is able to run on high sulphur fuel, but in this case the exhaust gas system must be equipped with a SO_X scrubber system. The EGR system and the SCR-LP system cannot be used for high sulphur fuel on two-stroke engines. When planning the Tier III installation, these conditions must be taken into account.

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2.3 NO_x compliance in service

A Tier III engine has two emission cycle operating modes: Tier II for operation outside NO_x Emission Control Areas and Tier III for operation inside NO_x Emission Areas.

Similar to the existing fleet of Tier I and Tier II engines, emission compliance needs to be verified in service. Annual surveys are required, but also ensuring day to day emission regulation compliance is an issue that must be covered. For this purpose Everllence B&W engines offer two different systems specifically developed for Tier III engines:

- Two specialized Onboard Survey Methods for demonstration compliance for each of the operating modes for Tier II and Tier III
- Engine control system output signals allowing monitoring of when Tier III mode is engaged

Onboard Survey Method

The specialized Onboard Survey Methods included in the engine NO_x Technical File for Tier II and Tier III modes offers a tool to verify that the engine fulfills the relevant NO_x levels.

The Onboard Survey Method is similar to the well-known Unified Survey Method developed and delivered with numerous Everllence B&W engines through the last 15 years. The Onboard Survey Method utilized the performance parameter method as described in MARPOL Annex VI and the NO_X Technical Code. By reading or measuring certain performance parameters and comparing to limit values, the compliance is verified. The Onboard Survey Method for Tier II mode on a Tier III engine is similar to the Onboard Survey Method delivered with standard Tier II engines. For the Tier III mode a few additional parameters are included.

Regarding EGR, NO_x reduction is closely correlated to the O_2 content of the mixed fresh intake air and cleaned recirculated exhaust gas. The parameter is also used for control of the EGR ratio. Due to this, O_2 is included as an Onboard Survey parameter for EGR.

Regarding SCR, the consumption of reducing agent and an exhaust emission concentration sensor is used to verify that the system is fully functional as intended and certified. The consumption of reducing agent is included as an onboard Survey parameter for SCR. The concentration sensor is used in the control system to catch two different phenomenon's indicating a system problem:

- Lower NO_x concentration than expected, indicating an overdose of reducing agent and thus a potential risk of Ammonia slip
- Higher than expected NO_x concentration, indicating a potential failure in the NO_x reduction system

The two indications should be followed up by a system diagnostics in order to find the potential problem. If a problem is found, possible solutions will be suggested.

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Monitoring of NO_x compliance

The requirement for operating the engine in Tier III mode is triggered when the ship is sailing inside a NO_x Emission Control Area. The operator must assure that the engine is operated in accordance with the requirements. Tier III compliance could be documented using a logging system but this is not part of the engine control system. To facilitate this, Everllence B&W engines are equipped with an engine control system which delivers signal output documenting the emission mode status of the engine.

Two Tier III compliance status signals are available:

- 'Tier III system started'. This signal is activated when 1) a Tier III mode command has been issued to the engine control system, and 2) the Tier III system is working (no failures, auto mode)
- 'NO_x reduction active'. This signal is activated when NO_x reduction begins

The first signal allows for logging when a Tier III mode command is issued by the ship crew, the second allows for logging when the engine is actually operating at reduced NO_x emission level. The difference between the two signals is caused by startup time or by specific operating conditions.

Certain cases will result in non-error situations where the operator has issued a command and the system is not reducing NO_x. This could happen in the following situations:

- Engine load change is faster than the guidance load change curve
- Rough sea conditions resulting in oscillating engine load
- Time during engaging and dis-engaging of control valves
- Engine load or ambient conditions outside the operating window of the emission control system as specified in the NO_x Technical File

Tier III systems are designed to minimize these cases as far as possible. As the engine is Tier III certified, and these are transient situations not covered by the certification cycle, the engine is still considered to be in Tier III mode although NO_x reduction is not occurring.

In case of system failures, the engine control system will issue an alarm code and text, allowing for the situation to be corrected. In addition, both Tier III compliance signals are removed.

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3 EGR – Exhaust Gas Recirculation

3.1 Principle

Exhaust gas recirculation (EGR) is a method to significantly reduce the formation of NO_X in marine diesel engines. By using this method, the Tier III requirements in NO_X ECA can be met.

In the EGR system, after a cooling and cleaning process, part of the exhaust gas is recirculated to the scavenge air receiver. In this way, part of the oxygen in the scavenge air is replaced by CO_2 from the combustion process. This replacement decreases the O_2 content and increases the heat capacity of the scavenge air, thus reducing the temperature peak of the combustion and the formation of NO_X. The NO_X reduction is almost linear to the ratio of recirculated exhaust gas.

The principle of EGR is illustrated in Fig. 5, Page 13.

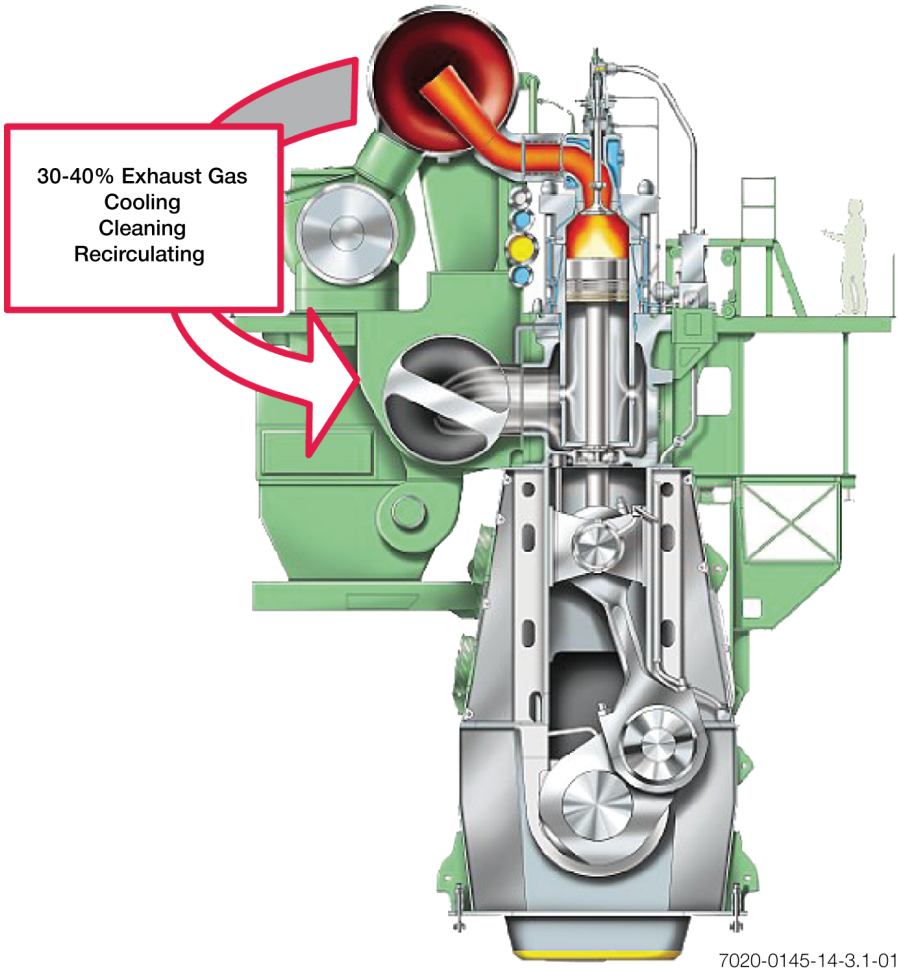


Figure 5: Principle of EGR

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3.2 System

Three different matching methods are used for the EGR systems:

- EGR with bypass, configured with only one turbocharger and used for engines of bore 70 or less.
- EGR with TC cut out matching, configured with two or more turbochargers and used for engines of bore 80 or greater.
- EcoEGR, configured as EGR with bypass. EcoEGR is a fuel optimised engine, which lowers the SFOC in both Tier II and Tier III mode, by using EGR to meet the relevant NO_x limit.

3.2.1 Bypass matching

An EGR system configured with bypass matching consists of two strings, a main string and an EGR string, which are available to direct the scavenge air into the scavenge air receiver.

An EGR system configured with bypass matching is shown in below Fig. 6, Page 14.

- The main string, with the capacity to lead all the scavenge air through the turbocharger compressor and the scavenge air cooler.
- The EGR string, with the capacity to lead up to 40% of the exhaust gas through the pre-spray and the EGR unit (EGR cooler and WMC) to a mixing chamber in the main string.

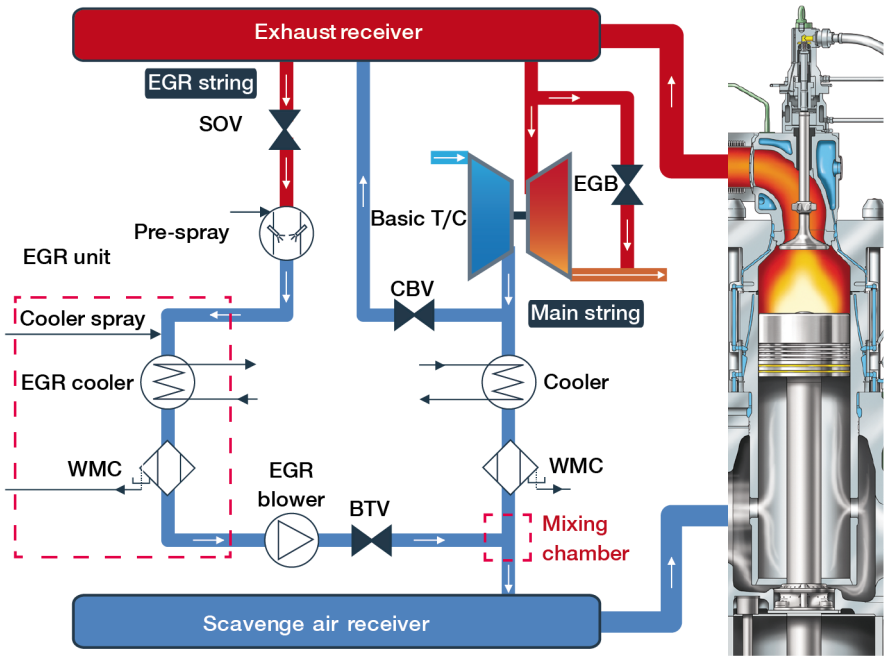


Figure 6: EGR Bypass matching

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Two modes are available for bypass matching:

- Tier II mode

  In Tier II mode only the main string is in operation. The valves in the EGR string (SOV/BTV) and the cylinder bypass (CBV) is kept closed. In this mode, the exhaust gas bypass (EGB) is fully open at high loads and partly open at low loads to balance the turbocharger.

- Tier III mode

  In Tier III mode, the EGR string is activated by opening the EGR shut-off valve and the blower throttle valve (SOV/BTV). The exhaust gas is led through the pre-spray and the EGR unit to the mixing point and scavenge air receiver, forced by the EGR blower. The EGR ratio is controlled by changing the flow of the EGR blower. The cylinder bypass (CBV) is active in this mode to increase the scavenge air pressure. The exhaust gas by-pass (EGB) is closed.

In Table 2, Page 15 an overview of the valve control is presented.

<table>
<tr><th colspan="7">EGR Bypass matching</th></tr>
<tr><th></th><th colspan="3">Tier II mode</th><th colspan="3">Tier III mode</th></tr>
<tr><th>MCR %</th><th>SOV
BTV</th><th>CBV</th><th>EGB</th><th>SOV
BTV</th><th>CBV</th><th>EGB</th></tr>
<tr><td>100</td><td rowspan="4">Closed</td><td rowspan="4">Closed</td><td>Open</td><td rowspan="4">Open</td><td rowspan="3">Open</td><td rowspan="4">Closed</td></tr>
<tr><td>75</td><td rowspan="3">Partly Open</td></tr>
<tr><td>50</td></tr>
<tr><td>25</td><td>Closed</td></tr>
</table>

Table 2: Control valve operation - EGR bypass

3.2.2 TC cut-out matching

An EGR system with TC cut out matching, consists of three, a main string, a cut out string, and an EGR string, which are available in the system to direct the scavenge air into the scavenge air receiver.

See Fig. 7, Page 16

- The main string, leads up to 70% of the scavenge air through the basic turbocharger and the scavenge air cooler.
- The cut out string, leads up to 40% of the scavenge air through the cut out turbocharger and through the EGR unit (EGR cooler and WMC) before entering the scavenge air receiver through the balance pipe.
- The EGR string, leads up to 40% of the exhaust gas through a pre-spray and EGR unit to a mixing chamber in the main string, forced by one, or more EGR blowers. In this case, the cut out string is closed.

On some larger engines, a configuration with two turbochargers will be needed. The principle is unchanged although the number of turbochargers and EGR units are increased, see Fig. 8, Page 17.

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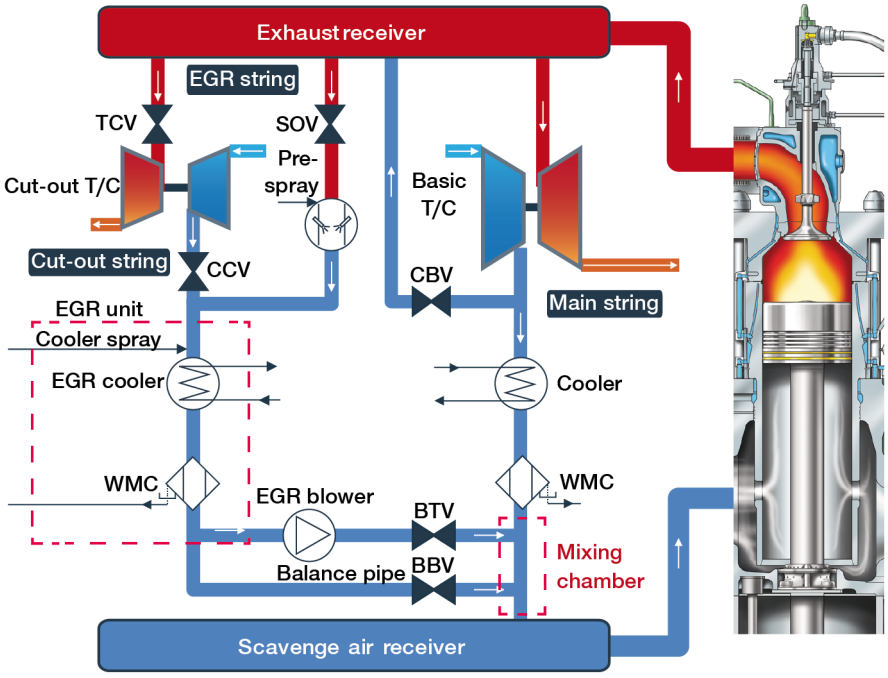


Figure 7: EGR TC cut-out matching - one basic TC

Three modes are available for TC cut out matching:

- Tier II mode - TC cut in

  The Tier II mode is the standard mode used outside NO_x ECAs. The main string and the cut out string are in operation. The TC cut out valves (TCV/CCV) and the blower bypass valves (BBV) are open, while the EGR string is kept closed by the EGR shut-off valve and the blower throttle valve (SOV/BTV). In this mode, the EGR cooler works as a normal scavenge air cooler. About 40% of the scavenge air is passed through the cut out string, the remaining 60% through the main string. The cylinder bypass (CBV) is kept close in this mode.

- Tier II mode – TC cut out

  The cut out string gives an opportunity to run the engine in Tier II mode at low loads with a TC cut out and the SFOC could thereby be reduced. In this case only the main string will be open, while the cylinder bypass valve (CBV) is kept closed.

- Tier III mode

  The Tier III mode is used inside NO_x ECAs. The cut out string is closed by the TC cut out valve and compressor cut out valve (TCV/CCV) and the EGR string is activated by opening the EGR shut off valve and the blower throttle valve (SOV/BTV). The exhaust gas is led through the pre-spray and the EGR unit to the mixing chamber and the scavenge air receiver, forced by the EGR blowers. The mixture of air and recirculated gas is finally led to the scavenge air receiver. The EGR ratio is controlled by changing the flow of the EGR blower so that the O_2 level meets the setpoint corresponding to Tier III NO_x levels. The cylinder bypass (CBV) is partly active in this mode to partly recover the scavenge air pressure.

In Table 3, Page 17 an overview of the valve control is presented.

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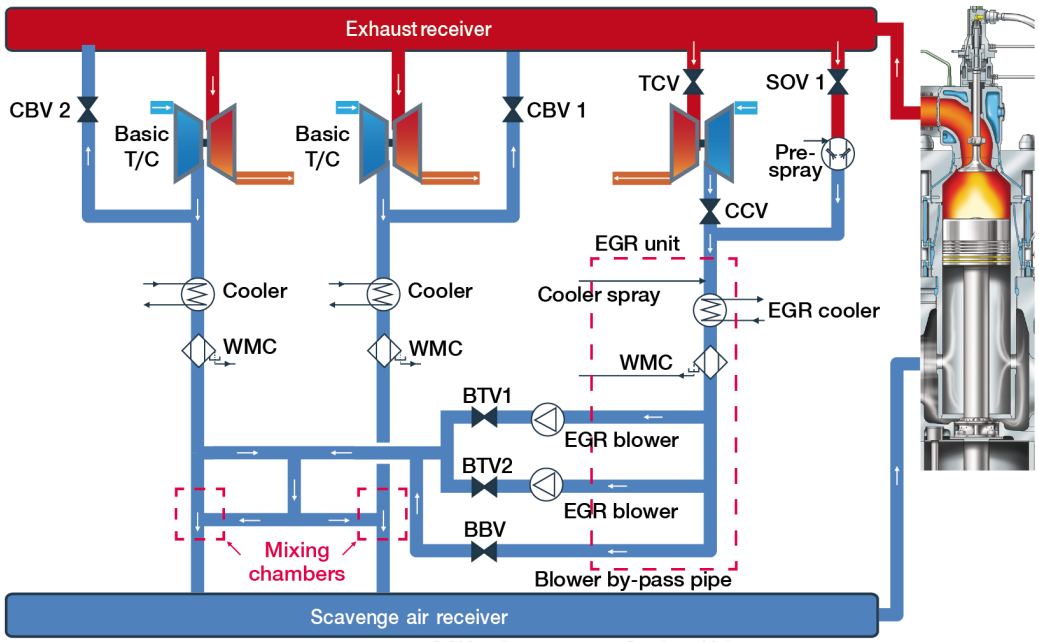


Figure 8: EGR TC cut-out matching - two basic TC

EGR TC CUT-OUT matching with 1 and (2) Basic TC			
MCR%	**SOV BTV 1 (BTV 2)**	**CBV 1 (CBV 2)**	**TCV CCV BBV**
Tier II mode			
100	Closed	Closed	Open
75			
50			
25			
Tier II mode - TC CUT-OUT			
100	Not Applicable		
75	Closed	Closed	Closed
50			
25			
Tier III mode			
100	Open	Closed	Closed
75		Partially Open	
50			
25		Closed	

Table 3: Control valve operation, TC cut-out configured with 1 (or 2) basic TC

3.2.2.1 TC cut out matching, 2-string EGR

In case the engine is configured with a specifically high SMCR power the engine will need two EGR units to supply the required amount of recirculated gas. This is needed for 10-12G95ME engines, depending on the specified MCR power. The process diagram of the 2-string EGR engine is shown in Fig. 9, Page 18. The valve control is presented Table 4, Page 18.

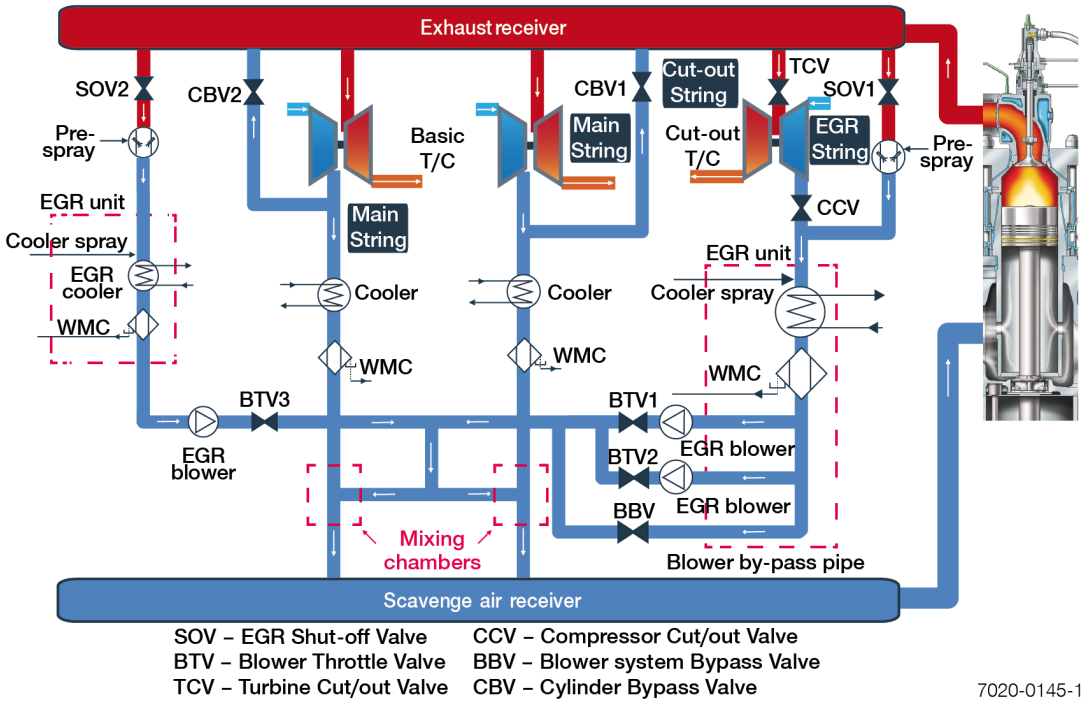


Figure 9: 2-string EGR TC cut-out

Two String EGR cut-out matching					
MCR%	CBV 1 CBV 2	TCV CCV	BBV	SOV 2 BTV 3	SOV BTV 1 BTV 2
Tier II mode					
100	Closed	Open	Open	Closed	Closed
75					
50		Closed			
25					
Tier III mode					
100	Open	Closed	Closed	Open	Open
75					
50					
25	Closed				

Table 4: Control valve operation, 2-string EGR TC cut-out

The engine is configured with two basic TC and one cut-out TC. The recirculated exhaust gas is supplied in two EGR strings, a By-pass string and a TC cut-out string and distributed by the EGR blowers to the mixing chambers before inlet to the scavenge air receiver. To obtain sufficient EGR capacity two EGR blowers will normally be needed for the TC cut-out string.

The process diagram of the 2-string EGR engine is shown in Fig. 9, Page 18 including two basic TC and one cut-out TC. There are no specific TC cut-out mode on 2-string EGR engines.

In Table 4, Page 18 an overview of the valve control is presented, covering EGR TC cut-out with one and two basic T/C.

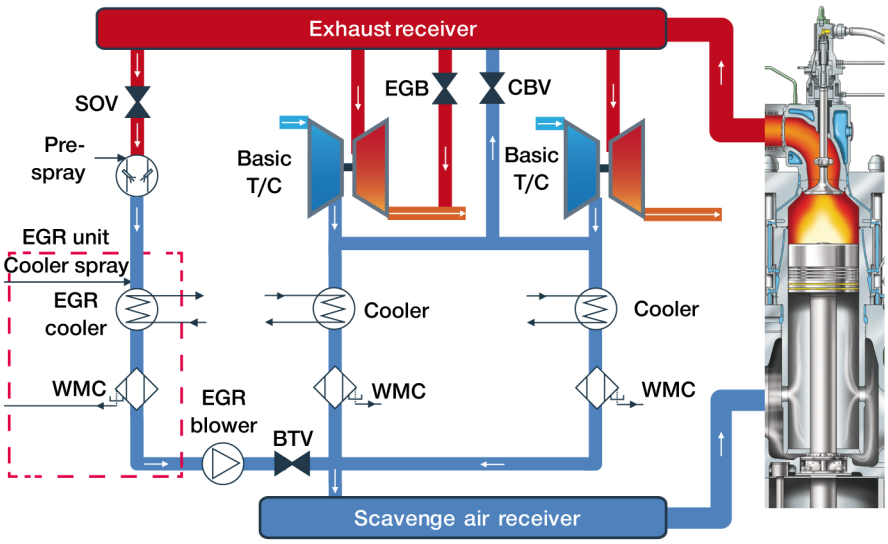
3.2.3 EcoEGR

The EcoEGR system operates permanently in EGR state regardless of sailing area. The EGR rate is adapted to the NO_x limits in the area, that is, Tier III mode inside NECA and Tier II mode outside NECA. The SFOC reduction is around 2.5% in Tier II mode and 1.0% in Tier III mode.

An extra Tier II fall-back mode is available to maintain Tier II compliance in case a serious failure to the EGR system occurs.

The EcoEGR system is configured similar to the EGR bypass concept, and can be installed with one or two turbochargers.

See Fig. 10, Page 19 and Fig. 6, Page 14 in the earlier chapter.



SOV – EGR Shut-off Valve
BTV – Blower Throttle Valve
CBV – Cylinder Bypass Valve
EGB – Exhaust Gas Bypass Valve

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Figure 10: EGR process diagram: EcoEGR matching with two TC

Two modes are available for EcoEGR:

- EcoEGR Tier II mode

  In EcoEGR Tier II mode the engine operates with a low EGR rate, around 10-15%. The EGR shut-off valve (SOV) and the blower throttle valve (BTV) are fully open, while the cylinder bypass valve (CBV) is closed. Except at high loads the exhaust gas bypass (EGB) is also closed.

- EcoEGR Tier III mode

  In EcoEGR Tier III mode the engine operates with an EGR rate 25–45%, similar to EGR Bypass matching. The EGR shut-off valve (SOV) and the blower throttle valve (BTV) are fully open. The cylinder bypass valve (CBV) is open except at low loads, while the exhaust gas bypass valve (EGB) is closed.

In Table 5, Page 20 an overview of the valve control of EcoEGR is presented.

	EcoEGR					
	Tier II mode			Tier III mode		
MCR %	SOV BTV	CBV	EGB	SOV BTV	CBV	EGB
100	Open	Closed	Open	Open	Open	Closed
75			Closed			
50						
25					Closed	

Table 5: Control valve operation

3.2.4 ME-GA engine

The ME-GA engine is a dual fuel engine, designed to operate on gas at low supply pressure in Otto-cycle process, and on fuel oil at high supply pressure in Diesel-cycle process. See Fig. 11, Page 21.

When operating on gas in Otto-cycle process, the generation of NO_x is largely suppressed and this operation mode will accordingly comply with the NO_x Tier III requirement. However, an unintended methane slip is likely to happen, if no specific measures are introduced. Furthermore, the Otto-cycle process introduces a risk of knocking, which must be prevented.

By introducing the EGR principle to the ME-GA engine, it is possible to suppress the methane slip and to prevent knocking. Accordingly, the ME-GA engine is configured as an EcoEGR engine.

When operating on fuel oil in Diesel-cycle process, the EcoEGR configuration is used to comply with NO_x Tier III requirement and to improve fuel efficiency in both Tier II and Tier III mode similar to other EcoEGR engines.

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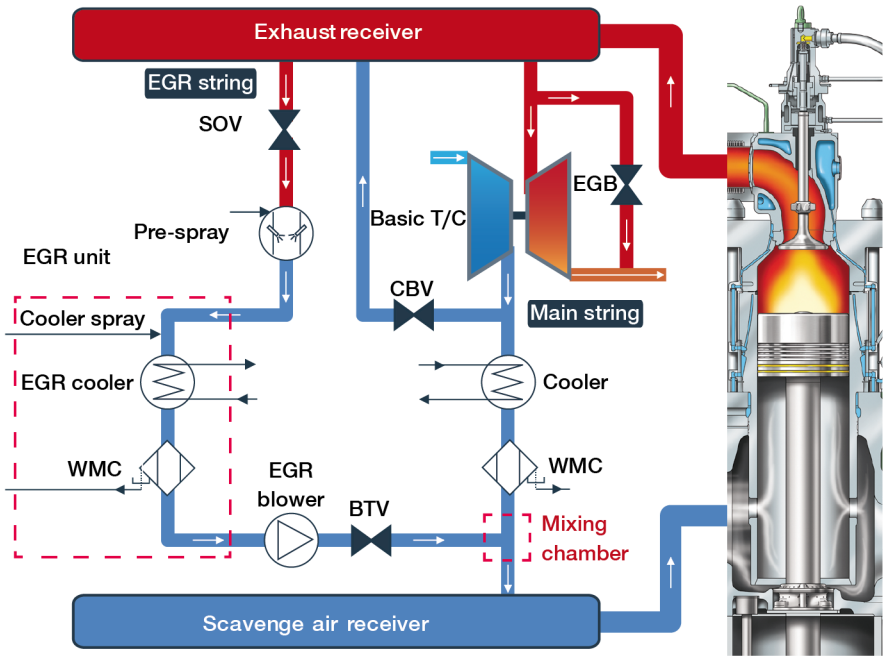


Figure 11: ME-GA process diagram

Three modes are available for ME-GA:

- **Gas Tier III mode**
  In Gas mode the ME-GA engine is permanently Tier III compliant. In this mode, the EGR rate is around 30%. The EGR Shut-off Valve, SOV, and the Blower Throttle Valve, BTV, are open. The Cylinder Bypass Valve, CBV, is closed. The Exhaust Gas Bypass Valve, EGB, is open at low load and closed at high load
- **Diesel Tier II mode**
  In Diesel Tier II mode the engine operates with a low EGR rate, around 30%. The EGR Shut-off Valve, SOV, and the Blower Throttle Valve, BTV, are fully open. The cylinder bypass valve (CBV) is closed. The exhaust gas bypass valve (EGB) is closed, except at high load.
- **Diesel Tier III mode**
  In Diesel Tier II mode the engine operates with a high EGR rate, around 35%. The EGR Shut-off Valve, SOV, and the Blower Throttle Valve, BTV, are open. The Cylinder Bypass Valve, CBV, is open except at high load. The Exhaust Gas Bypass Valve, EGB, is closed except below 25% and above 90% MCR.

In Table 6, Page 21 an overview of the valve control of EcoEGR is presented.

	Gas Tier III mode			Diesel Tier II mode			Diesel Tier III mode		
MCR %	SOV BTV	CBV	EGB	SOV BTV	CBV	EGB	SOV BTV	CBV	EGB
100	Open	Closed	Closed	Open	Closed	Open	Open	Closed	Open
75						Closed		Open	Closed
50			Open						
25									Open

Table 6: ME-GA Control valve operation

3.3 Layout

The EGR cooler and water mist catcher are installed in the EGR unit. The unit, shown in Fig. 12, Page 22 , includes a cooler spray with a function to increase the cooling efficiency and to keep the cooler clean. A pre-spray used to prepare the EGR gas for cooling and cleaning is installed in the gas pipe upstream of the EGR unit.

The EGR unit used for a low sulphur EGR system (LS EGR) is designed from a material selection perspective for a fuel sulphur limit of 0.5% S, covering not only the ECA sulphur limit of 0.1% S but also the 2020 global limit of 0.5% S as used for EcoEGR engines. The EGR unit is integrated on the engine, similar to a scavenge air receiver.

The presence of sulphur in the EGR gas requires that different grades of stainless steel are used for the EGR unit and the EGR cooler. These steel grades cannot be used in connection with seawater, as chlorides in the water will lead to corrosion, and accordingly a central cooling system using freshwater as cooling media is specified for the EGR cooler.

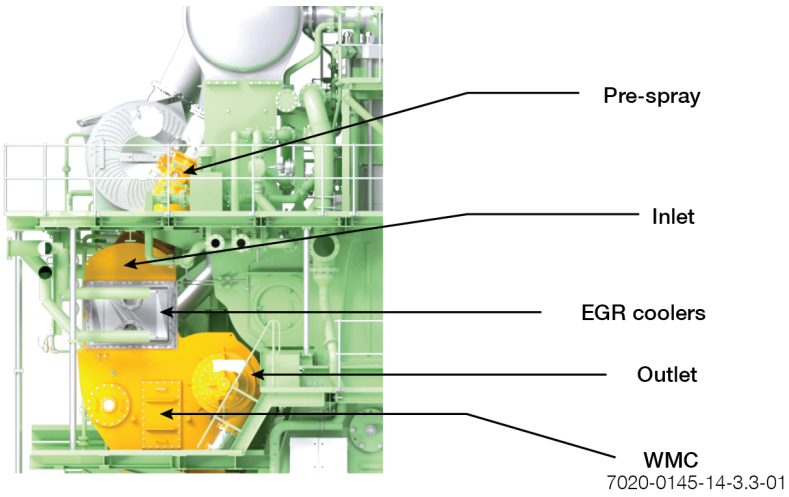


Figure 12: Model of EGR unit

The supply of water to the pre-spray and EGR cooler spray, and the removal of water from the EGR unit is part of the EGR water handling system, which will control and recirculate the water. The system – which also includes discharge of excess water generated in the combustion process - is described and illustrated in Chapter Water Handling System (WHS). Part of the water handling system, i.e. the Receiving Tank Unit (RTU) which includes a small tank and a circulation pump, is integrated on the engine.

The layout of the EGR engines is shown in Fig.13, Page 23 and Fig.14, Page 23.

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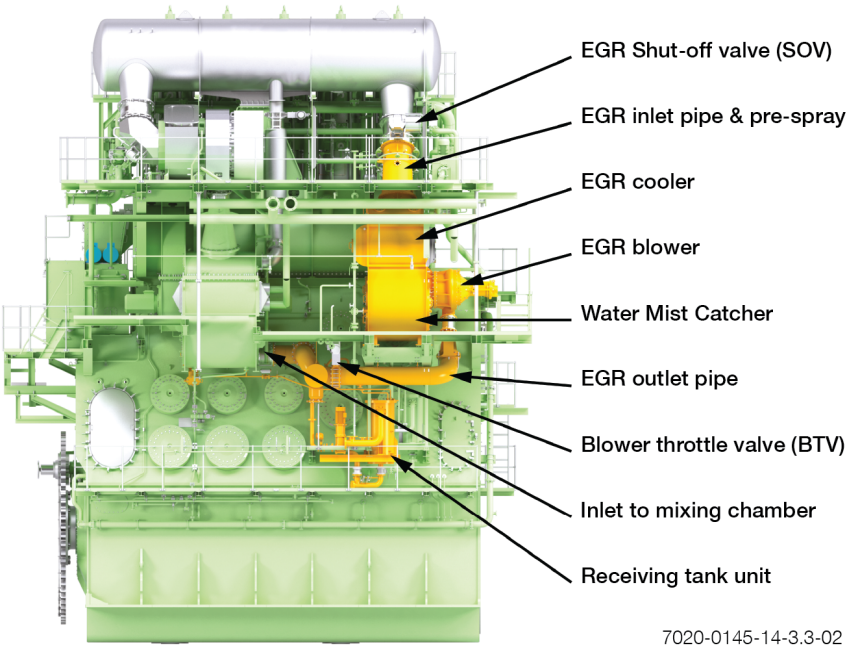


Figure 13: Layout for EGR bypass matching – 5G70ME-C

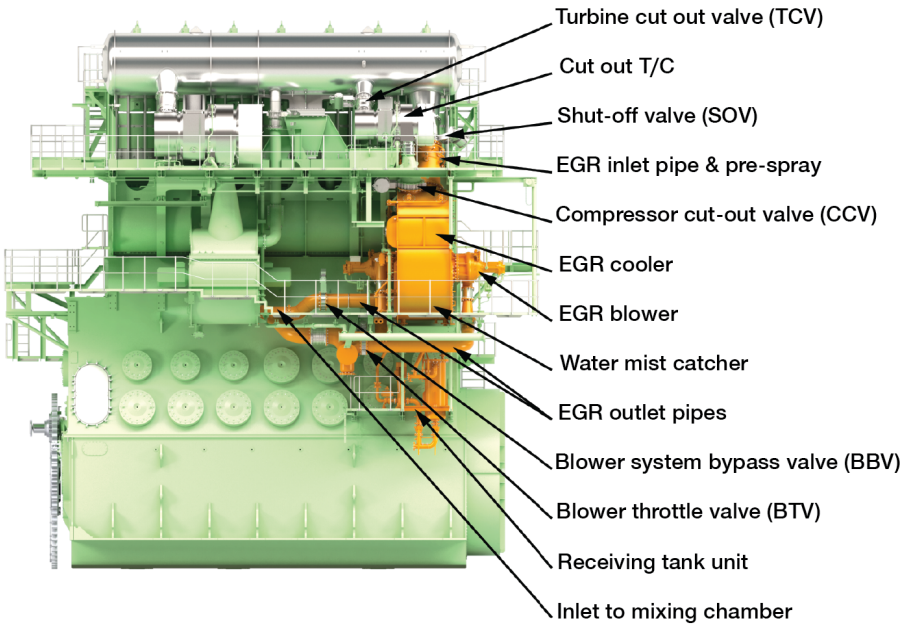


Figure 14: Layout for EGR cut-out matching – 7G80ME-C

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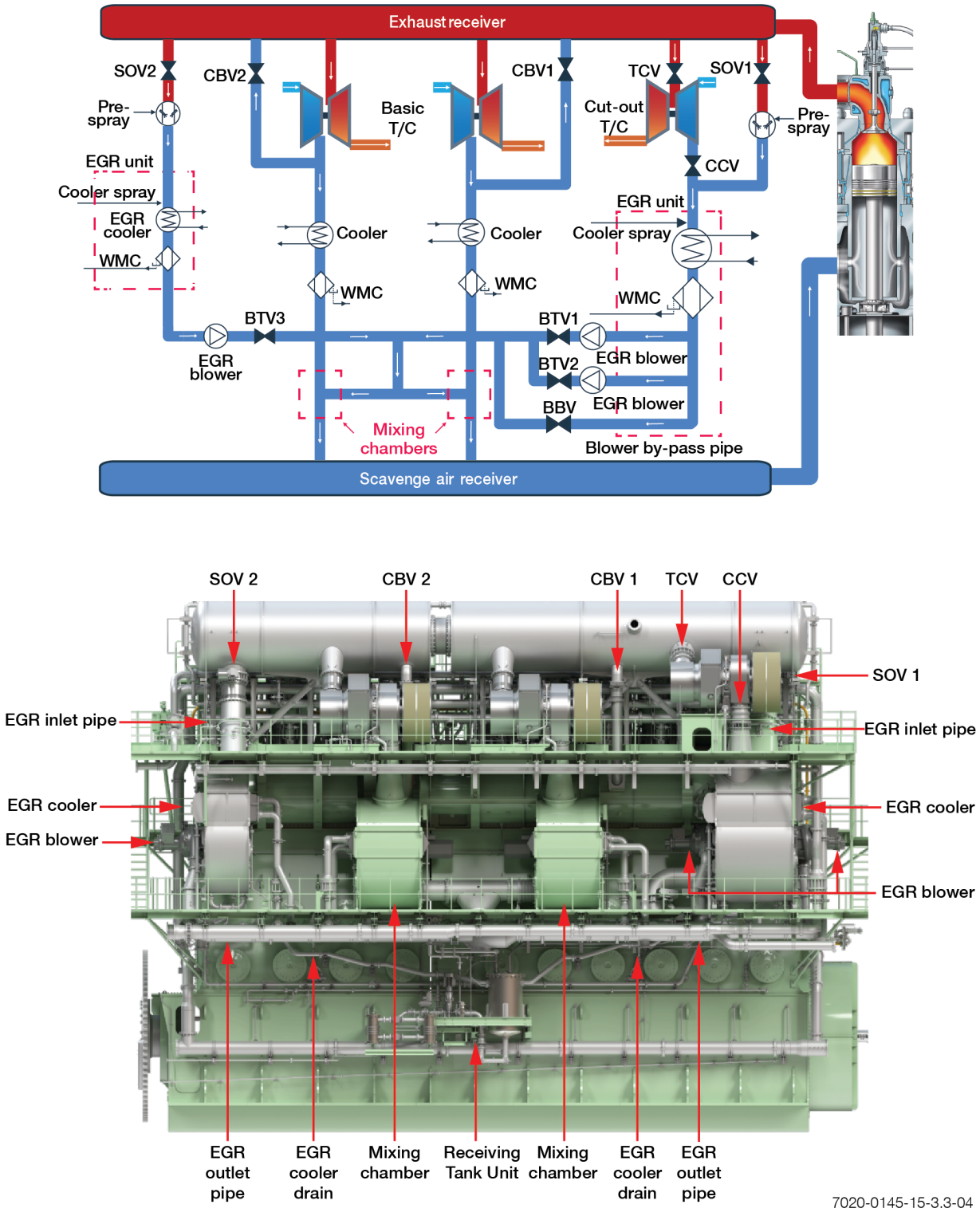


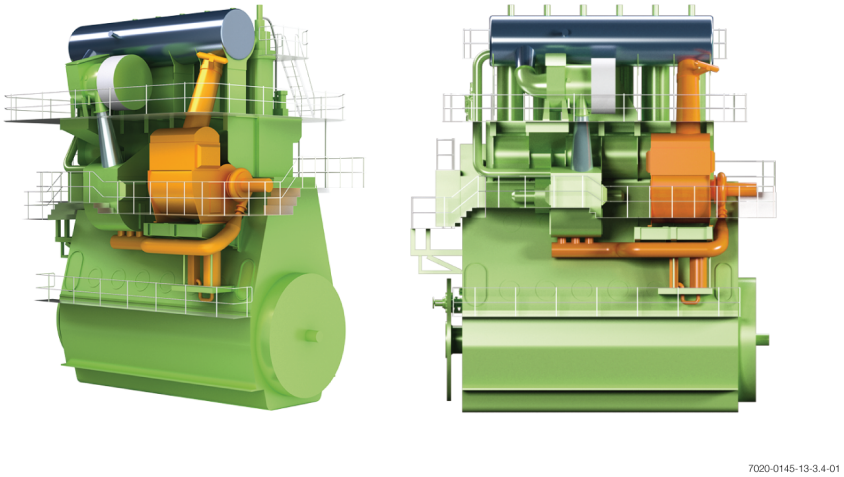
Figure 15: Layout for 2-string EGR cut-out matching - 10G95ME-C

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3.4 Configuration

Bypass matching

On an EGR system with bypass matching, the turbocharger is mounted either on the exhaust side or aft. In both cases, the EGR unit is mounted on the exhaust side. The configuration is shown in Fig. 16, Page 25.

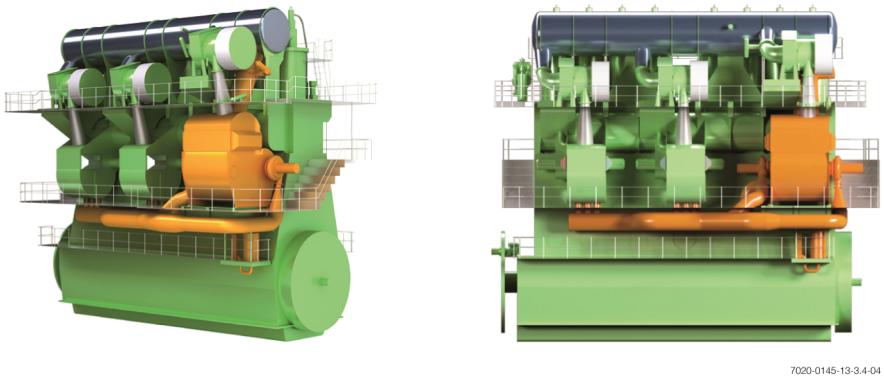


7020-0145-13-3.4-01

Figure 16: Side-mounted turbocharger and side-mounted EGR unit

TC cut-out matching

The configurations of EGR systems with TC cut-out matching are shown in Fig. 17, Page 25.



7020-0145-13-3.4-04

Figure 17: Two basic T/Cs, one cut-out T/C, and one EGR unit

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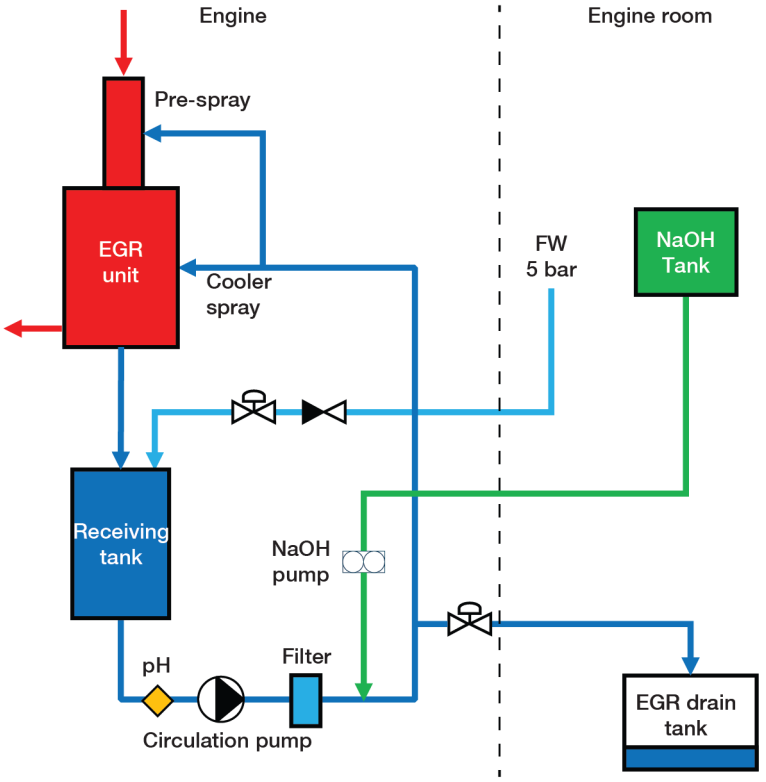
3.5 Water Handling System (WHS3)

To prevent the recirculated exhaust gas from damaging the engine, an appropriate treatment of the recirculated exhaust gas is required. This is performed in a combined cooling and cleaning process by a pre-spray and a cooler spray in the EGR string, using recirculated water for the process.

In order to maintain the ability of the recirculated water to clean, cool and neutralize the exhaust gas, a water handling system WHS 3 is needed. The system ensures the quality of the recirculated water, including an appropriate pressure and pH value. Furthermore, the WHS 3 controls the discharge of bleed-off water, which is the surplus of water accumulated in the system from the combustion process.

The WHS 3 is designed for engines operating on compliant fuels, i.e. S ≤ 0.1% in Tier III mode and S ≤ 0.5% in Tier II mode (EcoEGR engines). WHS 3 operates with an internal circulation of EGR water and includes a direct supply of NaOH and FW to the process.

The principle of the WHS 3 is shown in Fig. 20, Page 26.The receiving tank, circulation pump, filter and NaOH pump are part of the Receiving Tank Unit (RTU), which is placed on the engine below the EGR unit. The water from the EGR unit is drained to the receiving tank and recirculated to the EGR unit by the circulation pump. In this flow, an appropriate amount of NaOH is supplied to neutralise the sulphuric acid in the system to an acceptable pH value in the water. The surplus of water in the system originating from the combustion process is discharged as bleed-off water to the EGR drain tank.



7020-0145-16-3.6-01

Figure 18: Diagram for WHS 3 used for LS fuels only

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3.5.1 WHS 3 Discharge of LS-EGR bleed-off water

In accordance with the EGCS Guidelines – 2015 Guidelines for exhaust gas cleaning systems (MEPC.259(68)) – the bleed-off water generated by the EGR systems operating on compliant fuels may be discharged to the sea provided the oil content in the discharge does not exceed 15 ppm.

A water treatment system (LS-WTS), including an arrangement for continuous monitoring and recording of oil content, is required to ensure compliance before discharge.

A combined LS-WTS and Oily Bilge Water cleaning system may be installed to handle the discharge of both EGR drain and bilge water by the same system. In this case, EGR drain and bilge water must be handled separately without mixing the two streams

Fig. 21, Page 27 shows a diagram for the discharge of bleed-off water on LS-EGR, and Fig. 22, Page 27 shows a diagram for the combined EGR and OBW discharge.

If local restrictions prevent discharge in the area, the bleed-off water must be retained in the drain tank or in a separate storage tank, until discharge outside the restricted area is possible. Accumulated bleed-off water may alternatively be delivered at port.

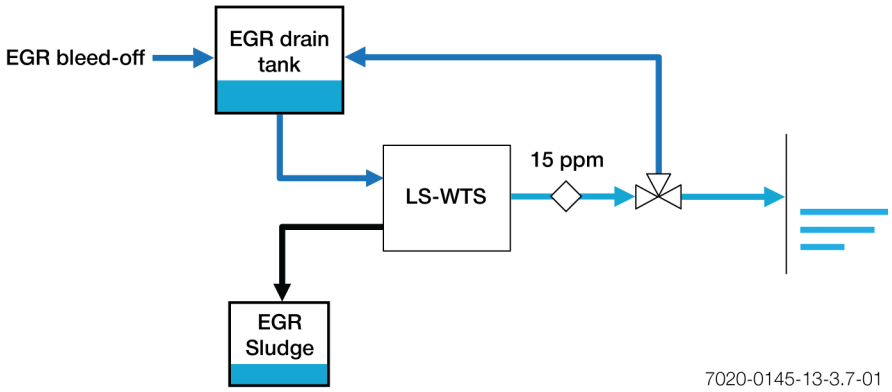


Figure 19: Diagram for the discharge of bleed-off water for LS-EGR (max 0.5% S)

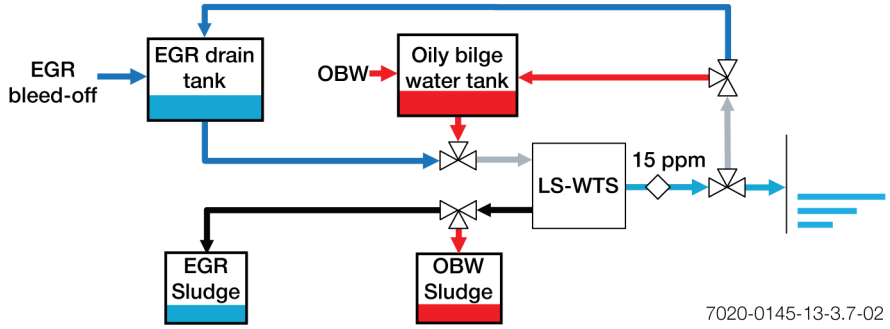


Figure 20: Diagram for the combined discharge of bleed-off water for LS-EGR and OBW

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3.6 Engine outline

Bypass matching

The outline of an EGR system with bypass matching is shown in Fig. 18, Page 28. The engine is shown with a side-mounted turbocharger but engines with aft-mounted turbochargers will also be available.

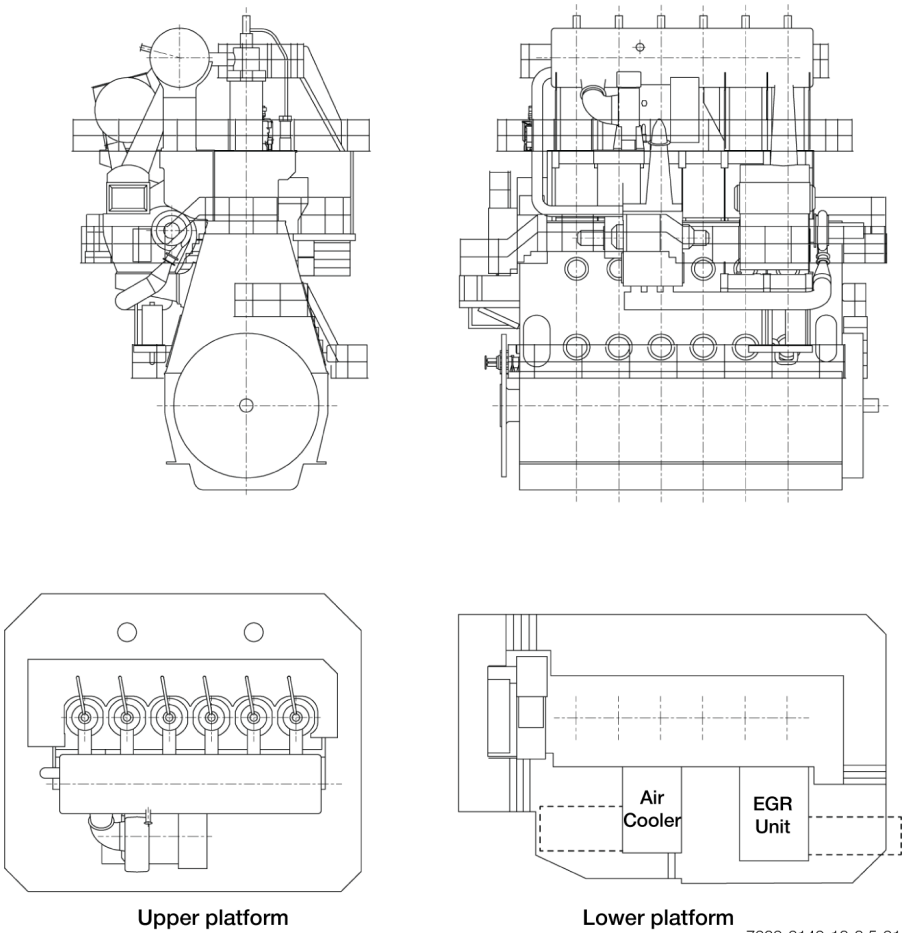


Figure 21: EGR engine with bypass matching, 6G70ME-C9

TC cut-out matching

The outline of an EGR system with TC cut-out matching is shown in Fig. 19, Page 29.

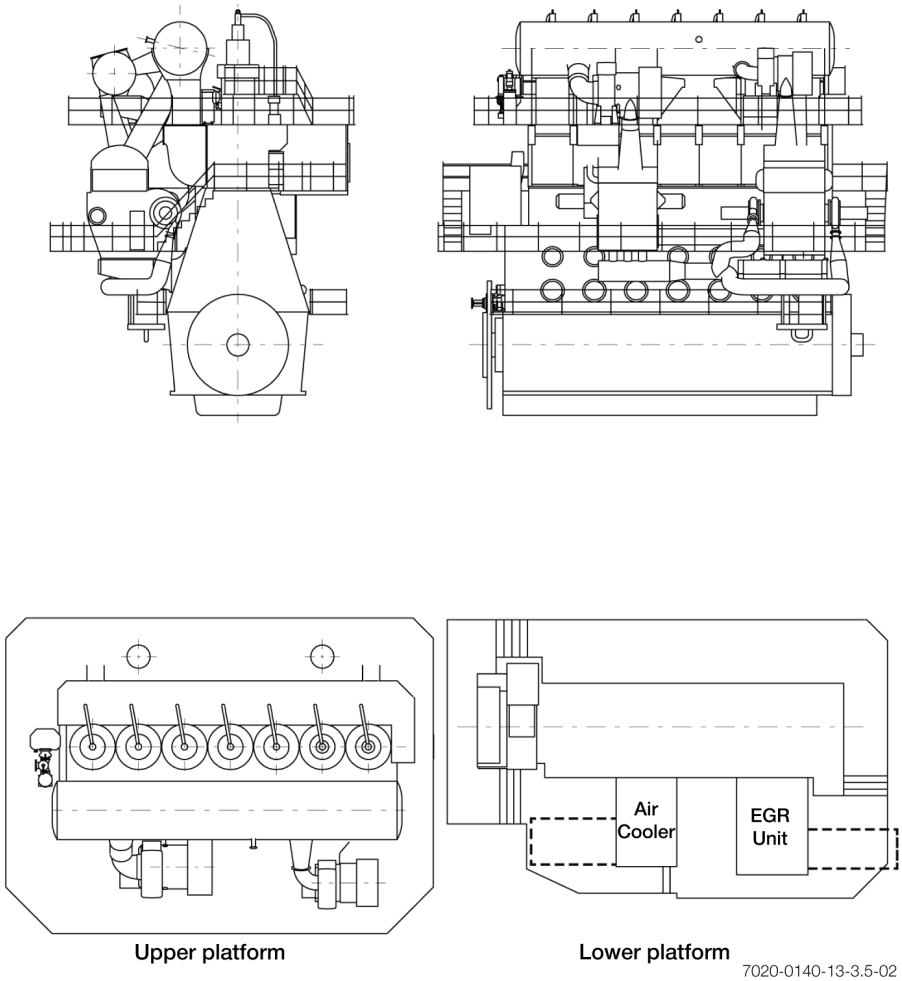


Figure 22: Outline of a 7S90ME-C9 Tier III engine with one basic T/C, one cut-out T/C and one EGR unit

3.7 EGR Control System

The EGR control is handled by the ME-ECS engine control system on engines with EGR, ME-ECS controls the EGR valves, the EGR blowers and part of the water handling system (WHS), i.e. the receiving tank unit (RTU), the supply unit (SU) and the interface to the water treatment system (WTS).

WHS 2 is supported on both the MPC and Triton hardware platforms, while WHS 3 is only supported on the Triton hardware platform.

The O_2 amount in the scavenge air receiver is controlled by the EGR controller in ME-ECS by adjusting the speed of the EGR blowers and thus the amount of recirculated exhaust gas.

3.7.1 EGR blower control

The EGR blower control system consists of a frequency converter with a local operating panel which supplies the EGR blower with power. An EGR system can have up to two EGR blowers, each one with a frequency converter.

The blower control system monitors and controls the blowers and adjusts the exhaust gas flow in the EGR line, in accordance with input from the EGR control system.

Special requirements apply for the power cabling between the frequency converter and the blower to ensure compliance with EMC directives. The interface between the EGR blower control and ERCS is hardwired.

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3.8 Installation

EGR cooling system

The EGR engines are specified with a central cooling system using freshwater as cooling media to prevent material damage to the EGR cooler and unit. In certain cases, if special precautions are taken, a combined cooling system can be used, using central cooling for the EGR cooler and seawater cooling for the scavenge air cooler.

An optimised cooling system for EGR could be installed to reduce the pump power consumption, when the EGR system is not operating. In this case the vessel cooling water pumps must be prepared for variable flow regulation in way of either variable frequency drives or a well-defined two-speed operation. The ad-on functionality at the engine comprises of a valve arrangement, which automatically shuts off the water supply to the EGR cooler when the engine runs in Tier II mode.

The EGR engines shall operate at the lowest possible temperature in the EGR Cooler and Scavenge Air Cooler, but not be less than 10°C. This is established by a set-point of 10°C for the central cooler 3-way valve.

Pipes for Water Handling System

The pipes installed for the WHS should be designed for a pH range of 3-9 and a maximum pressure of 10 bar. The material could be stainless steel, but other materials such as glass-fibre reinforced plastic suitable for the medium can be used. The sealing material between pipe flanges of stainless steel and normal steel must be of a suitable isolation material. Bolts and nuts for flanges must be of stainless steel. The pipe dimensions must be adequate for the water flow which is related to the engine power. The estimated water flow is found in Section Consumptions and capacities, Page 37.

NaOH tank

NaOH is a corrosive and harmful product with a tendency to crystallise at low temperatures, and the NaOH tank installation must therefore be designed with this in mind. The material could be stainless steel, specially coated steel, polymer or other materials suitable for the product. If a 50% NaOH solution is used, the liquid will start to crystallise at temperatures below 12 °C and the tank and pipes should therefore keep a minimum temperature of 16 °C. Accordingly, the tank should be installed in a room with a controlled temperature or be insulated and fitted with means for heating. Similar protection against crystallisation will be required for the NaOH supply pipes between the tank and the NaOH connection point at the engine. Pipes on engine will not need heating, but in case of longer periods of stand still - while docking or similar - the NaOH pipe on the engine may be drained. The installation of the tank should include precautions to prevent any leakage from the tank and tank connections.

When estimating the required capacity of the NaOH tank, several parameters must be considered: the Tier III sailing time and sailing pattern, the fuel sulphur content, the NaOH concentration and the planned bunker frequency. An example of estimating the NaOH tank capacity is given in Section Calculation of EGR data, Page 42.

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Engine room arrangement

A high degree of flexibility for installation of the WHS in the engine room is possible. An example of installation for LS-EGR is presented in Fig 23, Page 32.

Arrangements of EGR in the engine room based on the WHS 3 principle:

1. NaOH tank to be arranged with a natural flow to the NaOH pump installed on the engine.
2. EGR bleed-off is led directly from the engine to the EGR drain tank.
3. The arrangement of the LS-WTS should be in accordance with the supplier's requirements.

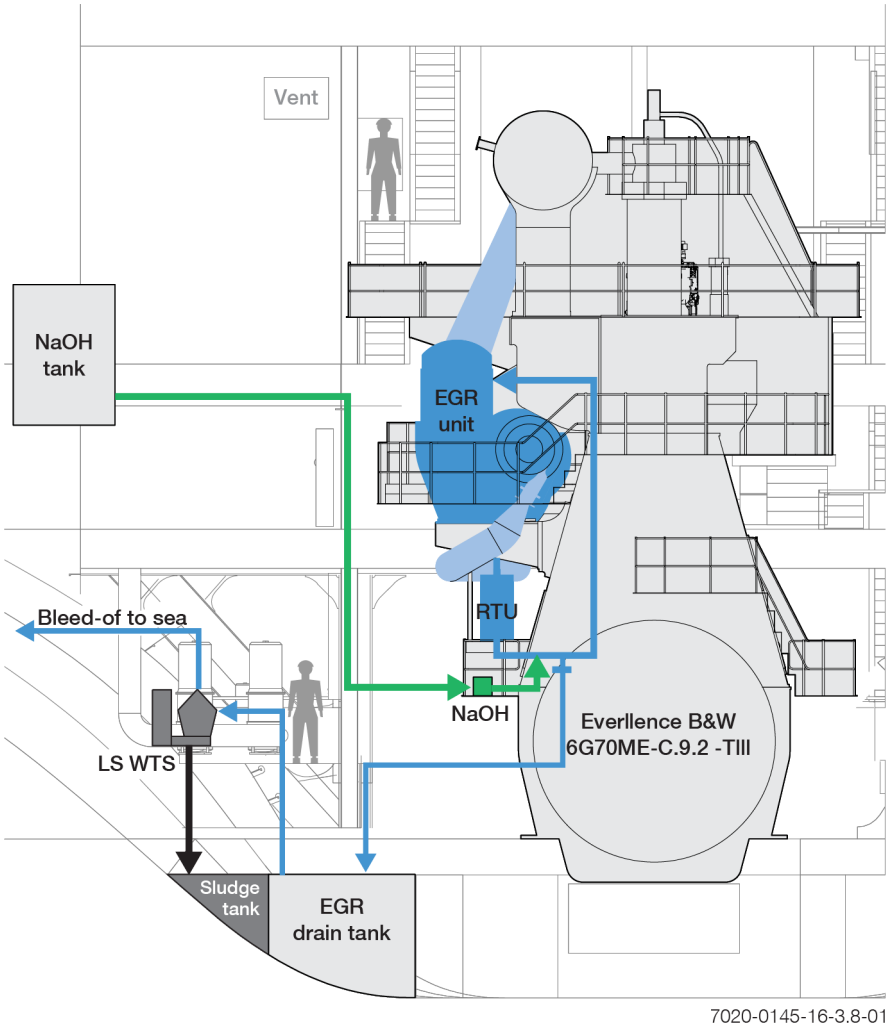


Figure 23: Example of arrangement on LS-EGR, designed for low-sulphur fuels

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Sludge tank

The sludge outlet from the WTS is an aqueous solution including the remains accumulated from the treatment of bleed-off water. The pH value normally varies between 6 and 9. The water content in the sludge is more than 90%, which makes it easy to discharge by a pump. The sludge tank could be a separate tank or part of another tank, which holds similar sludge to be discharged to reception facilities. The capacity of the sludge tank depends on the Tier III sailing time and sailing pattern, the fuel sulphur content and the planned discharge period. An example of estimating the sludge tank capacity is found in Section Calculation of EGR data, Page 42.

Drain tank

The drain tank holds the bleed-off water to be discharged to the sea when the relevant discharge criteria are met. The bleed-off water is discharged through an LS-WTS. The tank should be designed with a sufficient volume to hold the amount of bleed-off water generated in periods where discharge is not possible.

The design of the drain tank could be based on an estimate of the expected time and sailing distance in which a discharge could not take place. This may include time for an overhaul of the WTS.

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3.9 Spare parts

3.9.1 EGR engines

Recommended spare parts that support unrestricted EGR operation:

- 1 blindflange for exhaust gas receiver
- 1 blindflange for EGR mixing chamber
- 2 pre-spray nozzles
- 1 O-ring for EGR cooler
- 1 complete Siemens Sipart controller incl. NCS and magnet
- 2 pH-sensor probes
- 1 level sensor for RTU (can be used in various EGR applications)
- 1 bottle gas for SUC/OSU 2-point calibration
- 2 seals for EGR sludge trap

Spare parts for water treatment system and supply unit should be in accordance with the supplier's recommendation.

3.9.2 ME-GA

Recommended spareparts that support unrestricted operation of ME-GA engines:

EGR electronics

- 1 IP converter "Sipart" (single acting)
- 1 IP converter "Sipart" (double acting)
- 2 Pressure transmitter (0-10 bar - ½")
- 1 Pressure transmitter (1-15 bar G - ½'')
- 1 Temp. transmitter + sensor
- 1 Diff. pressure transmitter (gas-side)
- 1 Diff. pressure transmitter (water-side) - master
- 1 Diff. pressure transmitter (water-side) - slave
- 1 pH transmitter
- 2 pH sensor
- 1 Calibration tool (fluids), (pH4 & pH7)
- 1 Level switch "RTU, water ASO"
- 1 Connector for level switch

NaOH dosing pump

- 1 NaOH dosing pump "IWAKI" (Hillerød)
- 1 Overhauls service kit with membrane

Circulation pump PWCP

- Service kit

Flow

- 1 FW flow switch

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- 1 FW control valve
- 1 Coax valve

Cooler spray nozzles

- 2 Pos 1 Upper pre-spray
- 2 Pos 2 Lower pre-spray
- 2 Pos 3 EGR cooler spray

OSU

- 2 Press. transmitter (high press. side)
- 2 Press. transmitter (low press. side)
- 2 Air filter element
- 4 NOx sensor A+B
- 1 Nitrogen bottle for calibration of sensors

EGR Blower

- Blower spares

WHS filter

- 2 Filter inserts B&K

EGR cooler

- Stainless steel plugs for 5-10% of tubes

Tier III Valves

- Details of parts to be described

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3.10 Retrofit

If a ship is not intended during its lifetime to enter a NO_x ECA, in which it would be required to meet Tier III regulation, there would be no reason to include a comprehensive Tier III installation. However, any doubt on whether the ship in the future would enter the area could lead to a decision to install the equipment anyway or at least prepare the ship for a retrofit installation.

Two methods to prepare for EGR retrofit installation are available:

- EGR Tier III DS (Design Specification)
- EGR prepared Tier III DS (Design Specification)

EGR Tier III DS

EGR Tier III DS is the solution for ships where an EGR solution most likely will be needed in a later period of the ship. This gives the opportunity to postpone the purchasing and installation of several sub-components and thereby delay the related first cost expenses, installation cost and aging of components in the system. However, it should be kept in mind that installation on a ship in service, even when planned for docking period in connection with a renewal survey, is more complicated and time consuming than installation during new building. Accordingly, the extent of preparation for the EGR retrofit installation should be carefully considered.

The EGR Tier III DS solution would include the parent engine of a certain series of vessels to be tested and certified as a Tier III engine. If installed on board, including required auxiliary systems, the ship owner is provided with a Tier III compliant ship. However, if the date for Tier III compliance on this ship is uncertain, some Tier III components already produced and tested for this engine needs not be installed, and the additional Tier III auxiliary systems required for the system needs not be purchased before it is actually required.

The subsequent member engines for the ships in the series could be configured more or less prepared for EGR retrofit or as fully EGR Tier III compliant engines if convenient. It must be noted that in case some ships in the series are planned for alternative fuel sulphur compliance (HS versus LS) for Tier III mode, the engines for these ships need another parent engine certification for compliance even in case the engine rating is unchanged.

EGR prepared Tier III DS

EGR prepared Tier III DS is the solution for ships where the Tier III compliance will not be needed during the planned lifetime of the ship. However, the uncertainty of the future trade of the ship could be met by a minimum preparation of a later EGR retrofit installation. This gives the opportunity to avoid the cost of the EGR system and still keeping a door open for a later installation.

In case a retrofit is later decided, a major retrofit job would be required. In addition to the cost of the Tier III equipment and its installation, expenses for modification of the engine and T/C components should be included. The engine will need re-certification for both Tier II and Tier III modes, which calls for a new sea trial, on-board survey and class approval.

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3.11 Consumptions and capacities

Performance and consumption data for EGR engines are available by the engine calculation program, CEAS. CEAS is found at https://www.everllence.com/marine/products/planning-tools-and-downloads/ceas-engine-calculations. The data presented in the following are based on CEAS output for a specific engine in two different configurations, EGR and EcoEGR. For each of these configurations data for a low sulphur and a high sulphur installation are presented.

Engine:	6G70ME–C9.5
Power:	16,440 kW
Speed:	83.0 r/min
Condition:	ISO condition
Configurations:	EGR LS fuel (0.1% S)
	EcoEGR LS fuel (0.1% S and 0.5% S)

Specific fuel oil consumption

The specific fuel oil consumption (SFOC) of an EGR engine operating in Tier II mode is similar to the SFOC of a standard low-load tuned engine. When the EGR engine operates in Tier III mode, the SFOC will increase due to the change of the combustion process.

The concept of EcoEGR, which is introduced in chapter EcoEGR reduces the fuel consumption by using EGR to optimize the SFOC in both Tier II and Tier III mode. Compared to the EGR engine, the EcoEGR engine will provide an SFOC reduction of 2-4 g/kWh in Tier II mode. The SFOC for EGR and EcoEGR are shown in Figure 24, Page 37.

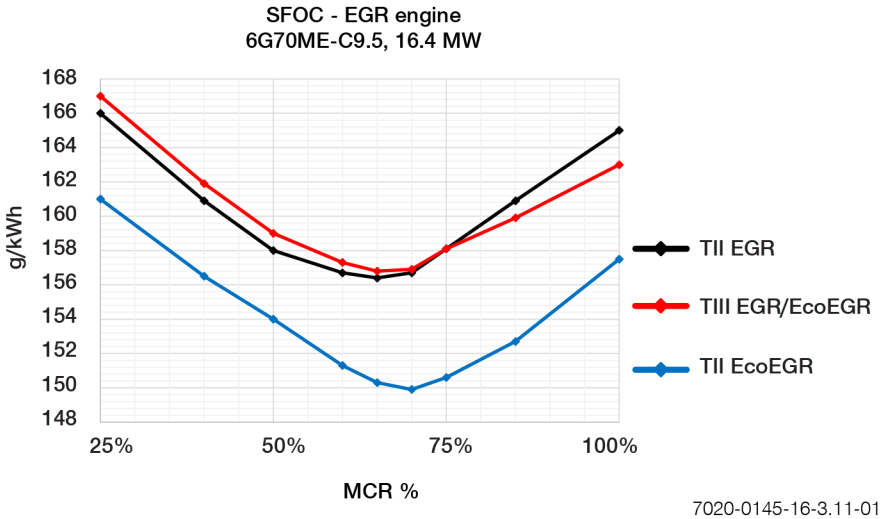


Figure 24: SFOC of EGR engines in Tier II and Tier III mode

Power consumption

The electrical power required for the EGR system is mainly related to the EGR blower and depends on the engine load and the EGR rate. Due to a relative high rate used for EcoEGR, the power required for this configuration is higher than the power required for the standard EGR. Furthermore, as EcoEGR also operates with EGR in Tier II mode, power for blower will also be required for EcoEGR in this mode. The power required is shown in Fig. 25, Page 38.

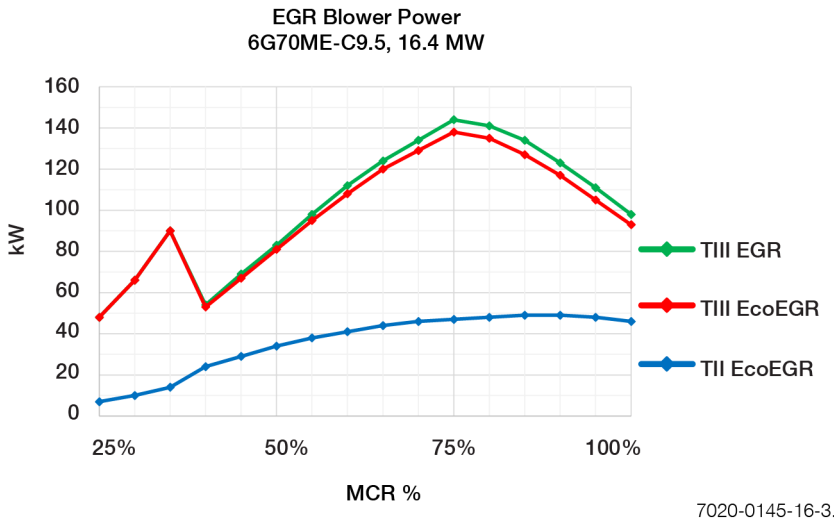


Figure 25: Estimated power for EGR blower

NaOH consumption

The NaOH consumption depends on the engine load, fuel sulphur content, EGR ratio and NaOH concentration. The estimated consumption for EGR and EcoEGR configurations are shown in Fig 26, Page 38.

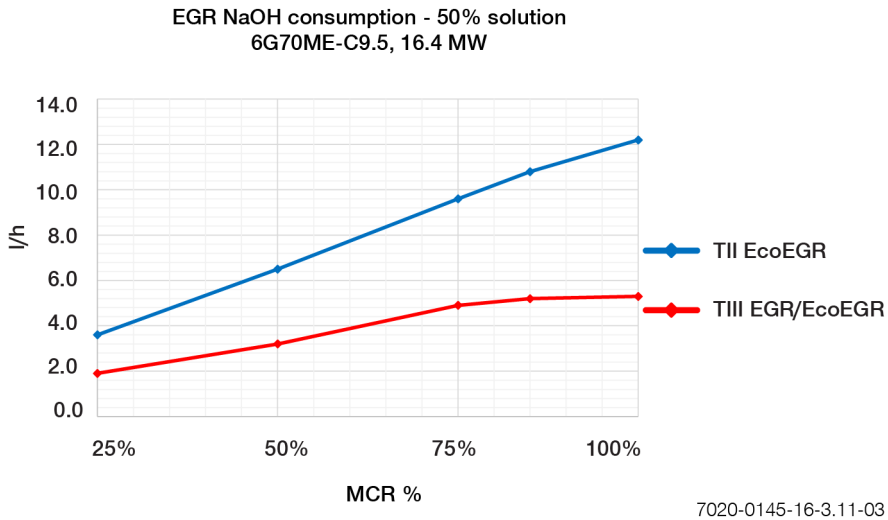


Figure 26: Estimated NaOH consumptions

NaOH tank

The NaOH is usually supplied in a 50% solution, but a 30% solution can be selected to prevent potential heating requirements, as explained in chapter Installation, Page 31. In case a 30% solution is chosen, the NaOH consumption will increase in accordance with the dilution ratio.

The volume of the NaOH tank should be designed to hold an appropriate volume for EGR operation. An example for designing the NaOH tank, based on specific criteria, is given in chapter Calculation of EGR data, Page 42.

Bleed-off water

The surplus of water generated by the EGR process is discharged as bleed-off water to the EGR drain tank. The amount of water relates to the engine power, the EGR rate and the fuel type.

In Tier III mode, the bleed-off amount will virtually be the same on EGR and EcoEGR engines. In Tier II mode, the EcoEGR engine generates bleed-off water in a reduced amount related to the EGR rate.

The estimated bleed-off amount are shown in Fig. 27, Page 39.

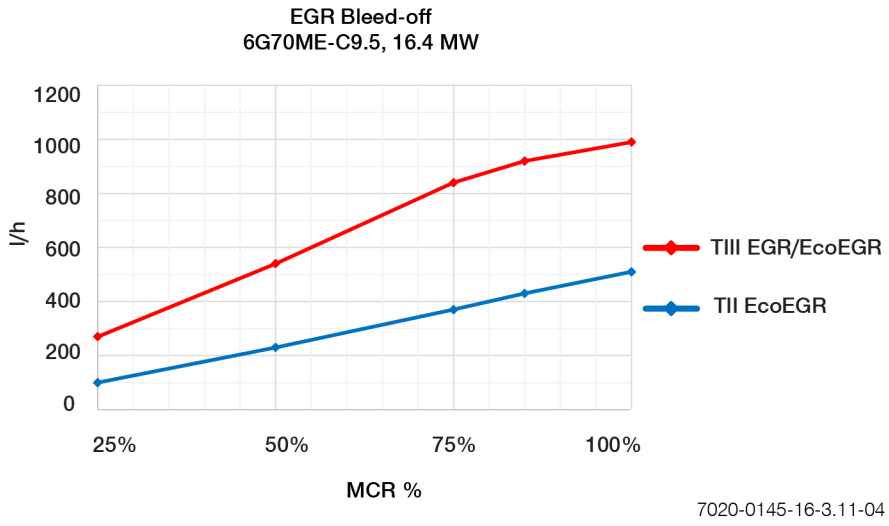


Figure 27: Estimated discharge of bleed-off water

Drain tank

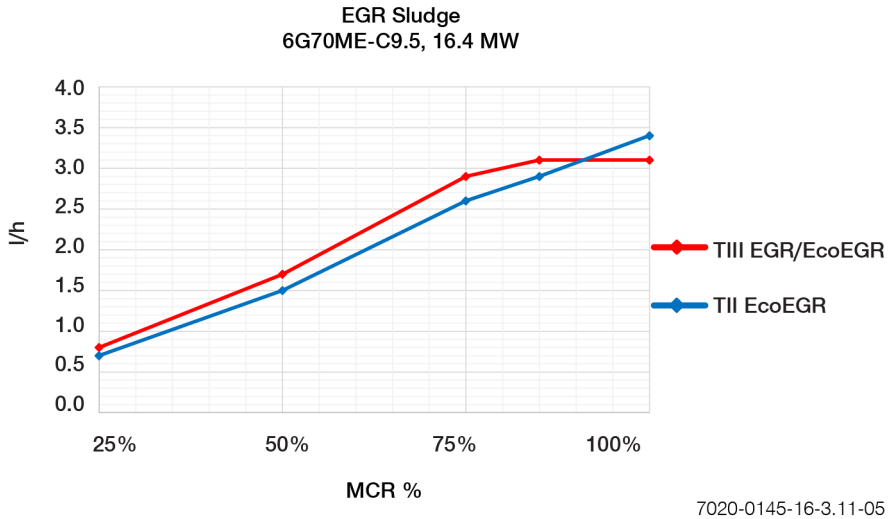
The EGR drain tank should be designed to include the estimated bleed-off water accumulated when discharge is not possible, either during an overhaul of the WTS or during a period when discharge is not allowed, i.e. in port, harbours or similar restricted areas. A period of 24 hours without discharge may be acceptable for an appropriate tank capacity, provided an overhaul of the WTS can be completed within this time frame. However, the capacity may be increased to take into account introduction of new areas where discharge of bleed-off water is not allowed. An example to estimate a proper volume of the EGR drain tank is given in chapter Calculation of EGR data, Page 42.

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Sludge production

The bleed-off water accumulated in the EGR drain tank must comply with the 15 ppm criteria before discharge as explained in the chapter Water Handling System (WHS 3), Page 26. The LS WTS, installed for this purpose, will accumulate a limited amount of sludge.

The estimated sludge amounts are shown in Fig. 28, Page 40.



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Figure 28: Estimated accumulation of sludge

Sludge tank

The sludge tank should be designed to include the estimated amount of sludge accumulated during the voyage. An example to estimate a proper volume of the sludge drain tank based on sailing pattern and discharge frequency is given in chapter Calculation of EGR data, Page 42.

Freshwater consumption

When operating in certain conditions on non-compliant fuels, addition of freshwater may be required to compensate for accumulation of sulphates in the recirculated water. Although consumption of FW is considered small, CEAS will provide data for FW when required in specific ambient conditions. In addition to CEAS data freshwater may also be required for proper function of the installed WTS equipment. This information should be provided by the supplier of the WTS.

EGR cooling water capacity

The capacity of cooling water for the EGR engine is increased due to the need for cooling of recirculated exhaust gas, which has a significantly higher temperature than the scavenge air it is replacing. The amount of cooling water for scavenge air cooling is increased by 45% in Tier III mode compared to Tier II mode.

Lube oil capacity

The lubricating oil flow is only slightly increased on an EGR engine. The lubricating oil flow for the EGR blowers, which are the only additional consumers, will be around 0.3 m3/h/MW SMCR with a minimum of 3.6 m3/h.

Compressed air capacity

Compressed air is needed for sealing of the EGR blower and for control purposes throughout the EGR system. The required sealing air for the EGR blower will be around 2.5 kg/h/MW SMCR with a minimum of 30 kg/h.

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3.12 Calculation of EGR data

In the following, an example of EGR data for a ship is presented. The data of the scenario, are based on an EcoEGR engine designed for low sulphur fuel. Please note that the tank size calculations are examples only and cannot be used as design basis.

Scenario for calculation for EcoEGR on LS fuel

General data	
Ship type	Bulk carrier
Ship size	182,000 DWT
Engine model	6G70ME - C9.5
EGR type	EcoEGR
Sailing condition	ISO
Engine power	16,440 kW
Fuel sulphur ECA	0.1 % S
Fuel sulphur global	0.5 % S
NaOH solution	50 % NaOH
Sailing time, Tier II	5400 hours/year
Sailing time, Tier III	600 hours/year

Table 7: General data for scenario

Sailing profile	MCR%	Time %	Time hours/year
Tier II	25%	5%	270
	50%	20%	1080
	75%	60%	3240
	85%	10%	540
	100%	5%	270
Tier III	25%	15%	90
	50%	30%	180
	75%	50%	300
	85%	5%	30
	100%	0%	0

Table 8: Sailing profile for scenario

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Operational Tank capacity	Margin	Tier II	Tier III	
NaOH tank	30%	540	60	sailing hours
Sludge tank	30%	540	60	sailing hours
Drain tank – no discharge	30%	0	48	sailing hours

Table 9: Example Scenario for tank capacities. The drain tank capacity may be increased if found appropriate

CEAS output for EcoEGR on LS fuel

The consumption and capacities of the specified engine are found by the engine calculation programme, CEAS, as explained in the previous section. The result is shown in Table 10, Page 43.

EcoEGR - LS 16,440 kW	MCR %	SFOC g/kWh	Blower kW	NaOH l/h	Bleed-off l/h	Sludge l/h
Tier II 0.5% S	25%	161.0	7	3.6	100	0.7
	50%	154.0	34	6.5	230	1.5
	75%	150.6	47	9.6	370	2.6
	85%	152.7	49	10.8	430	2.9
	100%	157.5	46	12.2	510	3.4
Tier III 0.1 % S	25%	167.0	48	1.9	270	0.8
	50%	159.0	81	3.2	540	1.7
	75%	158.1	138	4.9	840	2.9
	85%	159.9	127	5.2	920	3.1
	100%	163.0	93	5.3	990	3.1

Table 10: Output from CEAS on the specified 16.4 MW engine

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Consumption data for EcoEGR on LS fuel

Based on the specified sailing profile in the scenario and on the output from CEAS the consumptions of each load point are calculated. In the present scenario, covering a one-year period, the data in Table 11, Page 44 are found.

EcoEGR - LS 16,440 kW	MCR %	Time hours	Fuel ton	Blower MWh	NaOH m^3	Bleed-off m^3	Sludge m^3
Tier II 0.5% S	25%	270	715	2	1.0	27	0.2
	50%	1080	2734	37	7.0	248	1.6
	75%	3240	8022	152	31.1	1199	8.4
	85%	540	1356	26	5.8	232	1.6
	100%	270	699	12	3.3	138	0.9
Tier III 0.1% S	25%	90	247	4	0.2	24	0.1
	50%	180	471	15	0.6	97	0.3
	75%	300	780	41	1.5	252	0.9
	85%	30	79	4	0.2	28	0.1
	100%	0	0	0	0.0	0	0.0
Tier II	1 year	5400	13525	230	48.2	1844	12.7
Tier III		600	1576	64	2.4	401	1.3
Total Year		**6000**	**15102**	**294**	**50.6**	**2245**	**14.1**

Table 11: Consumptions and discharges according to the specified scenario on a 16.4 MW engine

Tank capacities for EcoEGR on LS fuel

The capacities of NaOH tank, sludge tank and EGR drain tank are calculated using the tank conditions given in the scenario, i.e. a capacity of 540 + 60 hours on NaOH and sludge tank, similar to around 36 days in service, and a 24 hours capacity for the EGR drain tank. The EGR drain tank is designed to hold a bleed-off volume, which may accumulate when operating in areas where discharge to sea is not possible, i.e. port, harbours and estuaries.

A tank margin is included to compensate for variations in the sailing profile and sailing time. The capacities for the specified scenario are presented in Table 12, Page 44.

EcoEGR - LS	Frequency hours		Volume m^3			Margin	Min. volume
0.1/0.5% S	TII	TIII	TII	TIII	Total	15%	m^3
NaOH tank	540	60	4.8	0.2	5.1	0.8	5.8
Sludge tank	540	60	1.3	0.1	1.4	0.2	1.6
Drain tank	0	24	0	16.0	16.0	2.4	18.5

Table 12: Tank capacities estimated for the specified scenario of a 16.4 MW EcoEGR engine using LS fuel of 0.5% global and 0.1% in ECA. The drain tank capacity may be increased if found appropriate

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4 SCR – Selective Catalytic Reduction

Unless stated otherwise the SCR solutions in this chapter assume low sulphur fuels (≤ 0.1% S) for Tier III running modes.

4.1 Principle

Selective Catalytic Reduction (SCR) is an exhaust gas treatment method by which the NO_X generated in a marine diesel engine can be reduced to a level in compliance with the NO_X Tier III requirements.
The NO_X reduction is obtained by a catalytic process in an SCR reactor installed in the exhaust gas line after the combustion process.

In the SCR reactor, the NO_X is reduced catalytically to nitrogen and water by adding ammonia as a reducing agent. The principle of the SCR can be seen below in Fig. 29, Page 45.

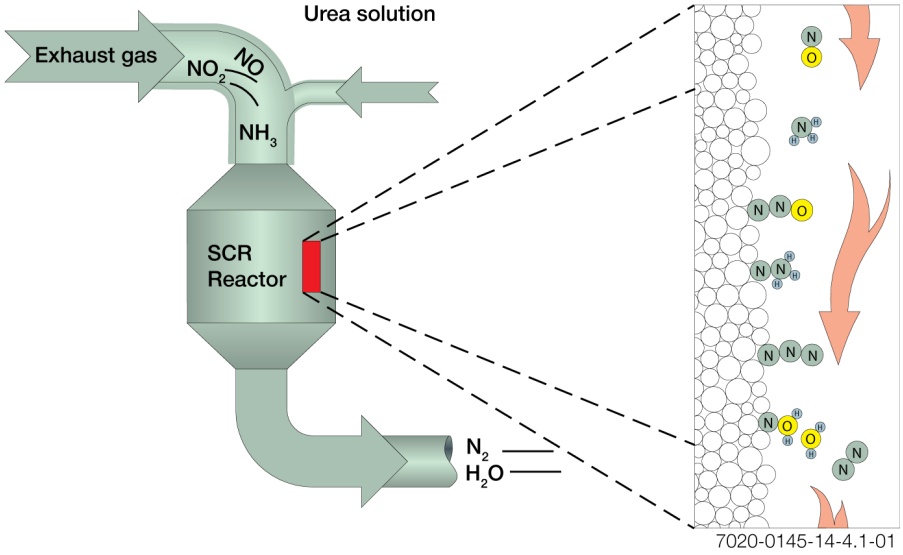


Figure 29: Principle of the SCR system

The catalyst in the reactor consists of blocks with a large number of channels, providing a large surface area, in which the catalytic process takes place

NO_X is reduced according to the following overall reaction scheme:
$4NO + 4NH_3 + O_2 \rightarrow 4N_2 + 6\ H_2O$
$2NO + 2NO_2 + 4NH_3 \rightarrow 4N_2 + 6H_2O$
$2NO_2 + 4NH_3 + O_2 \rightarrow 3N_2 + 6H_2O$
For reasons of safety, the ammonia is normally added to the system in the form of aqueous urea. This decomposes to ammonia and carbon dioxide when it is injected into the vaporiser:
$(NH_2)_2CO_{(aq)} \rightarrow (NH_2)_2CO_{(s)} + \times\ H_2O_{(g)}$
$(NH_2)_2CO_{(s)} \rightarrow NH_{3(g)} + HNCO_{(g)}$
$HNCO_{(g)} + H_2O_{(g)} \rightarrow NH_{3(g)} + CO_{2(g)}$

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4.2 System

4.2.1 SCR operation

An essential parameter of the SCR process is the inlet gas temperature. The lower temperature limit is dictated by the amount of sulphur in the fuel and the following formation of sulphuric acid in the gas (this limit may vary, depending on the catalyst type). Here, the sulphuric acid is neutralised by ammonia. This forms the by-product ammonium bisulphate (ABS - NH_4HSO_4), which may accumulate in the SCR elements. However, this reaction can be suppressed by keeping a high temperature of the exhaust gas. When the sulphur content in the fuel is equal or less than 0.1%, a temperature of approximately 310 °C would be sufficient. At low exhaust gas pressures, the required minimum temperature will be lower.

The minimum temperatures required to avoid the formation of ammonia bisulphate are found in the below Fig. 30, Page 46, which shows the relation between the fuel Sulphur content and the exhaust gas pressure. The figure shows a high pressure curve (4.0 bara) and a low pressure curve (1.5 bara), which is the approximate pressure at high engine load and at low engine load respectively.

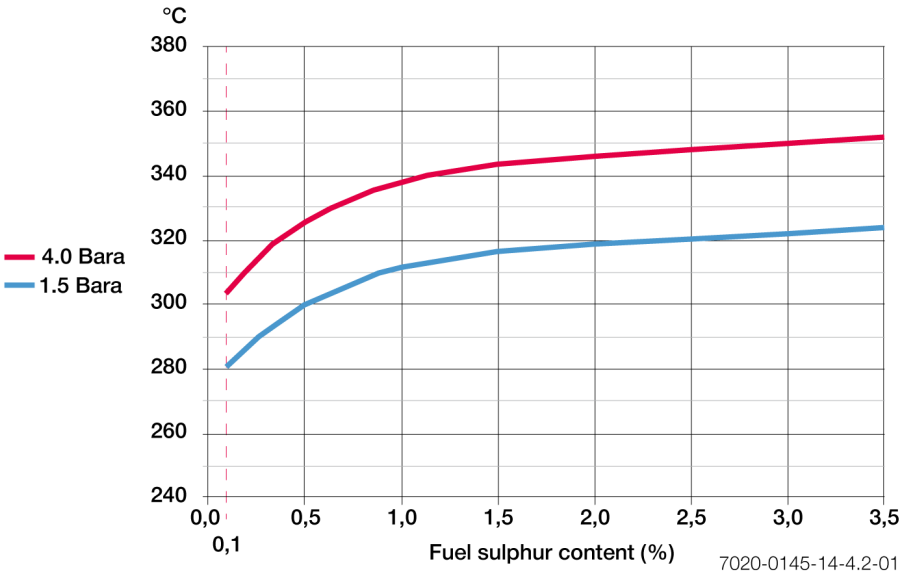


Figure 30: Required exhaust gas temperatures for SCR

On the other hand, the temperature must not be too high as this will result in an increased SO_3 formation in the catalyst. SO_3 subsequently reacts with water creating sulphuric acid, which appears as an undesired white aerosol plume. Another undesired reaction which also limits the upper temperature for SCR operation is the oxidation of NH3 as the exhaust gas temperature approaches 500 °C, i.e. more NH_3 is needed. Additionally, the catalyst material starts to sinter at temperatures above 500-550 °C.
In other words, to ensure a robust SCR operation it is crucial to maintain exhaust gas temperatures within a certain temperature window.
The SCR system could be chosen as a high-pressure installation(HPSCR) adapted for either low- or high-sulphur fuel, or as a low-pressure installation (LPSCR) applicable only for low-sulphur fuel.

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4.2.2 SCR process - High Pressure

The HPSCR process, illustrated in Fig. 31, Page 47, takes place in the SCR line, which consists of three major components: the SCR reactor, combined vaporiser/ mixer unit and the dosing unit.

The reducing agent is injected by the dosing system in the vaporiser/mixer, which will vaporise and mix with the exhaust gas. The prepared gas is led to the SCR reactor where the NO_x reduction takes place. Due to the demand for a relatively high temperature of the SCR process, it is convenient to place the SCR line on two stroke marine diesel engines on the high pressure side, i.e. before the turbocharger. Because of this aspect, the term HP is used. Depending on the engine load, the exhaust gas temperature on this side is 50-175 °C higher than on the low pressure side.

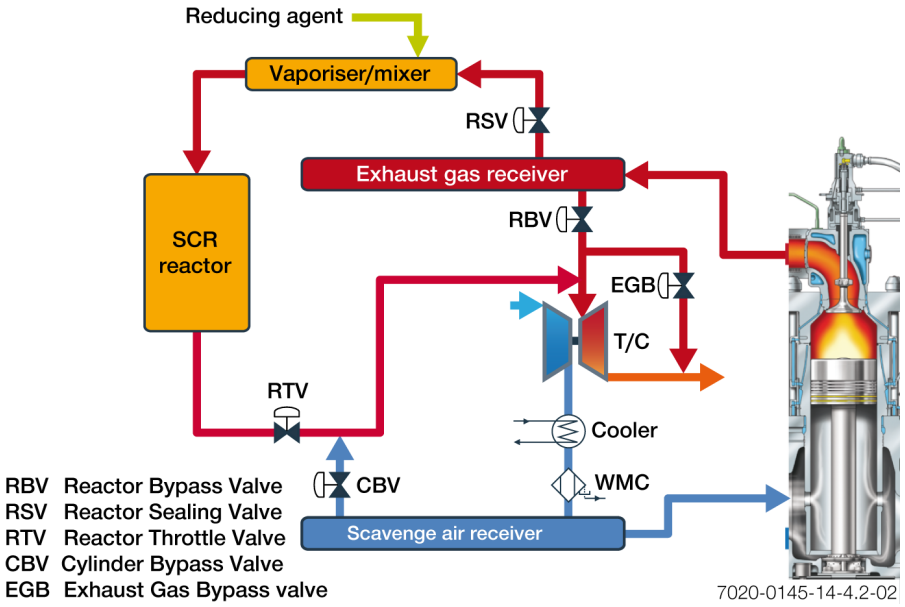


Figure 31: HPSCR installation

When operating in Tier II mode (SCR not yet engaged, reactor bypassed) the SCR system is cut off by the Reactor Sealing Valve (RSV) and the Reactor Throttle Valve (RTV). The Reactor Bypass Valve (RBV) is open and exhaust gas passes directly to the turbocharger. Venting is to keep an overpressure in the reactor in order to keep exhaust gases out.

When operating in Tier III mode the SCR system will be engaged if the exhaust gas temperature is above the sulphuric acid condensation limit (200°C). If not, a standby heat system will keep the SCR system above the sulphuric acid condensation limit, if possible. If the exhaust gas temperature is ok, the SCR line is opened by the valves, RSV and RTV, and hereafter the RBV will be closed. As soon as gas flows through the reactor, soot blowing is started, in order to avoid clogging of the reactor with soot particles.

Even though the reactor is placed before the turbine, the exhaust gas temperature will still not be sufficiently high at low loads for the SCR process to take place. To increase the temperature, a cylinder bypass from the scavenge air receiver to the turbine inlet is installed. The bypass is controlled by the cylinder bypass valve, CBV. When opening the bypass, the gas flow through the cylinders will be reduced without losing the scavenge air pressure and, accord-

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ingly, the exhaust gas temperature will increase. This system make-up enables maintenance of the sufficiently high temperature for the SCR process to take place. However, the cylinder bypass will increase the SFOC depending on the required temperature increase.

Fig. 32, Page 48, below illustrates the load ranges for low- and high-sulphur fuels in which the cylinder bypass must be open to keep a sufficient temperature for the SCR process. The required cylinder bypass range will be wider on an engine with a relatively low turbine inlet temperature compared to one with a higher temperature.

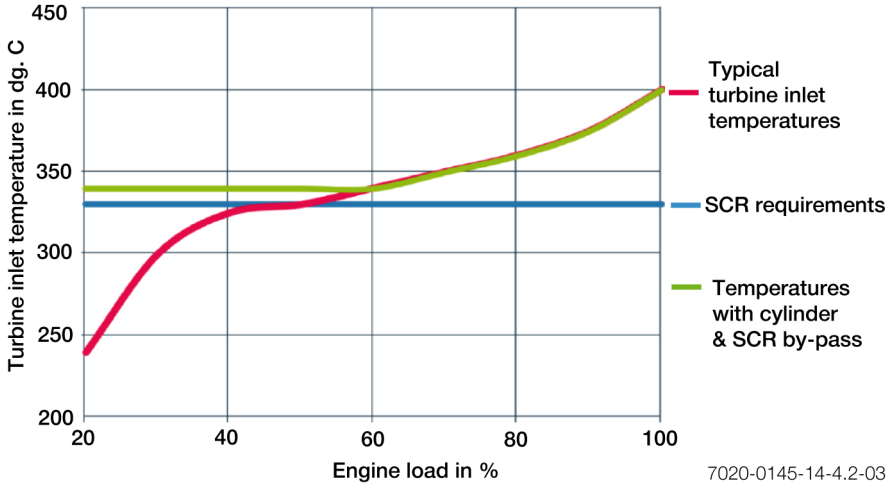


Figure 32: Cylinder bypass range

At low temperature i.e. when the temp is lower than the abs formation temperature, the urea injection will be suspended in order to prevent de-posits in the SCR system caused by insufficient temperatures.

The HPSCR reactor and vaporiser introduce a significant heat capacity and thermal delay between the exhaust receiver and the turbocharger. During Tier III operation this could lead to thermal instability of the engine and turbocharger at any engine load depending on the size and heat capacity of the installed SCR system. To counteract this instability, the auxiliary blowers will deliver additional charge air to stabilise the system. The auxiliary blowers are furthermore used to improve the heating time of SCR at all loads and during engine accelerations.

The auxiliary blowers will be running up to 47% load in Tier III mode in order to avoid oscillation of pressures and temperatures. The electrical motor on auxiliary blowers for engine with HPSCR is designed according to this requirement.

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4.2.3 SCR process - Low Pressure

When operational conditions restricts the sulphur equivalent in the fuel during the SCR operation to 0.1% S or less, it is possible to install a Low Pressure (LP) SCR system. In this system, the SCR line is placed after the TC which provides flexibility for arranging the SCR installation.

The LPSCR system consists basically of the same major components as the HPSCR system, i.e. SCR reactor, vaporizer/mixer and dosing system, see Fig. 33, Page 49.

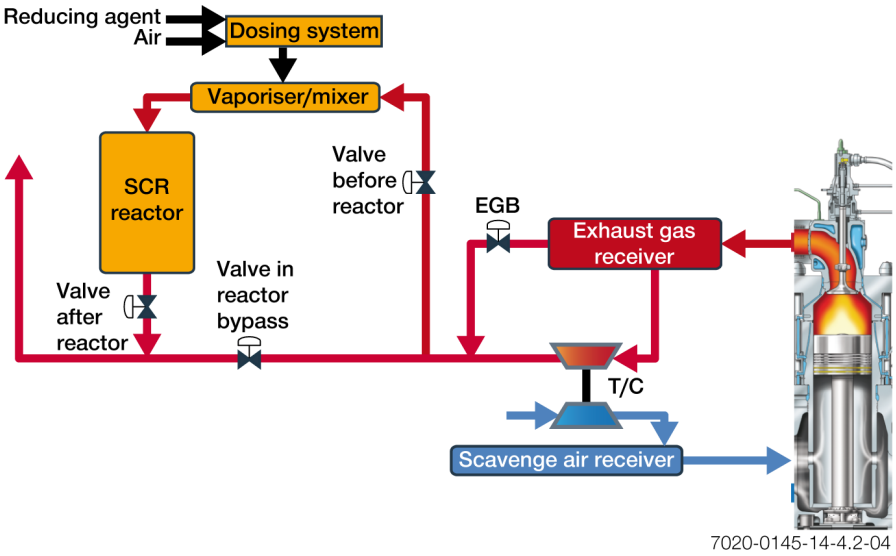


Figure 33: LPSCR installation

However, since the exhaust gas temperature is lower than on the high pressure side, direct injection of urea as reducing agent in the exhaust gas may not be feasible. Therefore a LPSCR system may utilize systems for dosing and vaporizing urea separately from the main SCR exhaust gas duct.
The urea is decomposed to ammonia outside of the SCR exhaust gas in a mixer or AIG (ammonia injection grid). Such a separate decomposition unit (DCU), which is placed in a gas line between the reactor outlet and mixer inlet, may consist of additional components such as a heater (burner), blower and vaporizer vessel, see example below in figure.

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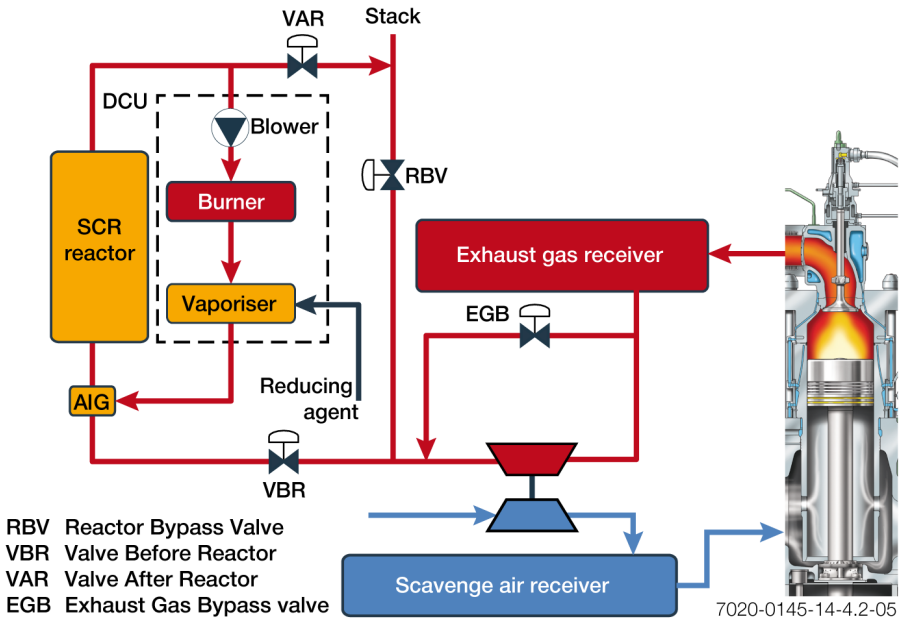


Figure 34: LPSCR with DCU installation

The reducing agent is injected into the vaporiser forming a mixture of ammonia vapour which is led to the mixer and finally to the SCR reactor, forced by the blower.
Although the fuel sulphur content is very low, ABS formation cannot be entirely avoided. One method to dissolve the ABS is to use the DCU to heat and circulate an appropriate amount of gas through the reactor to remove the ABS.
When operating in Tier II mode (SCR not yet engaged, reactor bypassed) the SCR system is cut off by the valve before reactor (VBR) and the valve after reactor (VAR). The reactor bypass valve (RBV) is open and exhaust gas passes directly to stack. When operating in Tier III mode the SCR system will be engaged by opening VBR and VAR and closing the RBV.

The exhaust gas bypass valve (EGB) will open to increase the temperature after the turbocharger. See Fig. 34, Page 50.

When T-Reactor in and T-SCR out measures a value a value above a specified limit, the injection of reducing agent, and hence NOx reduction, can begin.

4.2.4 Tuning methods

High pressure SCR

SCR systems designed for high-pressure operation apply HPSCR tuning. In Tier II mode, the SFOC and the exhaust gas properties are the same as for a standard Tier II engine with low-load EGB tuning. In Tier III mode the SFOC values are increased between 0.5 and 2.0 g/kWh compared to a low-load tuned Tier II engine. An overview of the valve control on HPSCR is shown in the table below. As the opening range of CBV depends on the specific engine rating and the fuel sulphur content, an undefined range between 25% and 75% MCR is shown for this valve.

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Valve control of HPSCR system								
	Tier II mode				Tier III mode			
MCR %	RBV	RSV	RTV	CBV	RBV	RSV	RTV	CBV
100	Open	Closed	Closed	Closed	Closed	Open	Open	Closed
85								
75								Open
50								
25								

Low pressure SCR

Valve control of LPSCR system						
	Tier II mode			Tier III mode		
MCR %	RBV	VBR	VAR	RBV	VBR	VAR
100	Open	Closed	Closed	Closed	Open	Open
85						
75						
50						
25						

SCR influence on boiler

The slip of ammonia from the SCR system combined with sulphur originating from the fuel can lead to deposits of ABS (Ammonium bisulfate) on the low temperature surfaces of the exhaust gas boiler. The amount of ABS deposits is dependent on the type of fuel used during SCR operation and on the amount of ammonia slip from the SCR reactor.

Low sulphur fuel operation (≤0.1% S)

For SCR systems designed for low sulphur fuels the formation of ABS in the boiler is limited due to the low amount of sulphur in the exhaust gas. Even if the ammonia slip from the SCR system is increased, the formation of ABS will be limited due to the low sulphur content. Furthermore, the deposits formed in the boiler during low sulphur operation are easily removed by standard cleaning methods

High sulphur fuel operation (>0.1% S)

SCR systems designed for high sulphur fuels can lead to significant ABS deposits when the sulphur content and ammonia slip is high. Furthermore, the deposits formed in the boiler under SCR operation with high sulphur fuel tend to be sticky and hard to remove by standard cleaning methods. It is the experience that well designed high sulphur SCR system will have low ammonia slip and the ABS deposits will be limited. However, to secure unrestricted

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passage of exhaust gas from the main engine in the exhaust gas line, it is recommended to install a bypass of the exhaust gas boiler to ensure unrestricted passage during SCR operation.

4.3 Layout

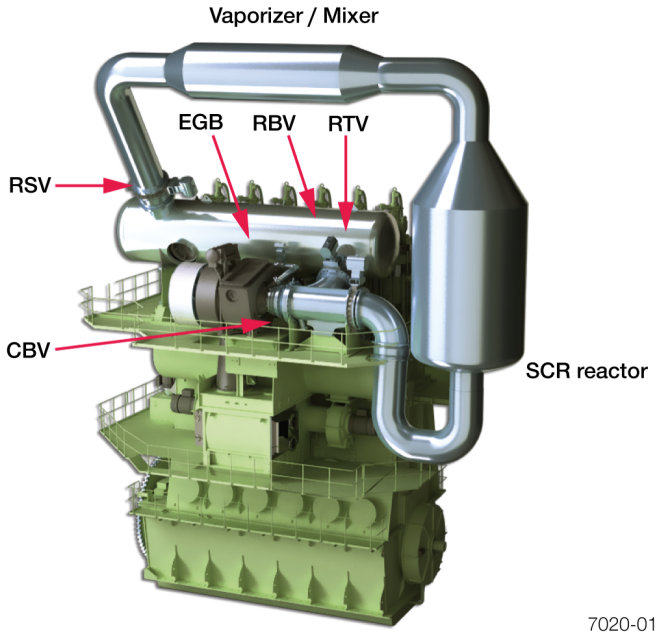
Although the SCR system is closely related to the engine, the SCR line is not part of the engine delivery. The system, however, must be based on specifications from Everllence.

The size of the SCR components is determined by the gas flow and depends on the specified engine power, but other factors will influence the size too. Among these factors are:

- The specified lifetime of the catalyst elements – if an increased lifetime of the catalyst elements is required, the volume of catalyst and accordingly the size of the reactor will increase
- the choice of reducing agent – if ammonia is chosen as the reducing agent, the process time for vaporising is reduced and only a small mixer is needed. However, the storage and handling of ammonia will be more complex compared to urea.

4.3.1 High Pressure SCR

An example of a high-pressure SCR system, supplied by Hitachi Zosen Corporation, is shown in Fig. 35, Page 52. As the exhaust gas is led from the SCR reactor to the turbocharger, the system is arranged close to the engine. The arrangement, which also includes a turbine bypass, could be chosen differently according to engine room restrictions.

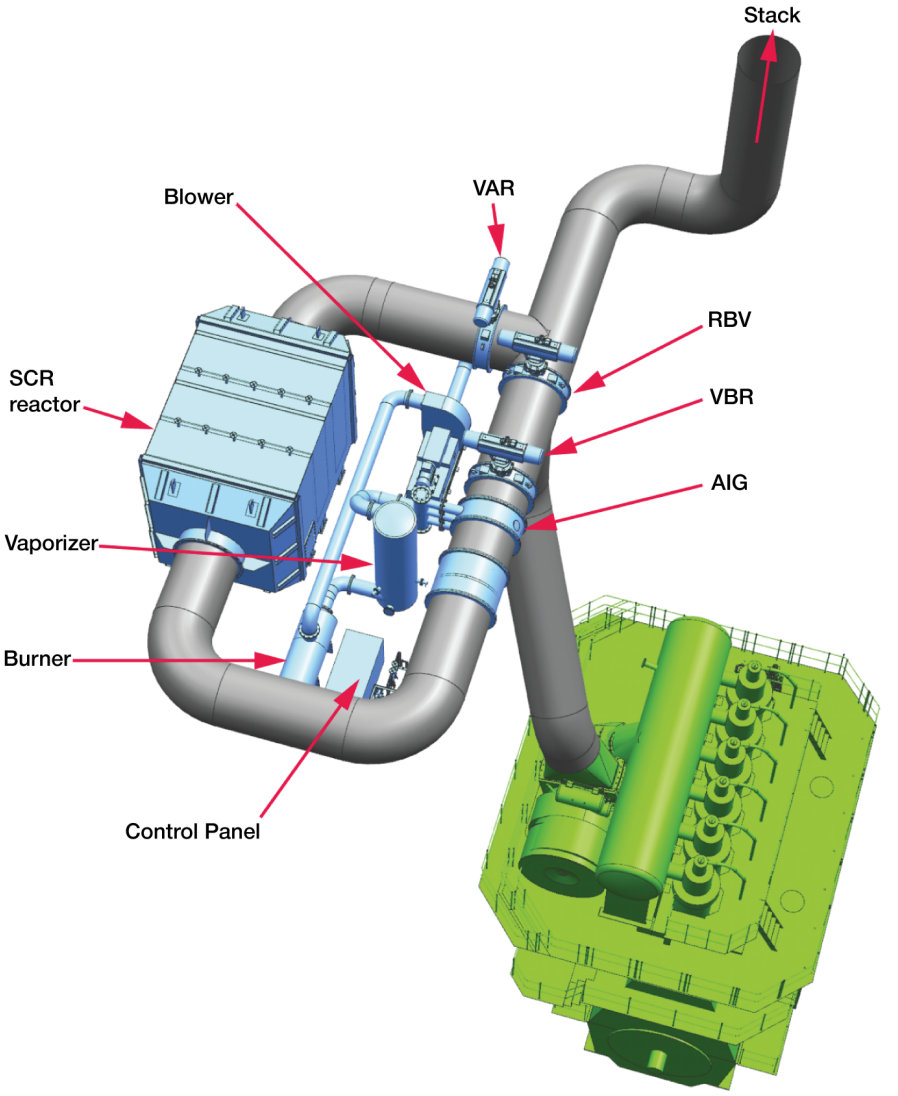


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Figure 35: Layout of a high-pressure SCR system, as supplied by Hitachi Zosen

4.3.2 Low Pressure SCR

An example of a low-pressure SCR system, supplied by Doosan Engine Corporation, is shown in Fig. 36, Page 53. The system is connected to the exhaust gas pipe after the turbine outlet, providing flexibility to arrange the SCR away from the engine.



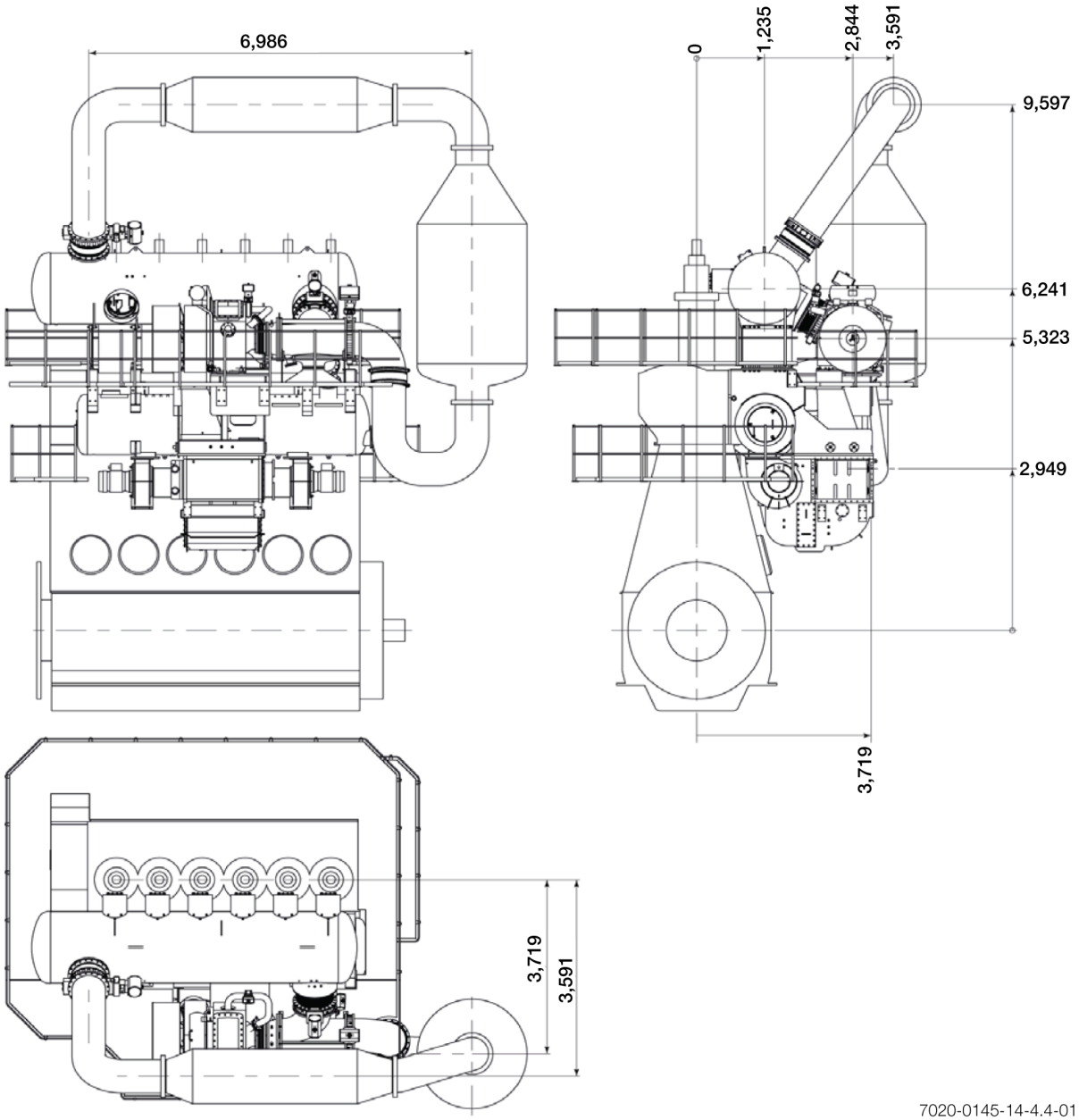
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Figure 36: Layout of a low-pressure SCR system, as supplied by Doosan

4.4 Outline

4.4.1 High Pressure SCR

An example of a high-pressure SCR outline is shown in Fig. 37, Page 54. The SCR line can be arranged in different ways to meet the engine room restrictions.



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Figure 37: SCR installation on an 8 MW engine (6S46ME-B) using Hitachi Zosen SCR-HP system

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4.4.2 Low Pressure SCR

An example of a low-pressure SCR engine is shown in Fig. 38, Page 55. The SCR line is placed in the exhaust gas line away from the engine, providing high flexibility for the arrangement.

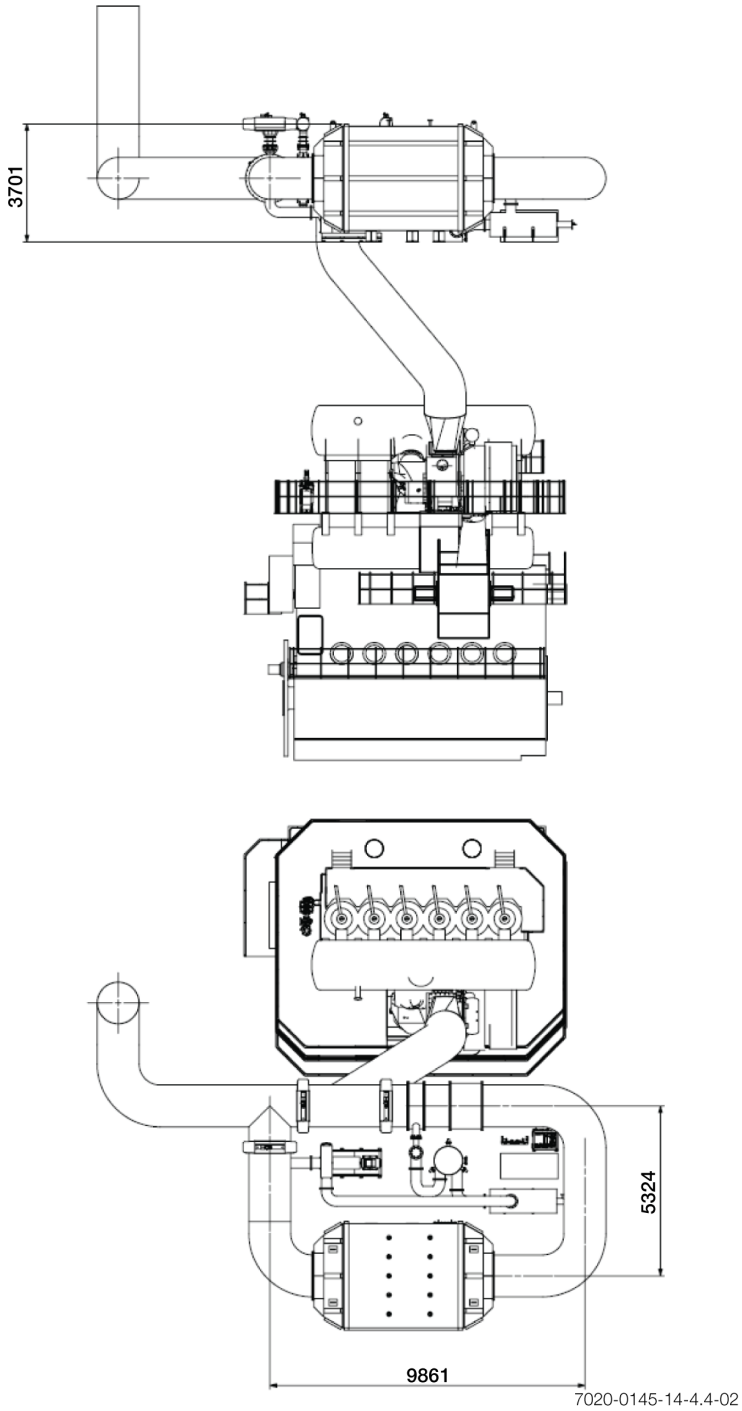


Figure 38: SCR installation on a 14 MW engine (6S60ME-C) using Doosan SCR-LP system

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4.5 Auxiliary systems

Supply system of reducing agent

The reducing agent used for the SCR process is either anhydrous ammonia (NH_3), aqueous ammonia (25% NH_3) or aqueous urea (32.5% or 40% solution).

As anhydrous ammonia (NH_3) is classified as a toxic and dangerous substance, it is convenient for marine purposes to use urea, which has no significant hazards. In addition, the urea supply system is less complex than the supply system for anhydrous ammonia, but the consumption and storage volume of urea is larger. In addition, urea requires a more complex vaporising and mixing process which influences the layout of the SCR system. Aqueous ammonia (25% NH_3), although corrosive and harmful for the health and environment, could with some precautions be handled like urea. Independent of the selected reducing agent, the injection is performed in combination with compressed air.

It is essential that both the injection and the mixing of the reducing agent are performed effectively. Any unused ammonia, defined as the ammonia slip, is likely to react with the exhaust gas to become ammonium bisulphate (ABS) when the temperature decreases, and involves the risk of deposits in the exhaust gas system, e.g. in the exhaust gas boiler. Fig. 39, Page 57.

Ammonia supplied as an aqueous solution of NH3 (<25% solution) is classified as corrosive and harmful for the environment. The storage tank and the part of the supply system that includes an evaporator must be situated in a separate room away from the machinery room and the accommodations.The consumption and storage volume for this solution is largely the same as for urea.

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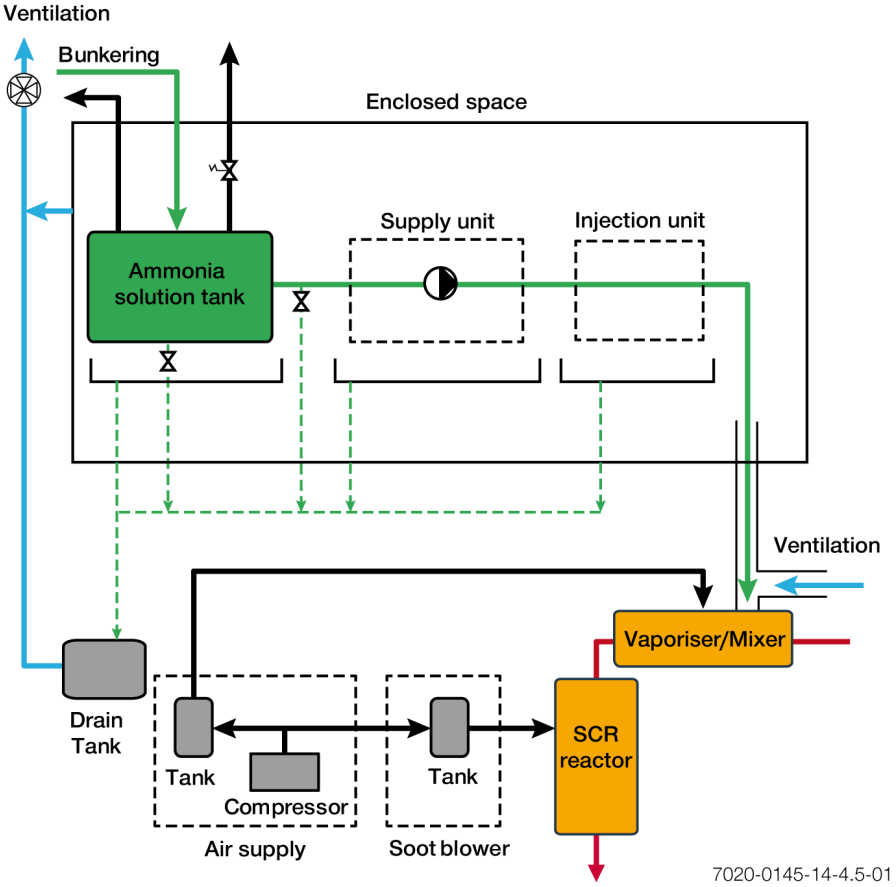


Figure 39: Aqueous ammonia supply system

From the storage tank, urea is pumped to the vaporizer/mixer by a urea pump in the supply unit. The supply unit also has a wash water tank and a pump for purging the urea injection nozzles. A control unit controls the injection of urea and compressed air into the vaporizer. When the SCR process is shutting down, the urea injection nozzles are purged with wash water and/or air to prevent clogging of the nozzles. This purging process is employed at various stages and phases of the SCR process and is referred to as Flushing. As an alternative to liquid, urea could be stored as solids and mixed on board.

Fig. 40, Page 58.

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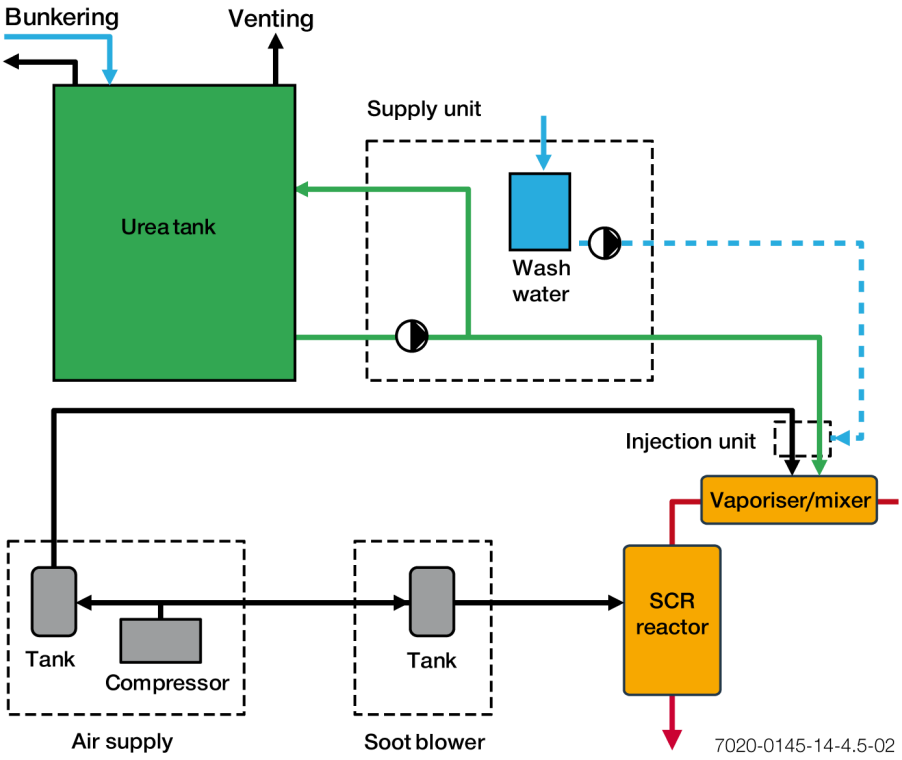


Figure 40: Urea supply system

Soot blower system

To prevent contamination of the reactor elements, a soot blowing system is installed. The soot blowing process is performed periodically when the exhaust gas passes through the SCR reactor and the soot is led out with the exhaust gas after being blown loose from the elements inside the reactor. The soot blowers installed in the SCR reactor are designed in a way that ensures only low permanent increase of the pressure loss across the SCR system over time i.e. keep the total pressure drop of the SCR system below the maximum pressure losses.

SCR heating system

The SCR reactor and the vaporiser have significant heat capacities due to the size and mass of the components. The system should normally be engaged in due time before entering a NO_x ECA to obtain the right operating temperature of the SCR reactor and vaporiser. However, when in harbour, i.e. at engine standstill, the temperature will slowly decrease and means to keep the temperature at the required level or to heat up the system must be available. To meet this demand, the system needs to be equipped with heat tracing or other appropriate means.

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4.6 Control system

The SCR control is handled by the Emission Reduction Control System (ERCS), which is mandatory on all MDT 2-stroke Tier III engines. The ERCS is delivered by the engine builder.

4.6.1 High Pressure SCR control system

On engines with High Pressure SCR the ERCS controls the reductant dosing amount and the SCR valves. It further handles the interfaces to a number of subsystems. These subsystems comprise a reductant dosing system, a soot blowing system, a standby heating system and a venting system. The subsystems mentioned may be implemented as one or more systems. The ERCS has a close integration with ME-ECS and communicates to ME-ECS via a bus connection. The ERCS on High Pressure SCR consists of 2-3 MPCs, depending on the configuration, and 1 SCR MOP.

4.6.2 Low Pressure SCR control system

On engines with Low Pressure SCR the ERCS controls the reductant dosing amount and handles interfaces to a number of subsystems. These subsystems comprise a reductant dosing system, a valve control system and a regeneration system. The subsystems mentioned may be implemented as one or more systems. The ERCS has a close integration with ME-ECS and communicates to ME-ECS via a bus connection. The ERCS on Low Pressure SCR consists of 1 MPC and 1 SCR MOP.

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4.7 Installation

4.7.1 Engine room arrangement

A schematic arrangement of an SCR installation using urea as the reducing agent is shown in Fig. 41, Page 60. The arrangement includes a compressor unit supplying compressed air to the injection process and to the soot blower system. The compressor can be part of the general supply of compressed air for the engine room or, alternatively, be dedicated to the SCR system.

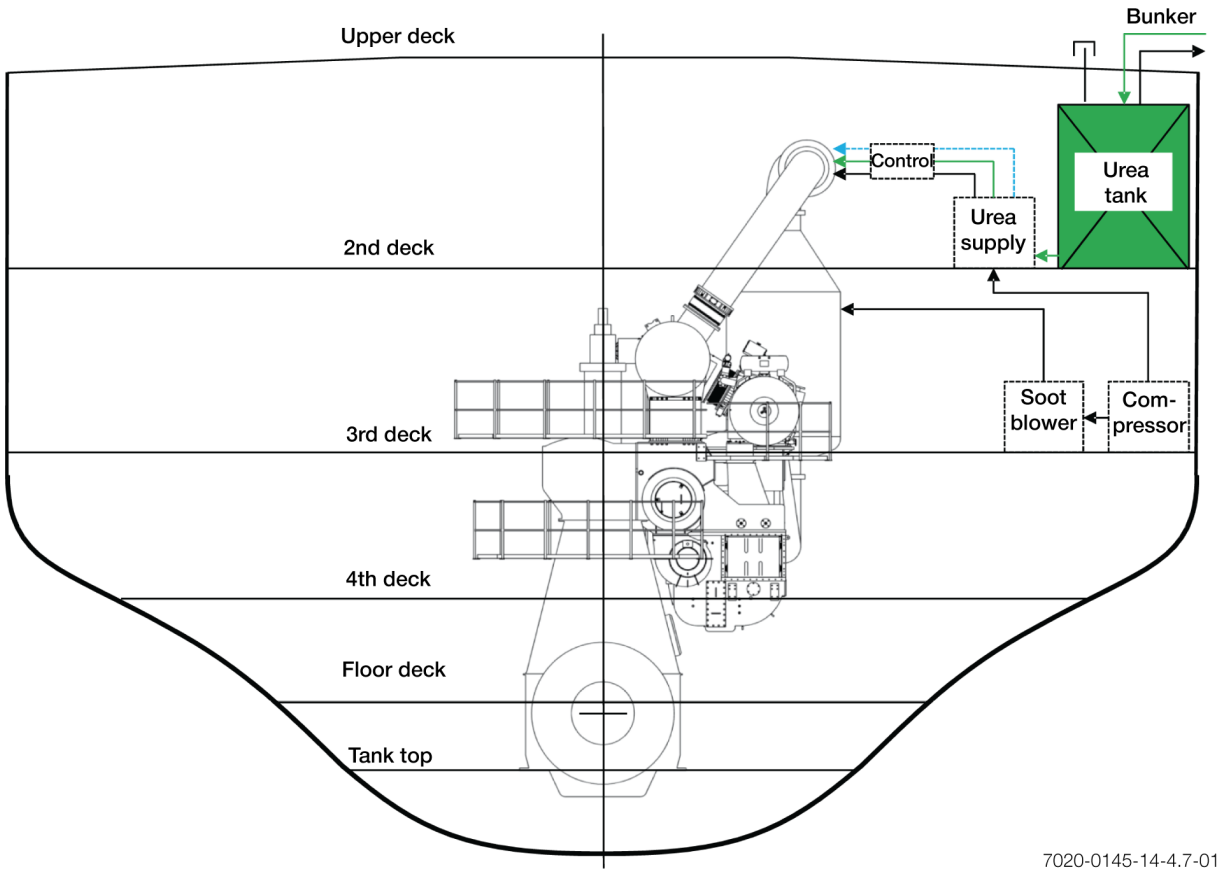


Figure 41: Example of an SCR arrangement in the engine room

4.7.2 Storage of reducing agent

Due to different hazards and different specific consumption figures, the arrangement, material and volume of the storage tank for the reducing agent will depend on the actual choice of reducing agent.

The required volume of the tank depends on the consumption of the specific reducing agent, the estimated ECA sailing time, the sailing pattern, and the planned bunker period. Furthermore, the lot size of the reducing agent when bunkering should be taken into consideration. An example of dimensioning the storage tank is found in the following chapter, 'Consumption and capacities'.

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All material used for storage, transportation and handling of the reducing agent including tanks, tubes, valves and fittings must be compatible with the specific reducing agent to avoid any contamination of the substance and corrosion of devices used. Furthermore, the storage temperature of the reducing agent should be in accordance with the supplier's recommendations.

- Urea tank

  The urea tank could be an independent tank suitable for the solution or an integrated tank properly coated. The tank must be ventilated to open air.

- Ammonia tank (aqueous solution)

  With aqueous ammonia as the reducing agent, it must be stored in an independent tank suitable for the solution. The tank and the supply system should be placed in a separate room ventilated to open air and the supply pipes in the engine room must be laid in ventilated ducts or double-walled pipes. The bunkering system must include a vapour return pipe to the bunker delivery.

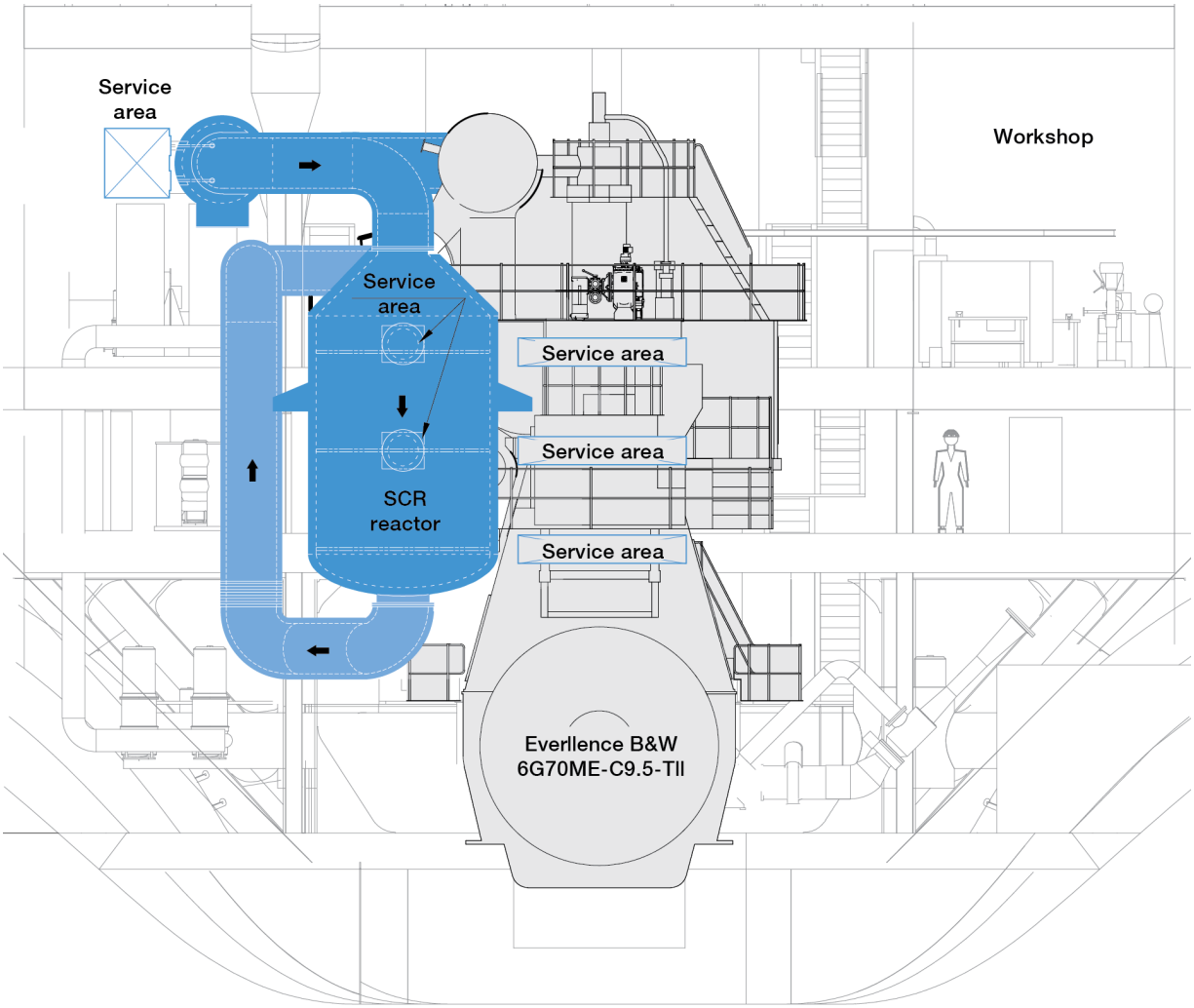
4.7.3 SCR circuit installation

The arrangement and installation of SCR reactor, vaporizer/mixer and gas pipes must be carefully considered, taking the high pressure and temperatures in the SCR system and the forces on the ship and engine into account. A guideline for installation and calculation of back pressure is available on request.

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4.7.4 Example of an SCR arrangement

The example presented in the following pages Fig. 42, Page 62 shows an SCR arrangement on a 6G70ME-C9.5 engine in a 182,000 DWT bulk carrier. Consumption and capacity data for this system, including capacity of the Urea tank, is given as an example in Section Calculation of SCR data, Page 67.



Transverse section at frame-42 (Looking aft)

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Ship: 182,000 DWT Bulk carrier
Engine: 6G70ME-C9.5, 16.4 MW
SCR system: High Pressure SCR

Figure 42: Example of SCR System on a 182,000 DWT bulk carrier. Arrangement by Odense Maritime Technology (OMT)

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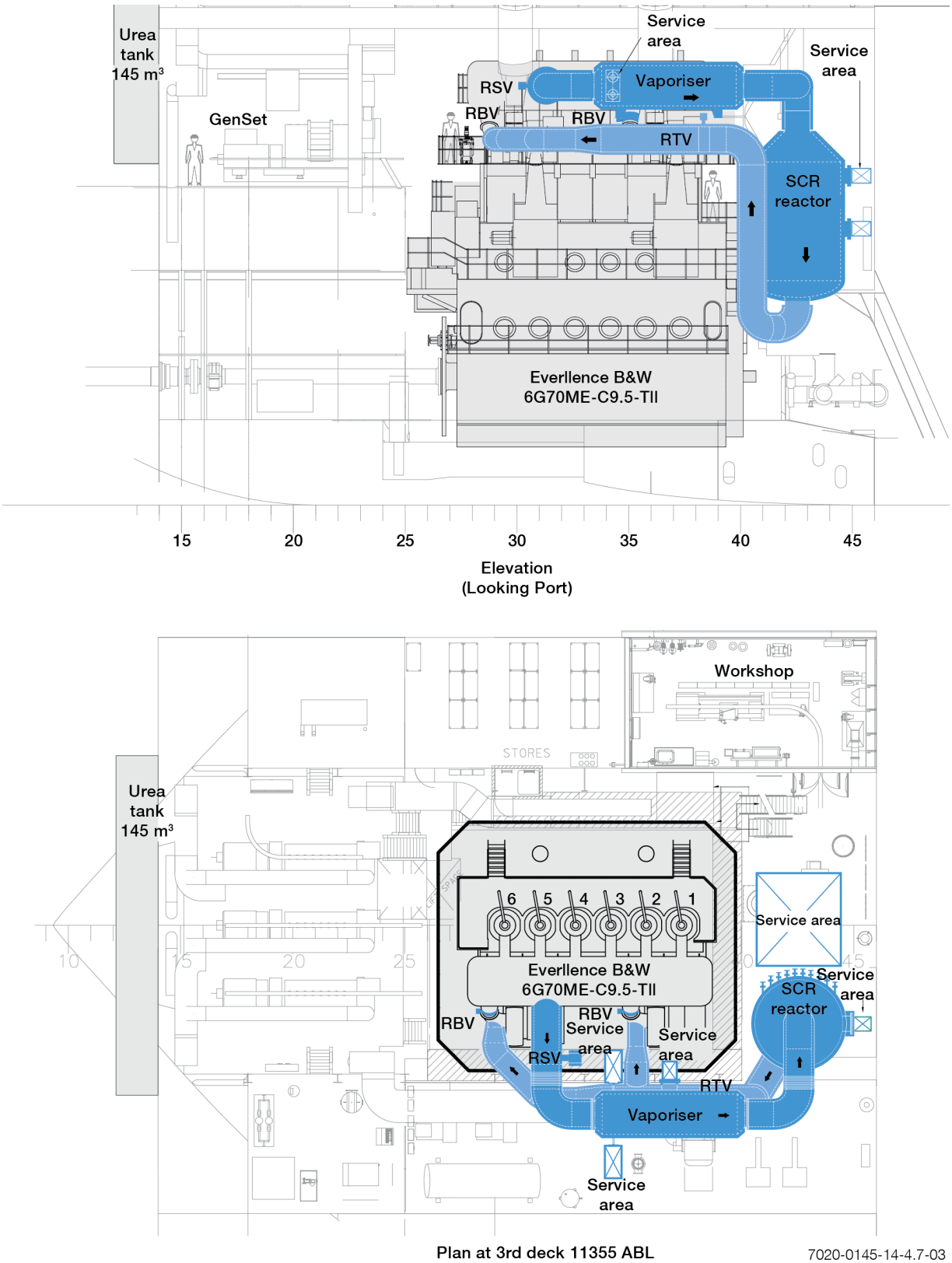


Figure 43: SCR arrangement on a 6G70ME-C9.5 engine

4.8 Spare parts

4.8.1 SCR-LP

Recommended spare parts that support unrestricted SCR operation:

- 2 NO_X sensor

Other spare parts recommended for unrestricted SCR operation should be in accordance with the SCR supplier's recommendation.

4.8.2 SCR-HP

Recommended spare parts that support unrestricted SCR operation:

- 1 blind flange for RSV
- 1 blind flange for RTV
- 1 dummy seal for RSV, RTV or RBV
- 1 dummy valve for RSV, RTV or RBV
- 1 differential pressure transmitter for RTV
- 2 NO_x sensor
- 1 SIPART – single acting
- 1 SIPART – double acting

Other spare parts recommended for unrestricted SCR operation should be in accordance with the SCR supplier's recommendation.

4.9 Retrofit

If a ship is not intended to enter a NO_X ECA in its lifetime, during which it would be required to meet Tier III regulations, there would be no reason to include a comprehensive Tier III installation. However, any doubt whether the ship would enter such an area in the future could lead to a decision to install the equipment anyway, or at least prepare the ship for a retrofit installation. SCR retrofit could be prepared for SCR-LP or SCR-HP. In any case a Tier II low-load EGB tuning is recommended for the SCR prepared engine. The matching of components for SCR retrofit can be evaluated by MDT case by case.

SCR-LP

The SCR-LP is located in the exhaust gas duct after the turbocharger, and it is not physically connected to the engine. However, the necessary space in the engine room and exhaust gas duct has to be prepared for later installation. The pressure drop and layout of the turbocharger and auxiliary blower need to be evaluated and adjusted for SCR-LP application. This can be carried out in connection with the installation of the engine, or in connection with the installation of the SCR-LP system. The retrofit of an SCR-LP requires a rematching of the turbocharger.

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SCR-HP

With regard to preparation for retrofit of SCR-HP, the challenge and dominant factor is the space and the general arrangement in the engine room. Any plans for later retrofitting of SCR-HP must be discussed with the yard before the engine room is designed. On the engine side, the turbocharger layout and auxiliary blowers will be influenced by the SCR-HP retrofit installation.

4.10 Consumptions and capacities

Performance and consumption data for SCR engines are available by the engine calculation program, CEAS. For a specific project, CEAS data provides the base to estimate the consumptions and capacities of a specific project, as exemplified in the subsequent chapter.

Specific fuel oil consumption

The SCR concept affects the performance data of the engine. The influence on the specific fuel oil consumption (SFOC) depends on the choice of SCR system, be it a high-pressure (HP-SCR) or a low-pressure system (SCR-LP). In addition, the engine type may have an influence on the SCR performance.

Electrical power consumption

The power required for the SCR system is related to the auxiliary systems for the SCR system. The power consumption includes power to supply the reducing agent and the compressed air, additional power for the auxiliary blowers and for the heating of SCR reactor. The electrical power consumption is roughly regarded independent on the engine load and estimated to 5 kW/MW SMCR.

4.11 Consumption of reducing agent

The consumption of reducing agent depends on the agent type, the engine load and the NO_X reduction rate. The estimated specific consumption required to reduce the NO_X level from Tier II to Tier III is shown in Table 6. Urea consumption for a specific engine could alternatively be found by the engine calculation programme, CEAS.

Reducing agent	g/kWh	l/MWh
Urea – 40%	17.9	16.1
Ammonia - 24.5%	16.6	18.4

Table 13: Consumption of reducing agent

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Catalyst replacement

Depending on the load of the SCR reactor, the catalyst elements will slowly lose the ability to facilitate the NO_X reduction process. To keep the required efficiency of the reactor, the elements should be replaced periodically according to the catalyst supplier. Therefore, the catalyst elements are regarded as consumables and should be included in the running costs of the SCR system, depending on sailing pattern and time in Tier III mode.

The catalyst lifetime depends on the need for NO_X reduction. The engine load, the NO_X reduction rate and the time, during which the reactor is engaged, will directly influence the lifetime of the catalyst. The type and relative volume of the catalyst compared to the engine size will also influence the lifetime. The lifetime of the catalyst should be specified by the supplier.

Compressed air capacity

The capacity of compressed air used for soot blowing and for the injection process relates to the reactor size, the type of reducing agent and the sulphur content in the fuel. As an alternative to a dedicated SCR compressor, it could be part of the general supply of compressed air for the engine room. The capacity of compressed air for the injection and soot blowing should be considered in the ship design process according to the supplier's standard.

SCR heating

The need for heating of the SCR components before leaving a port inside an ECA can be met by a number of different methods, but the capacity for the system chosen must be according to the SCR supplier's standard and be included in the capacity for ship.

Auxiliary blower capacity

The auxiliary blowers will be running up to 47% load in Tier III mode in order to avoid oscillation of pressures and temperatures. The electrical motor on auxiliary blowers for engine with HPSCR is designed according to this requirement.

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4.12 Calculation of SCR data

An example of SCR data for a 16.4 MW Everllence B&W engine is calculated below for a specific NECA sailing pattern. The consumption and capacities are found by the engine calculation programme, CEAS, as noted in the previous section. An engine room arrangement for this SCR installation is given as an example in section Installation, Page 60.

Assumptions

Ship	Bulk carrier
Size	182,000 DWT
Engine	6G70ME-C9.5
Power, SMCR	16,440 kW
Engine speed	83.0 rpm
SCR system	HP LS SCR
Reducing agent	Urea 40%
Tank margin	10%
Bunker frequency *	300 operating hours in NECA
NECA sailing time	600 h/year
NECA sailing profile 25% MCR	30% time/180 h
NECA sailing profile 50% MCR	30% time/180 h
NECA sailing profile 75% MCR	30% time/180 h
NECA sailing profile 100% MCR	10% time/60 h

* Please note, that the bunker frequency of 300 operating hours is an example of an adequate time between bunkering of urea for a return trip in the Northern European ECA (NO_X ECA from Jan. 2021)

Step 1

Based on the input from the specified engine CEAS provides the data used in the example for SFOC in Tier II and Tier III mode and for the urea supply in Tier III mode. The additional fuel consumptions in Tier III mode are calculated and shown in Table 14, Page 68. The electric power and the urea consumptions are shown in Table 15, Page 68. The electric power consumption are based on the data given in the previous chapter.

Step 2

The total consumption in an NECA area, i.e. when the SCR system is operating, depends on the sailing profile and the sailing time in the NECA. When multiplying the values found in step 1 with the profile values, the consumption for one hour could be found. The yearly consumption is found when the NECA sailing time is known. The result is shown in Table 16, Page 68.

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Step 3

The Urea tank capacity is calculated based on the bunker frequency of reducing agent. A margin should be included to compensate for variations in the sailing profile and sailing hours. The result of the calculation is shown in Table 17, Page 68.

Engine load, % MCR	25%	50%	75%	100%	
SFOC Tier III	166.8	158.0	157.5	162.0	g/kWh
SFOC Tier II	164.0	156.5	156.5	161.5	g/kWh
Additional SFOC	2.8	1.5	1.0	0.5	g/kWh
Additional fuel Tier III	11.5	12.3	12.3	8.2	kg/h

Table 14: Fuel consumptions in Tier II and Tier III mode

Engine load, % MCR	25%	50%	75%	100%	
El. power	82.2	82.2	82.2	82.2	kW
Urea	120	190	230	230	l/h

Table 15: Additional SCR operating values

Engine load, % MCR NECA load profile Time	25% 30%	50% 30%	75% 30%	100% 10%	Total		Total per year	
Additional fuel	3.5	3.7	3.7	0.8	1.7	kg/h	7.0	ton/year
El. power	24.7	24.7	24.7	8.2	82.2	l/h	49.3	MWh/year
Urea	36	57	69	23	185	l/h	110	m3/year

Table 16: Accumulated SCR operating values

In addition to the above consumption, the replacement of catalyst elements, which is also regarded as consumables, should be included in the evaluation.

Item	Parameter	Volume	Margin	Tank size
Urea tank	300 hours	55 m^3	10 %	61 m^3

Table 17: Tank capacity of reducing agent

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5 SO_x reduction

Sulphur limits

The international requirements on emissions of SO_X (sulphur oxides) and PM (particulate matter) are determined by the MARPOL convention Annex VI, which specifies a global limit and a local (SO_X ECA) limit on the sulphur content in marine fuel. The specified sulphur limits will change according to the illustration in Fig. 44, Page 69, showing a reduction in SO_X ECA from 1.0% to 0.1% sulphur in 2015, and a reduction in the global limit from 3.5% to 0.5% sulphur in 2020.

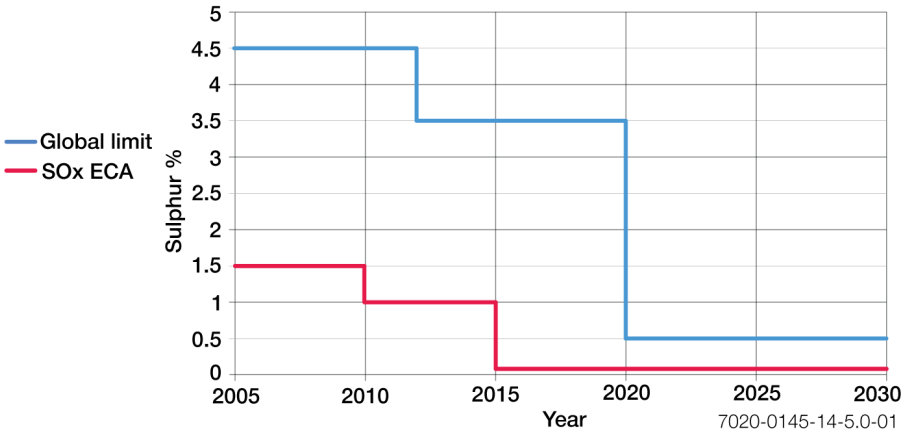


Figure 44: Fuel sulphur limits according to MARPOL Annex VI

Equivalents

Although the SO_X requirements can be met by using a low-sulphur fuel, the regulation allows alternative methods to reduce the emissions of SO_X to an equivalent level. The techniques used for this purpose must follow additional guidelines specified by IMO to prove equivalence with the fuel sulphur limits.

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5.1 Low-sulphur fuels

Diesel fuel

The SO_x ECA limit can be met using a low-sulphur fuel, e.g. marine gas oil (MGO) with a sulphur below 0.1%. The limit outside SO_x ECA (non-ECA) can be met using e.g. marine diesel oil (MDO) with a sulphur content below 0.5%, which will be required from 2020. Certain precautions must be taken when using these fuel types.

Further information can be found in the paper 'Low-sulphur fuel operation', published by Everllence.

Gas fuel

As liquified natural gas (LNG) contains no sulphur, the SO_x limits can be met by installing an Everllence B&W ME-GI dual fuel engine, provided also the pilot oil meets the sulphur limits. Furthermore, when running in fuel oil mode, the SO_x limit must be met by using low-sulphur fuels, if no alternative method for SO_x reduction is available.

Further information on ME-GI dual fuel engines can be found in the paper 'MEGI Dual Fuel Everllence B&W Engines', published by Everllence. The paper is available for download at: www.everllence.com → 'Marine' → 'Planning tools and downloads' → 'Technical Papers'.

5.2 SO_x scrubber

The cost of low-sulphur fuels such as MDO and MGO is high compared to heavy fuel oil (HFO). Therefore, alternative low-cost methods to reduce the emissions of SO_X by exhaust gas cleaning have been developed.

The process of exhaust gas cleaning is performed in a scrubber unit using a dry or wet agent to remove SO_X and PM. Marine engines are normally fitted with wet scrubbers using either seawater (SW), which is easily available, or recirculated freshwater (FW) with chemical addition.

This project guide describes the SO_X scrubber systems from Alfa Laval, which are based on the wet scrubber principle, but other scrubber systems are available. Further information on available EGC systems can be found in 'EGCSA Handbook 2012' published by the Exhaust Gas Cleaning Systems Association (EGCSA), www.egcsa.com

Principle

In a wet scrubber, the exhaust gas is cleaned by water on its way to the funnel. The water is injected into the exhaust gas stream and is discharged from the bottom of the scrubber. The sulphur oxides generated in the combustion process due to the sulphurous fuel are dissolved and removed by the scrubber water following a simple chemical reaction:

$SO_2 + H_2O \rightarrow H_2SO_3$ (sulphurous acid)

$SO_3 + H_2O \rightarrow H_2SO_4$ (sulphuric acid)

The water used in the process could be either seawater (SW) or freshwater (FW), which calls for different solutions for both the installation and the operation.

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System

Basically, SO_X scrubber systems are divided into open loop systems using SW, and closed loop systems using FW as medium. Both systems could be chosen for an installation. Furthermore, when a high degree of flexibility is required, a hybrid solution could be installed, combining open and closed loop systems with the ability to switch between SW and FW scrubbing.

Open loop system

When SW is used for scrubbing, an open loop system is chosen as illustrated in Fig. 45, Page 71. The natural chemical composition of seawater neutralizes the impact of SO_X in the scrubber water. The water is taken directly from the sea and fed to the scrubber. Leaving the scrubber, the water is discharged into the sea without any further treatment. The discharge criteria set by the IMO guidelines is met by the high water flow through the scrubber.

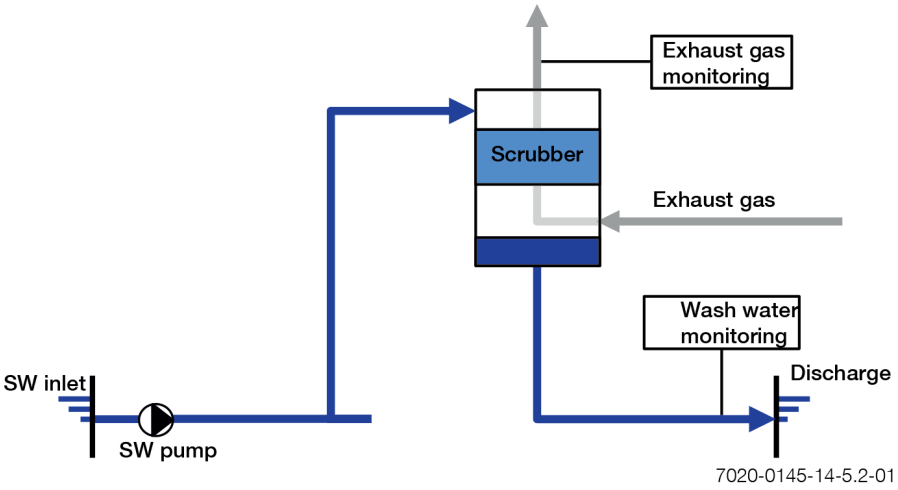


Figure 45: Open loop system

The open loop system is typically used in open waters where the alkalinity of the seawater is sufficiently high for effective scrubbing. The system is simple and the cheapest solution in regards to installation and operating cost. However, an open loop system lacks flexibility when local regulations prevent or limit the use of the system due to low alkalinity or restricted discharge criteria. Open loop operation requires a SW amount of approximately 45m^3/MWh when a 2.7% sulphur HFO is used.

Closed loop system

When FW is used for scrubbing, a closed loop system is chosen, as illustrated in Fig. 46, Page 72. To neutralise the sulphuric acid in the scrubber water, an addition of chemicals is needed. This could be sodium hydroxide (NaOH) forming a sulphate in the following process:

$$H_2SO_3 + 2NaOH + ½O_2 \rightarrow Na_2SO_4 + H2O$$

$$H_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + H_2O$$

However, the sulphate and the particulate matter (PM) from the combustion process accumulates in the scrubber water. To avoid an increase in salinity and contamination of the system, the sulphate and PM must be removed continuously. This is done by bleeding off scrubber water from the system

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and adding FW to replace the lost volume. Most of the FW is regained in the scrubbing process by condensed water from the combustion process. To minimise the loss of FW escaping with the exhaust gas, the scrubber water is led through a cooler before it is injected into the scrubber. A demister is installed to prevent droplets escaping through the funnel. Any loss of water is supplied by the FW supply on board. Before discharging the bleed-off water, a cleaning process is required to meet the IMO guidelines criteria. The cleaning process is performed in a water cleaning unit (WCU) and the sludge is led to a sludge tank.

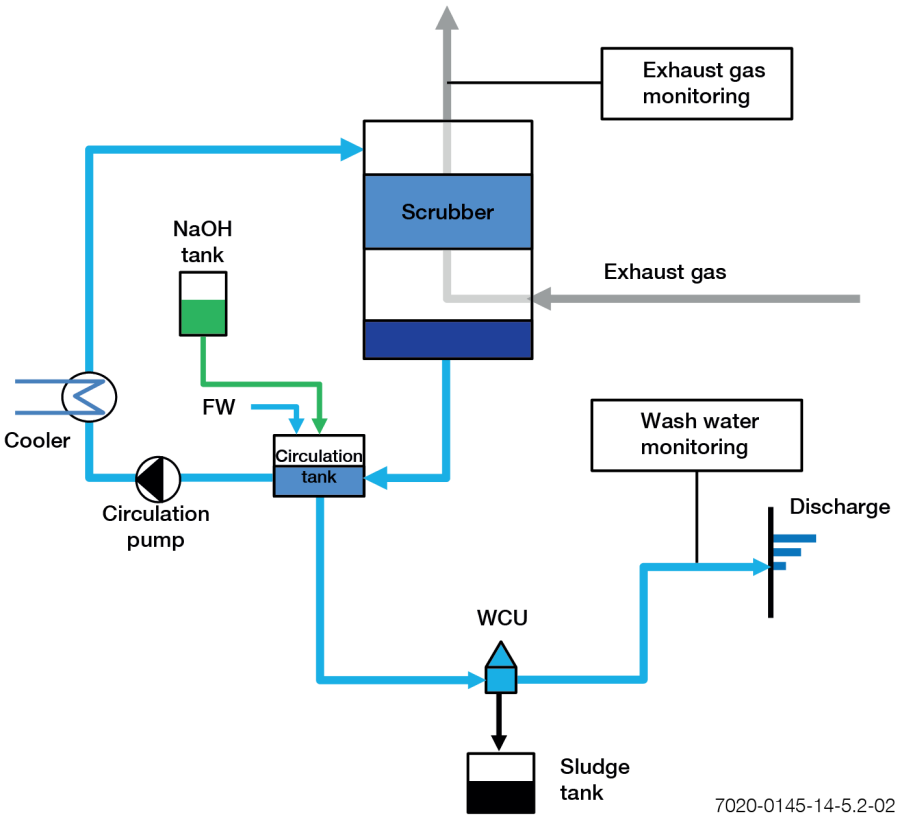


Figure 46: Closed loop system

The closed loop system offers a high degree of flexibility for the vessel as the use is not restricted by local regulations. However, the initial costs are higher, compared to the open loop system, due to the additional equipment. In addition, operating costs are higher mainly because of the constant addition of chemicals. The flow rate in a closed loop system is about half that of an open loop, 30m^3/MWh. Typically, closed loop operation requires a constant discharge at the rate of 0.1 to 0.3 m^3/MWh, although the system can operate with zero discharge for limited periods.

Hybrid system (Open/Closed loop)

The hybrid system, illustrated in Fig. 47, Page 73, combines both an open and a closed loop system and each of their operation modes. Due to the combination, the hybrid system is more complex, but it offers the highest degree of flexibility. The open loop mode is typically used in open waters where the alkalinity is sufficiently high for effective scrubbing. The closed loop system is used in certain enclosed waters, harbours and estuaries or where the alkalinity of the seawater is low. This combination optimises the chemical consumption and ensures that discharges do not affect sensitive areas with little water exchange.

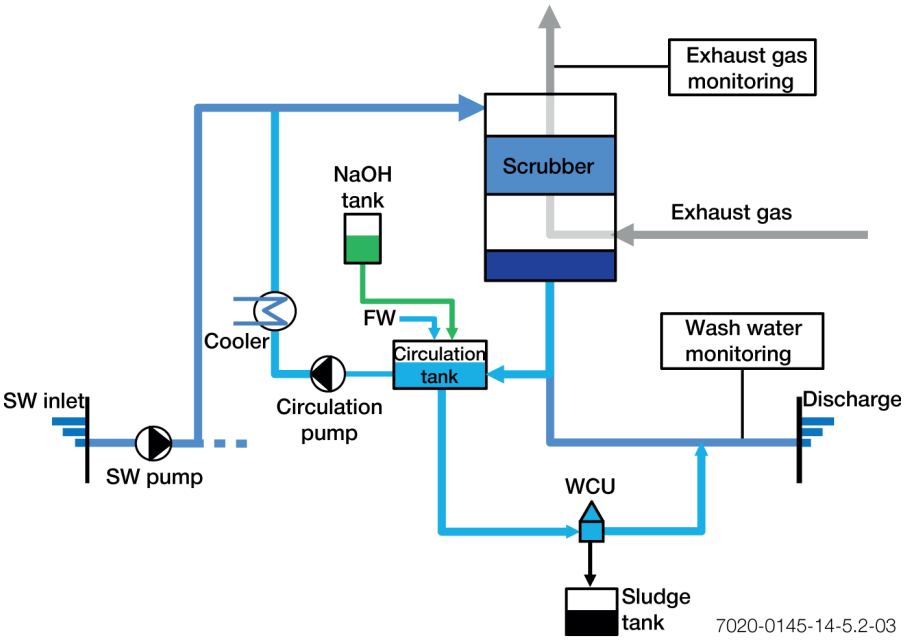


Figure 47: Hybrid system

The initial cost of the hybrid system is higher as it includes equipment for both open and closed systems to gain the flexibility. The hybrid system, however, offers the lowest operating costs as it can switch to the most economic mode in any situation. In each operation mode, the scrubber water flows are similar to the flows specified for open and closed loop systems accordingly.

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Layout

Various types of wet scrubbers exist. Fig. 48, Page 74 shows some typical methods used by the manufacturers, including open spray, cyclonic, packed bed, wet bath, bubble plate and venturi scrubbing. Combinations of these methods are also available.

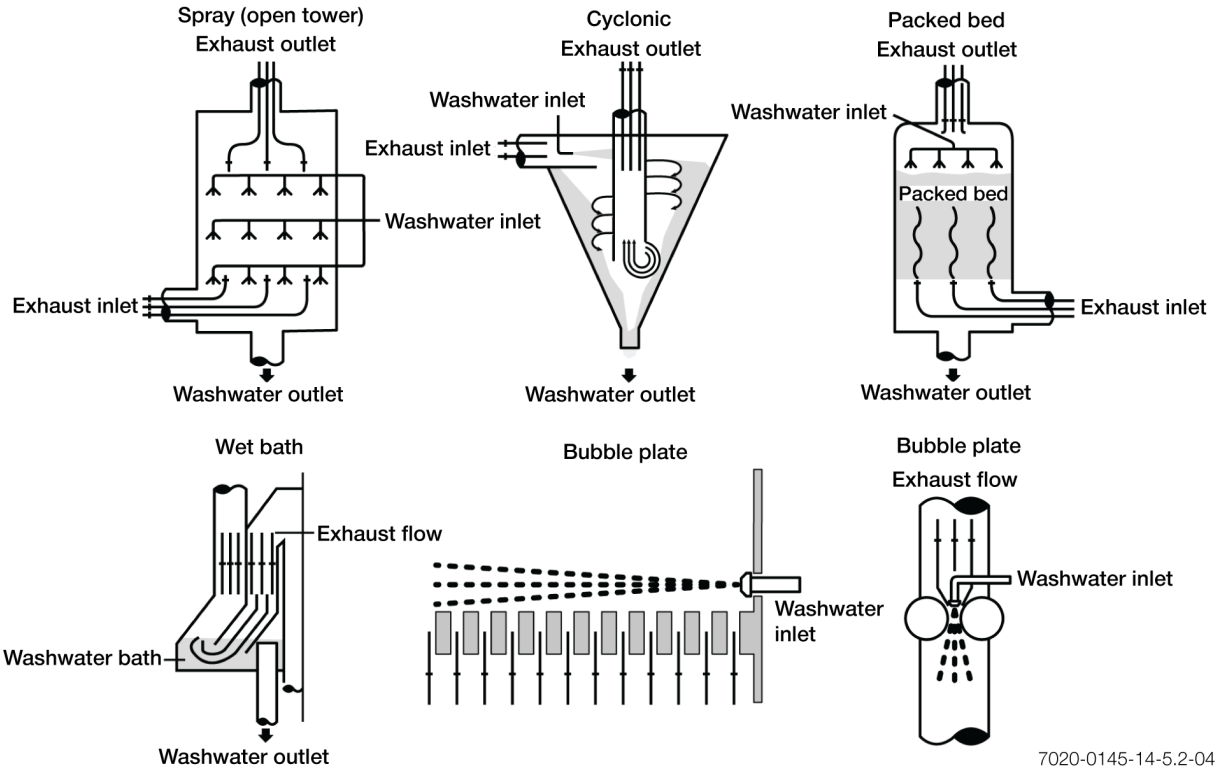


Figure 48: Different methods used for wet scrubbers (courtesy of EGCSA)

The layout of an Alfa Laval SO_X scrubber is shown in Fig. 49, Page 75. The scrubber consists of two parts, a jet scrubber and an absorber. The jet scrubber is a pre-scrubber, starting the scrubbing process with a jet spray into the incoming exhaust gas. Placed upstream of the absorber, it increases the scrubbing efficiency, especially on PM. From the jet scrubber, the gas stream is led through the absorber, a packed bed scrubber where the SO_X is removed to the required level. The jet scrubber could be replaced by a venturi scrubber to increase the PM trapping, but it increases the pressure drop across the unit.

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Figure 49: SO_X scrubber from Alfa Laval

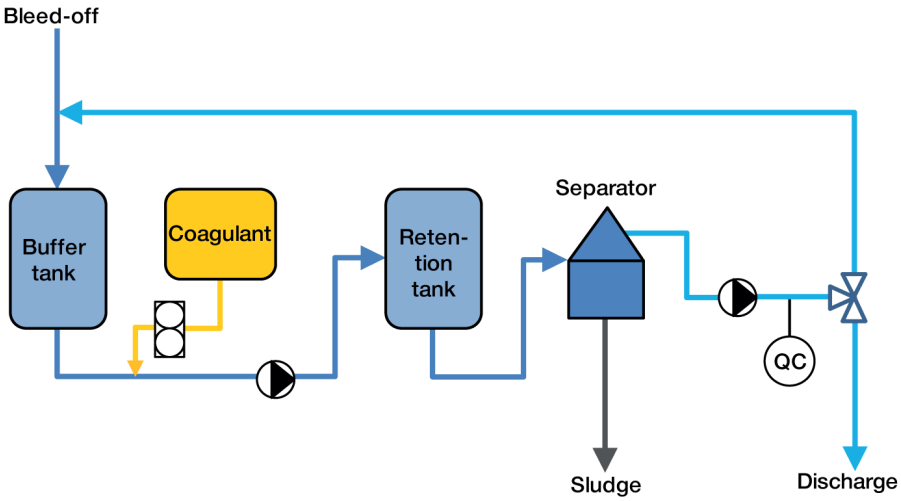
Dimensions

The different types of SO_X scrubber systems vary in size and shape of the scrubber. The total volume of a scrubber unit depends on the amount and condition of the exhaust gas and its content of sulphur and particles. Furthermore, restrictions on the maximum acceptable additional backpressure from the exhaust system influence the scrubber size.

Water cleaning system

When running a closed loop system, it is necessary to bleed off scrubber water to avoid accumulation of salt generated in the process. Before discharging the bleed-off water into the sea, it must be cleaned in a water cleaning unit (WCU). The diagram in Fig. 50, Page 76 illustrates the method used in the Alfa Laval WCU. The bleed-off water from the system is collected in a buffer tank. After addition of a coagulant, the bleed-off is led to a retention tank and forwarded to the high-speed separator for the final cleaning process. A monitoring system (QC) controls the quality of the water with regard to pH value, turbidity and polycyclic aromatic hydrocarbons (PAH) concentration. In case the IMO discharge criteria are not met, the bleed-off is recycled in the unit to increase the quality.

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Figure 50: Water cleaning performed in the WCU

An example of the Alfa Laval WCU is shown in Fig. 51, Page 76. The foot-print of the frame is approximately 2.5 by 2.5 m.



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Figure 51: Alfa Laval Water Cleaning Unit

Control system

The scrubber control panel serves the scrubber, the water cleaning unit and the water discharge. A hardwired interface is connected to the ship's general alarm system. If an alarm is triggered, or an emergency button is activated, the SO_x scrubber system shuts down automatically and the scrubber bypass opens without stopping the engine. After the failure has been eliminated, the alarm disappears from the screen and the system can be restarted.

Alarms and related information is integrated and displayed on the control panel's touch screen. To minimise the energy consumption in the individual operating modes, the pumps in the WCU circuit are controlled by a PLC.

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5.3 Installation

Engine room arrangement

Hybrid System

Below Fig. 52, Page 78 illustrates an engine room arrangement of a hybrid SO_x scrubber system that can run in open loop (on SW) and in closed loop mode (on FW).

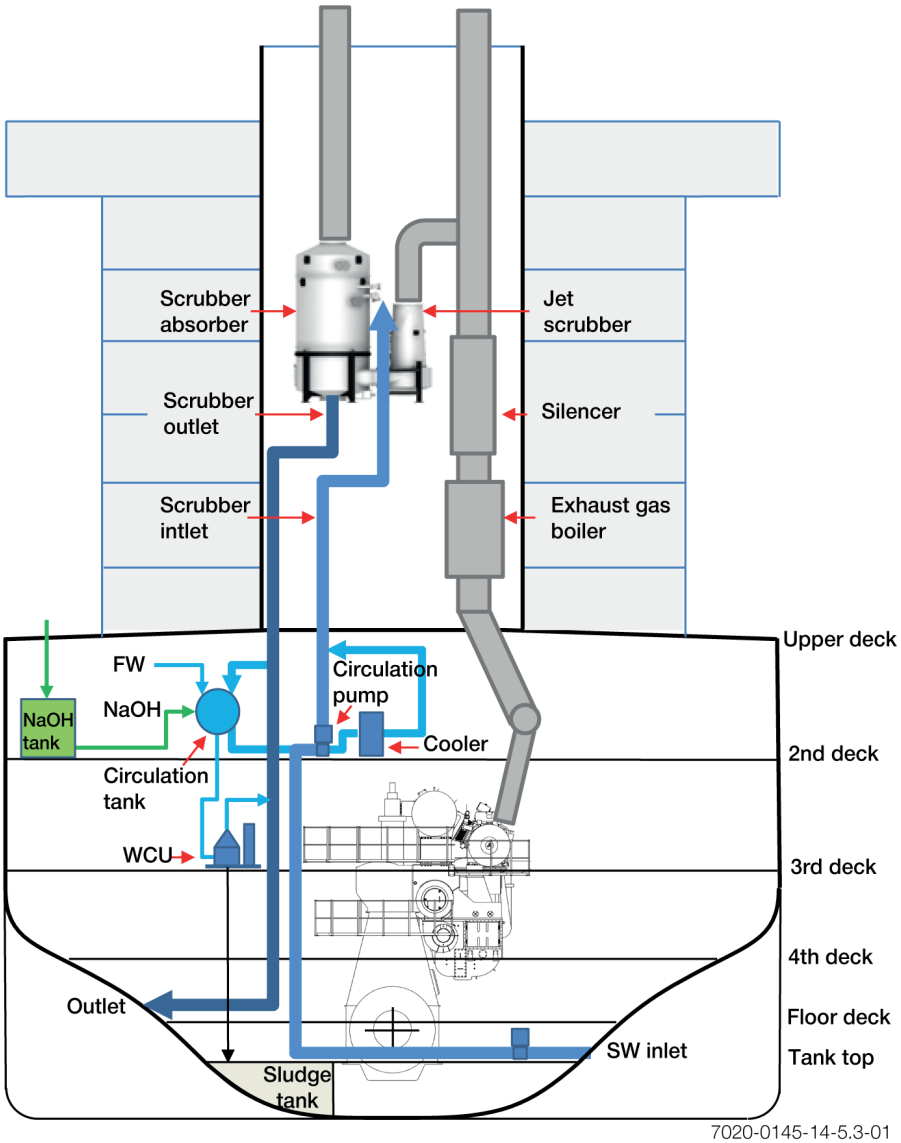


Figure 52: Schematic arrangement of a hybrid SO_x scrubber system (on SW/ FW)

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The exhaust gas cleaning units are normally placed high up in the ship, in or around the funnel area, where more space is available and access is easier. The installation will normally include a bypass to be able to run the engine without the scrubbing process, even though the scrubber in certain designs can run dry without the scrubbing process. In most cases, a SO_X scrubber is an effective silencer even when running dry, which means that the existing silencer can be replaced by a scrubber. As the exhaust temperature is significantly reduced during the scrubbing process, any waste heat recovery system, such as the exhaust gas boiler, must be positioned upstream of the scrubber.

The scrubber water installation in the hybrid system is a combination of the system used in open loop and closed loop installations, as described in the following.

The hybrid system combines the low running costs of the open loop with the flexibility provided by the closed loop system. The hybrid system provides additional flexibility, as the open loop mode can be used also at low SW alkalinity with the addition of NaOH without the need for switching to closed loop mode.

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Open loop system

The SW installation in open loop systems, illustrated in Fig. 53, Page 80 is relatively simple as SW is supplied by the ship's SW system directly to the scrubber. From the scrubber outlet, water is led to the SW discharge system after a quality control has verified compliance with the IMO guidelines.

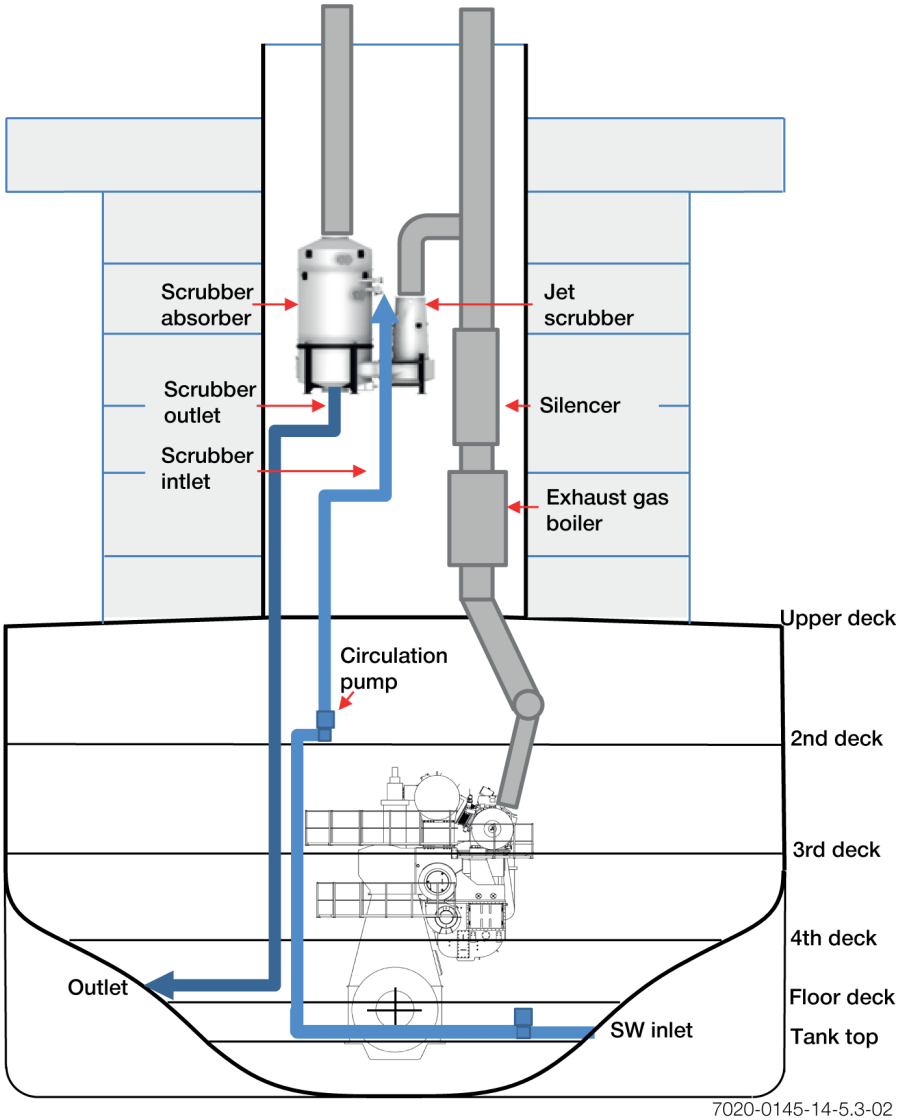


Figure 53: Schematic arrangement of an open loop SO_X scrubber system (SW)

The system has low running costs as no additional treatment is required. However, to obtain a sufficient scrubbing quality, the SW flow rate is relatively high. Combined with the required pressure for the highly placed scrubber, the power needed for SW scrubbing is a running cost that cannot be ignored.

In certain cases, in areas where the seawater alkalinity is too low or restricted outlet criteria is in force, the system cannot be used and running on low-sulphur fuel is required.

Closed loop

The FW scrubbing used in closed loop systems is illustrated in Fig. 54, Page 81. The installation is more complex compared to open loop because a water treatment system is needed. The equipment includes a circulation tank, sludge tank, NaOH tank, circulating pump, FW cooler and a WCU. An alternative to the WCU could be a holding tank to store the bleed-off water for discharge in port. Compared to open loop systems, the scrubber water flow is significantly reduced as the scrubbing efficiency using FW is high compared to SW. Due to the reduced flow, the dimensions of the inlet and outlet pipes are reduced.

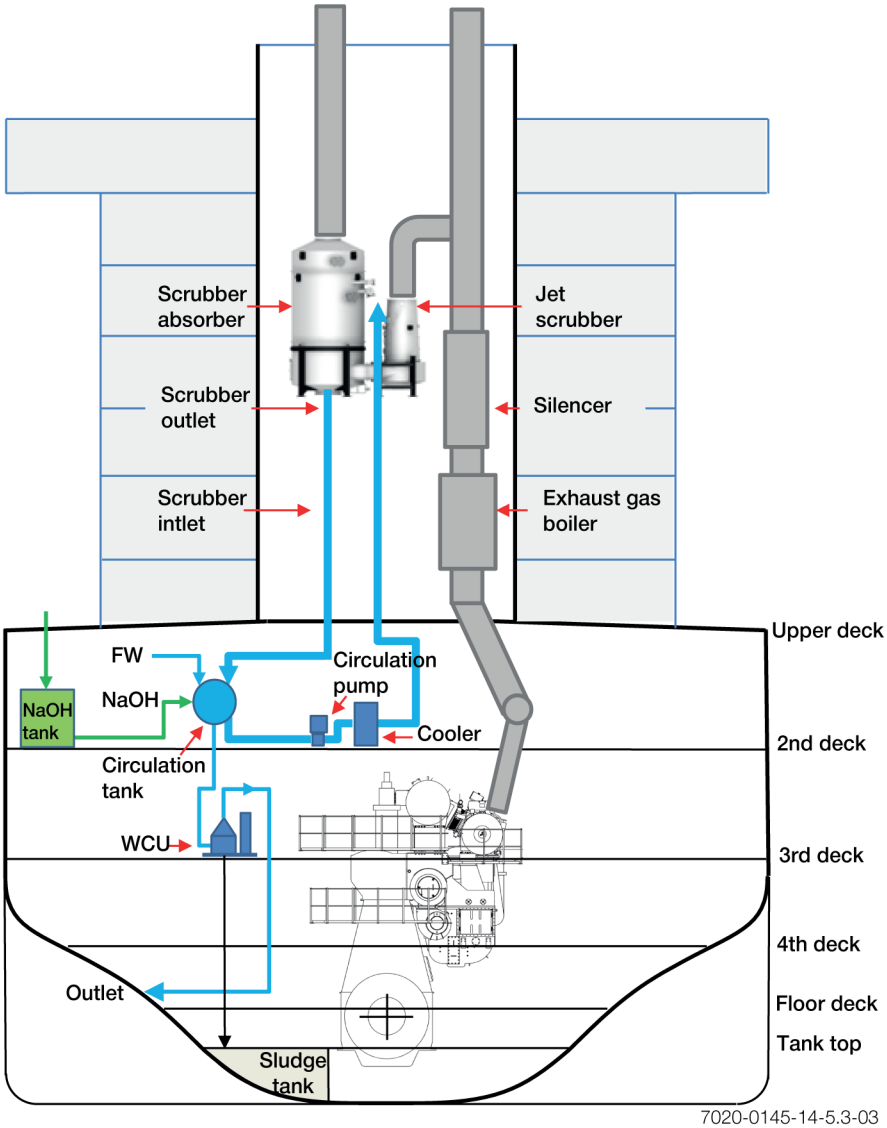


Figure 54: Schematic arrangement of a closed loop SO_x scrubber system (FW)

The running costs of a closed loop system is higher compared to an open loop system, mainly because of the addition of chemicals in the process. However, the closed system can be used in any area without restrictions thanks to the water treatment system.

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NaOH tank

The storage tank for the chemical additives used in the closed loop systems should be suitable for the media, e.g. the chemical solution. Normally, the scrubbing process uses a 50% NaOH solution. Such a solution will start to crystallise below 12 °C, and the tank should therefore keep a minimum temperature of 16 °C. Accordingly, the tank should be installed in a room with a controlled temperature or be insulated and fitted with means for heating. The material of the tank must meet the specific requirements for the solution, such as stainless steel, coated steel, polymer or other suitable materials. See also The Chlorine Institute, Pamflet 94 regarding storage and piping.

When estimating the necessary capacity of the NaOH tank, the ECA sailing time, the sailing pattern, the fuel sulphur content, the NaOH solution and the planned bunker period must be taken into account. Furthermore, the capacity could include additional volume to receive a full standard bunker volume when refilling. An example of how to dimension the NaOH tank is given in Section: Calculation of SOx scrubber data.

Sludge tank

The sludge outlet from the WCU in a closed loop systems is an aqueous solution of combustion particles, sulphur compounds and other material separated from the scrubber water. The pH value would normally vary between 6 and 9. The sludge can be stored in a separate sludge tank or in a general tank on board, e.g. the dirty bilge tank, which holds similar sludge from the engine room. The tank could be made of coated steel while taking the variation of pH value into consideration.

When estimating the capacity of the sludge tank, it is important to take into account the ECA sailing time, the sailing pattern, the fuel sulphur content, the water content and the planned discharging interval. An example of how to dimension the NaOH tank is given in Section: Calculation of SOx scrubber data.

Circulation tank

The circulation tank is used as a buffer tank in closed loop and hybrid systems. During start-up in closed loop mode, the tank ensures that there is enough FW for the process. In hybrid systems, it acts as a reservoir for FW during open loop operation and ensures a smooth transition when changing between open and closed loop mode. The tank size defines the time in which the system can operate without bleed-off when operating in closed loop mode. Typical tank volumes are given in Table 18, Page 82.

Engine power MW	Circulation tank m^3
< 10	10
10-20	20
> 20	30

Table 18: Typical volumes of circulation tank

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5.4 Consumptions and capacities

The following data refers to ISO conditions, except where otherwise stated. The estimated data are based on the principles described in previous chapters. The data may not fully cover data for a specific SO_X scrubber system and it is therefore suggested to contact the supplier for further information. All data presented is approximate values and subject to change without further notice.

Scrubber efficiency

The SO_X scrubber system is a method equivalent to meeting the low-sulphur fuel requirements. Accordingly, the efficiency of the system must be sufficient to achieve a SO_X emission level, measured as the fraction SO_2/CO_2, that is equal to or lower than the required limit. The efficiency depends on the sulphur content in the fuel related to the sulphur limit. The required efficiencies are listed in Table 19, Page 83 for various fuel sulphur content values.

Fuel sulphur S%	Scrubber efficiency in ECA, % Sulphur limit: 0.1%	Scrubber efficiency in non-ECA, % Sulphur limit: 0.5%
3.5	97.1	85.7
3.0	96.7	83.3
3.0	96.0	80.0
3.0	95.0	75.0
1.5	93.3	66.7
1.0	90.0	50.0

Table 19: Required SO_X scrubber efficiency

Although the required scrubber efficiency depends on the area and the fuel used, the data in this chapter is based on an efficiency of 97.1%, which is sufficient to clean the exhaust gas from a 3.5% sulphur fuel to meet the requirements. Information on systems including varying efficiencies should be given by the scrubber supplier.

Back pressure

The use of a SO_X scrubber increases the pressure drop (back pressure) in the exhaust gas system. The maximum design back pressures in the exhaust gas system on new engines and the total acceptable back pressure including service margin are found in Table 20, Page 83.

Power % MCR	Piping mBar	Scrubber mBar	Max design pressure mbar	Incl. service margin mBar
100	30.0	30.0	60.0	75.0
75	17.9	30.0	40.4	56.4
50	8.6	30.0	23.6	37.6
25	2.5	7.5	10.0	19.0

Table 20: Total back pressure acceptable in the exhaust gas system

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Engine performance

The increased back pressure will slightly influence the engine's performance. The exhaust gas amount decreases and the turbine outlet temperature increases depending on the additional back pressure. The SFOC increases accordingly. The scavenge air pressure is roughly unchanged. Table 21, Page 84 shows the influence on these parameters in relation to the maximum additional back pressure. In cases where only a fraction of the maximum back pressure is present, the influence on the parameters is reduced accordingly.

Power % MCR	Δ P (max) mBar	Δ SFOC g/kWh	Δ Exhaust gas % mass	Δ TC outlet °C
100	60.0	+1.0	÷7	+20
75	50.0	+1.0	÷7	+20
50	40.0	+1.0	÷10	+20
25	20.0	+1.0	÷10	+20

Table 21: Relation between additional back pressure and engine parameters

The additional back pressure of a SO_X scrubber depends on the scrubber type. Typically a back pressure of 20 to 40 mm mbar at 100% MCR can be expected. Depending on the performance parameters, the SFOC penalty is 0.3-0.7 g/kWh.

Scrubber water flow

Open loop

The necessary scrubber water flow is determined by the exhaust gas amount, which depends on the engine power. An estimate of the open loop SW flow is estimated as follows:

FlowSW = 50 m3/h/MW

Closed loop

The required flow of FW for sufficient closed loop scrubbing is significantly smaller than required for SW in open loop. The relation between the engine power and FW flow is estimated as follows:

FlowFW = 30 m3/h/MW

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Electric power consumption

Open loop

The electric power consumption in open loop mode relates to pumping SW into the scrubber. Accordingly, the power relates to the flow and pressure delivered by the scrubber pumps. The required pressure reflects the injection pressure and the lifting height, i.e. the vertical distance between sea level and the scrubber injection point. If the installation details are unknown a rough estimate of the power required for open loop mode can be estimated by:

$P = 0.70\% \times P_{ME} \times MCR\ \%$

If the height (H) between the seawater level and scrubber inlet is known, and assuming an injection pressure of 10 m WC and a pump efficiency of eff_{Pump}, the required power can be calculated as follows:

$P = P_{Pump} = P_{ME} \times MCR\ \% \times Flow_{SW}/3{,}600 \times 1.025 \times 9.81 \times (H+10)/eff_{Pump}$

Closed loop

The power consumption in closed loop mode relates to the power to circulate the FW scrubber water and to treat and discharge the bleed-off water. Compared to open loop mode, the required power for closed loop is smaller as the FW flow and the water column height is smaller. The power required for closed loop mode could be estimated as:

$P = 0.25\% \times P_{ME} \times MCR\ \%$

When the height (h) between the circulation pump and the scrubber inlet is known, the required power P which includes the pumping power PPump, and auxiliary power PAux, could be estimated more specifically. Assuming an injection pressure of 10 m WC and further a 10% additional power for covering the WCU and cooler, the required power is:

$P = P_{Pump} + P_{Aux} = P_{ME} \times MCR\ \% \times Flow_{FW}/3{,}600 \times 1.000 \times 9.81 \times (h+10)/eff_{Pump} \times (100\% + 10\%)$

NaOH consumption

In closed loop mode, the required additive applied to neutralise the accumulated sulphur in the scrubber water is normally a 50% NaOH solution. The amount of NaOH depends on the engine size, engine load, SFOC and the sulphur content in the fuel.

Using a solution of 50% NaOH to neutralize the sulphur (S) in the scrubber water, the consumption is:

NaOH (l/h) = P(MW) × MCR% × SFOC (kg/MWh) × S% × 3.27

Freshwater consumption

Depending on the fuel sulphur percentage, the closed loop process accumulates salt in the scrubber water creating a risk of deposits in the system. However, in several conditions the closed loop system generates a surplus of water due to the condensation of exhaust gas and the salt is diluted and discharged through the bleed-off system. In cases where the condensation is not sufficient, there is a need for adding FW to the system

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In addition to diluting the salt in the scrubber water, FW is also used as process water in the WCU. The water is used for the discharge of sludge, and the solution of water and sludge is finally dumped to the sludge tank.

A specific rule for the FW consumption could not be given here as the calculation depends on a wide range of parameters, among these the sulphur percentage and the temperature of air and seawater. But a rough estimate at ISO, Winter and Tropical conditions using high sulphur fuels is given in Table 22, Page 86.

Condition	Air	Sea °C	FW consumption l/MWh
ISO	25 °C	25	100
Winter	25 °C	10	50
Tropical	45 °C	32	0

Table 22: Estimated FW consumption in closed loop mode using high sulphur fuels

Cooling water capacity

To minimise the FW consumption in closed loop mode, the water circuit includes a scrubber water cooler that reduces the evaporation of the scrubber water through the exhaust gas stream. The capacity of the cooler depends on the engine size and could roughly be estimated to 50% of the main engine power.

Sludge production

The sludge accumulated in closed loop mode in the bleed-off system is removed by the separator in the WCU. The amount of sludge accumulated depends on the engine size, engine load, SFOC and the sulphur content (S) in the fuel. Furthermore, the water content in the sludge has a significant influence on the sludge amount. In this paper, a solution of 93% water and 7% sludge is chosen. A lower fraction of water will increase the viscosity and might give problems in handling the sludge. Furthermore, a higher value will rapidly increase the volume needed to store the sludge.

An estimate of the accumulation of sludge in a 93% water solution could be expressed as:

Sludge (l/h) = P (MW) × MCR% × SFOC (kg/MWh) × (S% × 3.45+0.022)

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