Exhaust Gas Scrubber Systems

Status and Guidance

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FOUNDED 1862 ABS

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The mission of ABS is to serve the public interest as well as the needs of our clients by promoting the security of life and property and preserving the natural environment.

Quality & Environmental Policy

It is the policy of ABS to be responsive to the individual and collective needs of our clients as well as those of the public at large, to provide quality services in support of our mission, and to provide our services consistent with international standards developed to avoid, reduce or control pollution to the environment.

All of our client commitments, supporting actions, and services delivered must be recognized as expressions of quality. We pledge to monitor our performance as an ongoing activity and to strive for continuous improvement.

We commit to operate consistent with applicable environmental legislation and regulations and to provide a framework for establishing and reviewing environmental objectives and targets.

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Introduction

The marine industry is now facing the challenges of adopting new technologies and/or operational practices to comply with stricter international, national and local regulations introduced to reduce air emissions from ships. The adverse effects from internal combustion engine and boiler exhaust gases on human beings and sensitive ecosystems have been well documented by the scientific community. The objective of regulations introduced by the International Maritime Organization (IMO), the European Union (EU), the US Environmental Protection Agency (EPA) and the California Air Resources Board (CARB) is to reduce the contribution shipping makes to global and local emissions.

Critical amongst these regulations are the measures to reduce the sulfur oxide (SOx) emissions inherent with the relatively high sulfur content of marine fuels. Ship designers, owners and operators have three general routes to achieve SOx regulatory compliance:

- Use low sulfur residual or distillate marine fuels in existing machinery,
- Install new machinery (or convert existing machinery where possible) designed to operate on an inherently low sulfur alternative fuel, such as liquefied natural gas (LNG), or
- Install an exhaust gas cleaning (EGC) aftertreatment system.

This Advisory has been produced to summarize the regulatory requirements applicable to SOx EGC systems, or scrubbers as they are more typically known, provide an overview of available technologies and highlight some of the selection, installation and operational issues that need to be considered when selecting EGC systems as a means for ships to comply with current and future exhaust gas emission regulations.

Marine air pollution regulations typically require the use of low sulfur fuel in order to reduce SOx gaseous emissions and the sulfate portion of the particulate matter (PM) emissions. The use of EGC technology is generally permitted as an alternative means of compliance to operating with these regulated low sulfur fuels. While EGC systems have limited commercial marine references at present, they are a proven existing technology with extensive land based experience and numerous applications to inert gas systems on tankers; they are considered a practical alternative for meeting SOx emission regulations. Scrubbers can be effective in complying with regulations that require the use of fuel with 1 percent or 0.5 percent sulfur content; however the ability of certain scrubbers to provide equivalent SOx emissions to 0.1 percent sulfur fuel is more uncertain.

With regard to meeting the regulatory requirements for emissions of nitrogen oxides (NOx), a typical scrubber provides only negligible reduction in NOx emissions and would not normally be considered a method for obtaining compliance with the NOx emission requirements. There are a number of primary (engine) and secondary (aftertreatment) techniques for reducing NOx emissions. One of those primary engine techniques currently being developed for marine applications is the use of exhaust gas recirculation (EGR), which involves the recirculation of a portion of the exhaust gases, typically 20 to 40 percent, back into the combustion chamber. For marine applications

this technique may need to include a scrubber to prevent engine fouling, corrosion and wear issues because of the relatively high fuel sulfur content. In these circumstances the general concepts detailed in this Advisory would be applicable to the scrubber part of an EGR system, with, in particular, compliance with the IMO washwater discharge criteria expected. Selective catalytic reduction (SCR) aftertreatment systems may be used as a secondary abatement means of reducing NOx emissions and NOx reduction efficiencies of up to 95 percent are possible. EGR and SCR systems are not specifically covered by this Advisory.

While scrubbers offer the potential for lower operating costs through the use of cheaper high sulfur fuels, purchasing, installation and operational cost issues associated with scrubbers would also need to be considered on a vessel-specific basis. These costs should be assessed against the alternatives of operating a ship on low-sulfur distillate fuel or an alternative low-sulfur fuel, such as LNG. Fuel switching, meaning using higher sulfur fuel where permitted and lower sulfur fuel where mandated, has its own complications and risks but should also be considered as part of the evaluation of possible solutions to the low sulfur fuel regulations. The ABS *Fuel Switching Advisory Notice* should be referred to for more information on the issues related to fuel switching.

The operating profile of the ship will often dictate which solution offers the best capital expenditure versus operational expenditure compromise and through life benefits. It is the intent of this Advisory to highlight the relevant regulatory and technical issues associated with SOx EGC system technology and assist shipowners and operators in making an informed decision about the selection of scrubber technology as a means to meet SOx emission regulations. This Advisory contains five sections:

Section 1	Regulatory Background and Requirements
Section 2	Overview of EGC System Technologies
Section 3	Considerations for EGC System Selection, Installation and Operation
Section 4	Frequently Asked Questions and Evaluation Checklists
Appendix	EGCSA Members, EGC Systems Data Sheets and Low Sulfur Fuel Availability

Regulatory Background

IMO Regulations

Following development of the regulatory text by IMO's Marine Environment Protection Committee (MEPC), an International Conference of Parties to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978 (MARPOL Convention), adopted the 1997 Protocol to the MARPOL Convention which added a new Annex VI on Regulations for the Prevention of Air Pollution from Ships. This Annex entered into force after acquiring the requisite number of signatories and tonnage on 19 May 2005. To reduce the harmful effects of SOx emissions on human health and the environment, Regulation 14 to the new Annex introduced a worldwide limit on the sulfur content of marine fuels of 4.5 percent and a limit within SOx emission control areas (SECA) of 1.5 percent. The Baltic Sea was the inaugural SECA adopted with the Annex and was followed, in accordance with the criteria for designation given under Appendix III to the Annex, by entry into force of the North Sea/English Channel (see Figure 1) on 22 November 2007 through the adoption of IMO Resolution MEPC.132(53).

Figure 1: Baltic and North Sea/English Channel SECA

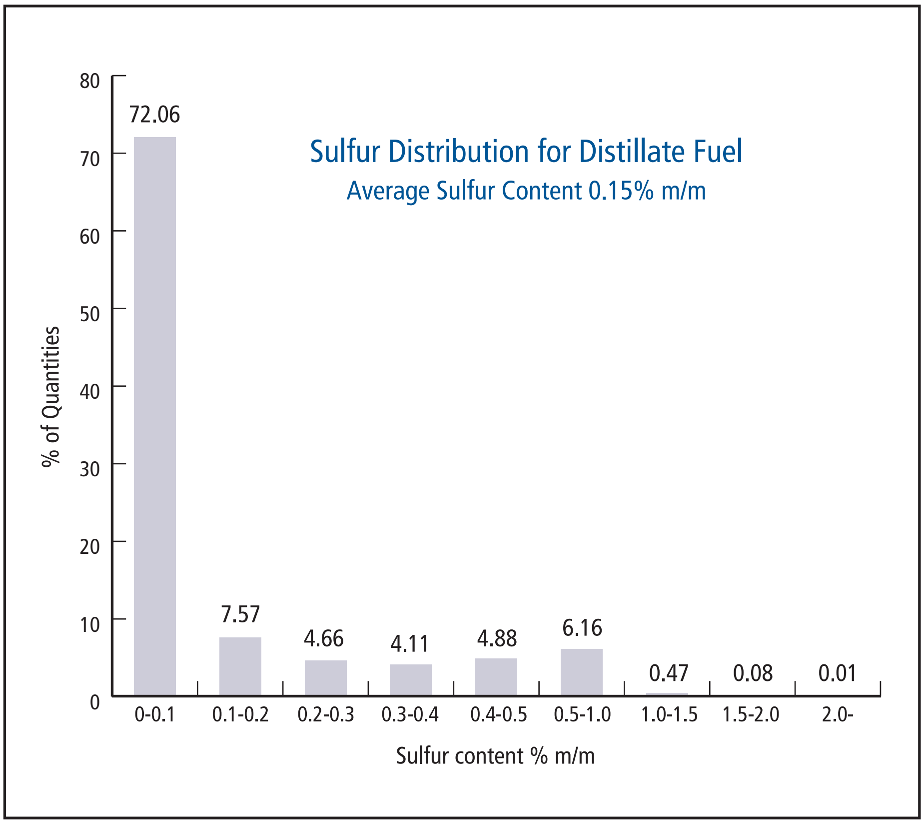


Figure 2: IMO Sulfur Monitoring Program

In October 2008, the 58th IMO MEPC session adopted significant changes to Annex VI under Resolution MEPC.176(58). This introduced a reduction in the global sulfur fuel limit to 3.5 percent from 1 January 2012 with a further global reduction to 0.5 percent from 1 January 2020. The implementation date of 2020 is to be reviewed in 2018 to assess the availability of fuel oil to meet the 0.5 percent limit. This review will determine whether the implementation date is to be extended to 2025 at the latest.

The original Regulation 14 also mandated the monitoring of the sulfur content of residual fuel oils in accordance with the subsequently developed guidelines under IMO Resolutions MEPC.82(43), MEPC.183(59) and MEPC.192(61); the average global fuel oil sulfur contents reported to MEPC 62 were 2.61 percent for residual and 0.15 percent for distillate fuel oils. The distillate results were obtained from a total of 26,189 samples corresponding to 2,396,849 tonnes (see Figure 2).

The revised Annex VI also introduced a tiered reduction to the sulfur content of fuels for use in Emission Control Areas (ECA) to 1.0 percent from I July 2010 and more significantly, 0.1 percent from 1 January 2015 (see Table 1). In addition to the IMO monitoring of fuel availability a number of other studies have been undertaken to assess the impacts of the regulatory requirements and the availability of low sulfur residual and distillate fuels for the 2015 and 2020 implementation dates. Although there is a degree of uncertainty the general consensus is that there will be sufficient quantities of low sulfur fuel available by 2015 for use in ECAs, however the picture at 2020 is far more uncertain. A more detailed summary is included under Appendix III to this Advisory.

The revised Annex VI also included a revision to the terminology and regulations associated with the coastal air emission control areas with the revision from SECAs to ECAs. This added the provision to designate the areas as SOx, NOx and PM Emission Control Areas. However, at present IMO does not define PM limit criteria but PM is significantly reduced through the reduction of the sulfate portion of the PM, by the use of low sulfur fuels or other technological means such as EGC systems.

A new SOx, NOx and PM ECA applicable to US and Canadian coastal areas and covering an area extending to 200NM from the coast, except for

Table 1: Fuel Oil Sulfur Limits

	GLOBAL	ECA
Initial limits	4.5%	1.5%
1 July 2010	4.5%	1.0%
1 Jan. 2012	3.5%	1.0%
1 Jan. 2015	3.5%	0.1%
1 Jan. 2020	0.5%	0.1%

Figure 3: North American ECA

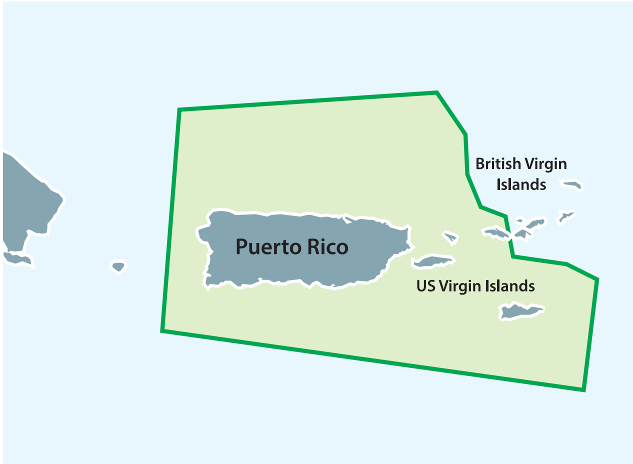


Figure 4: US Caribbean Sea ECA

Arctic waters, was adopted by IMO Resolution MEPC.190(60) with entry into force on 1 August 2012 (see Figure 3). A study by LQM Petroleum Services has indicated that many bunker suppliers are planning to be able to provide 1.0 percent sulfur fuel in the US to meet this implementation date.

IMO Resolution MEPC.202(62) has added a further new ECA applicable to the US Caribbean waters including Puerto Rico and the US Virgin Islands (see Figure 4) and will be effective from 1 January 2014. The marine community can expect that more ECA zones will come into effect in the next few years in response to a worldwide trend toward reducing harmful emissions from ships, particularly in heavily populated areas with significant maritime trade.

Regional and Local Regulations

European Union

In addition to the global and local controls implemented through the IMO Annex VI Regulations there are also further regional requirements for the use of low sulfur fuel implemented through the EU Sulphur Directive 1999/32/EC, as amended by Directives 2005/33/EC and 2009/30/EC, which mandated a limit of 0.1 percent sulfur content for operation in European ports from 1 January 2010 together with limits on the maximum sulfur content of fuels for vessels in regular service between EU ports. The Directive also permits trials of emission abatement technology for a period of 18 months or the fitting of approved EGC systems meeting the requirements of the IMO guidelines that provide equivalent emission reductions and are fitted with continuous emission monitoring equipment.

The requirement has been further amended under Directive 2012/33/EC to align with the revised IMO regulations and which includes the mandatory requirement for the fuel sulfur limit in EU waters outside SECAs to be 0.5 percent by 2020, regardless of the outcome of the IMO review scheduled for 2018. This amendment indicates that scrubbers will be permitted as an equivalent when operating in closed mode, and with continuous monitoring in place.

United States

The US has adopted MARPOL Annex VI through Title 40 of the Code of Federal Regulations (CFR), CFR Part 1043 for the control of NOx, SOx and PM emissions from marine engines and is applicable to all US flagged vessels wherever they operate and foreign flag vessels while operating in US navigable waters and the US Exclusive Economic Zone (EEZ). The use of EGC technology is permitted but does not exclude the application of additional requirements or prohibitions by other statutes or regulations mainly with respect to water pollution. California Air Resources Board (CARB) does not specifically allow alternatives to low sulfur fuel. CARB has allowed for such scrubbers to be used under a testing scheme. Vessels planning for operation in those areas with an EGC system are advised to contact the Californian Authorities.

Figure 5: California OGV Low Sulfur Fuel Coastal Zone

Environmental regulatory policy in the US is advised through the EPA and for marine applications has also been implemented through 40CFRs 94, 1042 and by reference other applicable CFRs. The CFRs divide engines into three categories based on cylinder displacement: Category 1: under 5 liters; Category 2: 5 to under 30 liters; and Category 3: 30 liters and above. Additional limits on hydrocarbons (HC), carbon monoxide (CO) and, for Category 1 and 2 engines, PM, apply. The US EPA has a goal to reduce PM as part of the overall objective of reducing harmful emissions from engine exhausts, and requires specific PM tests and reporting for Category 3 engines, we can conclude with a view to defining certification limits in the future.

The EPA, rather than specify a PM limit at this stage for Category 3 engines, has followed the same approach as IMO and noted that PM formation is heavily dependent on SOx compounds, and have therefore stated their expectation that operation with low sulfur distillate fuel will significantly reduce PM. EPA certification is required for all US flagged and US registered vessels. The EPA requirements differ in a number of fundamental areas from the IMO requirements, for example, the requirement for the engine to remain within the certified emissions limit throughout its service life and the 'not to exceed' (NTE) concept requiring engine emissions to remain within defined limits away from the individual emission test cycle mode points.

Furthermore the control of the sulfur content of fuels in the US is implemented through the EPA Nonroad Diesel Equipment Regulatory Program which is aimed at regulating supply of low sulfur fuel for use in locomotives, ships and nonroad equipment. The eventual goal to reduce the sulfur level to meet an ultra-low sulfur diesel (ULSD) limit of 15 ppm (0.0015 percent) and enable advanced emission control strategies. For Category 3 engines the EPA diesel fuel program regulates production and sale of marine fuel oil for these engines to 1,000 ppm. The EPA emissions requirements are complex and full explanation of applicability is outside the scope of this Advisory but the intent is to highlight the difficulties faced by engine builders and shipowners when designing and operating engines that may need to meet a number of international and/or regional emissions regulations.

The US CARB requirements also represent an additional requirement for the use of low sulfur distillate fuel within 24 nautical miles of the

Table 2: CARB Fuel Sulfur Requirements for Oceangoing Vessels

Fuel Requirement	Effective Date	CARB's California OGV Fuel Requirement Percent Sulfur Content Limit
Phase I	July 2009	Marine Gas Oil (DMA) at or below 1.5% sulfur; or Marine Diesel Oil (DMB) at or below 0.5% sulfur
	August 2012	Marine Gas Oil (DMA) at or below 1.0% sulfur; or Marine Diesel Oil (DMB) at or below 0.5% sulfur
Phase II	January 2014	Marine Gas Oil (DMA) at or below 0.1% sulfur; or Marine Diesel Oil (DMB) at or below 0.1% sulfur

coast of California (see Figure 5), implemented through the Ocean Going Vessel (OGV) regulations, which have been in place since July 2009 and further refined from December 2011. This mandates the use of marine gas oil (MGO) or marine diesel oil (MDO) distillate fuels to the International Organization for Standardization (ISO) 8217:2005 specification for marine distillate fuel grades DMA and DMB (ISO 8217:2010 grades DMA/DMZ and DMB) within this coastal zone on a phased basis with the requirement for the use of 0.1 percent sulfur fuels to commence from 1 January 2014, which precedes the global ECA implementation date (see Table 2). The CARB Marine Notice 2012-1 of 2 July 2012 provides advice to owners and operators regarding application of the ECA and OGV requirements from 1 August 2012.

Regulatory Requirements

IMO Exhaust Gas Cleaning System Guidelines

The development of EGC systems for use on board ships has been in response to the aforementioned IMO, national and local regulations. These EGC systems were envisaged by the original Regulation 14.4 (b) to Annex VI whereby SOx emissions were limited to 6.0g/kWh for systems that met the IMO requirements in the subsequently developed guidelines of IMO Resolutions MEPC.130(53), MEPC.170(57) and the current guidelines MEPC.184(59) 2009 Guidelines for Exhaust Gas Cleaning Systems which were adopted on 17 July 2009 (hereinafter referred to as the '2009 Guidelines'). These guidelines provide guidance for the monitoring of the SO_2/CO_2 content of the exhaust gases for varying sulfur contents of the fuel (see Table 3) to provide equivalency to the prescribed specific SOx emission limits as stipulated in Regulations 14.1 and 14.4.

The 2008 revision to Annex VI removed the specific reference to EGC systems from Regulation 14 and approval of an EGC system is now undertaken in accordance with the requirements under Regulation 4 of the Annex as an 'equivalent'. This requires the flag Administration to take into account any relevant guidelines developed by IMO when assessing the equipment and to notify IMO (for circulation to all Administration parties) the details of that assessment. It is important to note that the 2009 Guidelines are not regulations, however it is understood that EGC system installations that meet these guidelines will be accepted as equivalent by the Administrations; this would need to be confirmed by the flag Administration of the vessel onto which the equipment is to be installed on a case-by-case basis. It also needs to be recognized that the 2009 Guidelines will likely be further revised in the future as the knowledge and experience with installed EGC systems matures.

The 2009 Guidelines in particular urge IMO Administrations to collect data on washwater discharges according to Appendix III of the guidelines to enable this criterion to be subsequently reviewed by IMO taking into account any advice from the Group of Experts on the Scientific Aspect of Marine Environmental Pollution (GESAMP).

The stated purpose of the 2009 Guidelines is to specify the requirements for the testing, survey, certification, and verification of EGC systems that are permitted under MARPOL Annex VI, Regulation 4, to ensure that they provide equivalence to the fuel sulfur content requirements of Regulations 14.1 and 14.4 and are applicable to all fuel oil combustion machinery installed on board ships except incinerators.

The Guidelines permit two basic Schemes to be used for EGC system approval, Scheme A or Scheme B, at the choice of the equipment manufacturer. Approval is to be undertaken in accordance with the initial and ongoing survey requirements of the 2009 Guidelines by, or on behalf of a flag Administration, typically by a class society recognized by the Administration (as a Recognized Organization or RO).

The approval regimes are similar to those applied for diesel engines under the IMO NOx Technical Code (NTC) whereby technical manuals are approved, certification issued (Scheme A) and continuing compliance verified through parameter checks and continuous monitoring.

The two EGC system schemes apply the following concepts:

- Scheme A is based on initial emission performance unit certification together with a continuous parameter check of operating parameters and daily exhaust emission monitoring.
- Scheme B is based on continuous exhaust emission monitoring together with a daily parameter check of operating parameters.

In both cases the condition of any water used in the scrubbing process is to be monitored and recorded.

Scheme A

For Scheme A approvals, the EGC system must be certified as meeting the emission limit value specified by the manufacturer (the ‘certified value’) for continual operation with fuel oils of the manufacturer’s specified maximum sulfur content, over the range of declared exhaust gas mass flow rate. There are mechanisms within the guidelines for the emissions testing to be reduced for ‘serially manufactured units’ of nominally similar designs where an agreed ‘conformity of production’ arrangement is in place.

Alternatively it is possible for the manufacturer to obtain a ‘product range approval’ for the same scrubber design by undertaking emissions testing at the highest, intermediate and lowest capacity ratings. This certification can be undertaken prior to, or after, installation on board and is approved by the issue of a serial number-based SOx Emissions Compliance Certificate (SECC) on behalf of the Administration of the vessel’s flag. The basis of the approval and the EGC system operating and maintenance parameters, together with survey procedures, are to be contained within the EGC Technical Manual-A (ETM-A) which is also to be approved by the Administration, or RO acting on its behalf.

The EGC unit is to be surveyed after installation to ensure that the scrubber is installed in accordance with the ETM-A, and has the relevant SECC. This would enable the ship’s Annex VI International Air Pollution Prevention (IAPP) Certificate to be amended and re-issued to reflect the EGC system installation. Subsequent surveys will be undertaken at the usual Annex VI annual/intermediate and renewal survey intervals. Continual compliance is verified by the continual monitoring of EGC system operating parameters, daily checks of the exhaust emissions and continual monitoring of the washwater discharge.

The shipowner is required to maintain an EGC Record Book which records the maintenance and service of the EGC unit and is to be available for inspection at EGC unit surveys. The form of this record book is to be approved by the Administration and may form part of the vessels planned maintenance record system.

Scheme B

Scheme B EGC units do not need to be pre-certified as meeting the emission limit value but must demonstrate compliance with the required equivalent emission values to the fuel sulfur content requirements 14.1 and 14.4 of Annex VI Regulation 14, at any load point, including during transient operation, by verification of the SO_2/CO_2 ratio after the scrubber in accordance with Table 3. This must be undertaken on a continual basis by the use of a continuous exhaust gas monitoring system approved by the Administration that records data at a rate not less than 0.0035 Hz.

Similar to Scheme A, Scheme B EGC units are to be supplied with an approved EGC Technical Manual-B (ETM-B) detailing the EGC unit operating parameters and limits. The EGC unit is to be surveyed after installation and at the usual Annex VI Annual/Intermediate and Renewal Survey intervals in the same manner as Scheme A for issue of the IAPP Certificate. Continual compliance is verified by continuous monitoring of the exhaust emissions, by daily spot checks of the EGC unit operating parameters and by continual monitoring of the washwater discharge. Scheme B EGC units are to be supplied with an EGC Record Book in the same manner as Scheme A EGC units.

Required EGC System Documentation

For ships intending to use an EGC system in part, or in full, to comply with Regulation 14 of Annex VI then a SOx Emissions Compliance Plan (SECP) is required to be approved on behalf of the Administration and is to detail the method of compliance for all fuel oil combustion machinery installed on board.

Furthermore an approved Onboard Monitoring Manual (OMM) is also to be retained on board the vessel for each installed EGC unit.

The OMM should be approved by the flag State of the vessel and include the following parameters:

- Data on the sensors used in the EGC emissions and washwater monitoring system including service, maintenance and calibration

Table 3: EGC System Sulfur Content Emission Equivalence

Fuel Oil Sulfur Content (%m/m)	Ratio Emission SO_2 (ppm)/CO_2 (%v/v)
4.5	195.0
3.5	151.7
1.5	65.0
1.00	43.3
0.50	21.7
0.10	4.3

- Positions where the exhaust and washwater measurements are to be taken together with any necessary supporting services or systems
- Data on the analyzers to be used in the emissions and washwater systems including operation, service, and maintenance requirements
- Procedures for analyzer zero and span checks
- Other information and data needed to properly operate and maintain the monitoring systems
- Details on how the monitoring systems are to be surveyed

Table 4 details the approved EGC system documentation that needs to be on board a ship utilizing EGC systems under Scheme A or B of the 2009 Guidelines.

Emissions Monitoring

For EGC units operating on distillate and residual fuel oils, exhaust emission compliance with the equivalent fuel oil sulfur content is verified from the measured SO_2/CO_2 concentration ratio. Table 3 from the 2009 Guidelines shows the required SO_2/CO_2 ratio in a diesel engine's exhaust and the equivalent sulfur concentration in the fuel.
If the exhaust from the scrubber has the same or lower SO_2/CO_2 ratio as that tabulated, for example less than 4.3 for a vessel operating in an ECA from 1 January 2015 where fuel of a maximum of 0.1 percent sulfur would be applicable, then the scrubber is considered to be providing equivalent effectiveness.

The verification through the SO_2/CO_2 ratio enables a much simpler verification of exhaust emissions. The derivation of this ratio and its applicability to typical marine fuels is given by Appendix II to the 2009 Guidelines and demonstrates correspondence with the 6.0g/kWh prescribed by the original Annex VI requirements based on a brake specific fuel consumption of 200g/kWh.

For those scrubbers for which the exhaust gas cleaning process may affect the amount of CO_2 in the exhaust gases the CO_2 concentration is to be measured before the scrubber, and the SO_2 concentration after it, to calculate the ratio correctly.

Washwater Discharge Criteria and Monitoring

The IMO 2009 Guidelines specify the discharge water quality criteria and monitoring requirements for a number of parameters.

Table 4: List of Required EGC System Documentation

Document	Scheme A – Parameter Check	Scheme B – Continuous Monitoring
SOx Emissions Compliance Plan (SECP)	X	X
SOx Emissions Compliance Certificate (SECC)	X	
EGC Technical Manual, Scheme A (ETM-A)	X	
EGC Technical Manual, Scheme B (ETM-B)		X
Onboard Monitoring Manual (OMM)	X	X
EGC Record Book or Electronic Logging System	X	X

pH Criteria

The pH of the discharged washwater from the scrubbing process should be no lower than 6.5, except during maneuvering or transit where the pH difference between the ships inlet and overboard discharge can be up to 2 pH units, measured at the overboard discharge. The washwater can be diluted by mixing with other sea water, such as cooling water discharge, to achieve the required pH level. For those EGC systems using chemicals or additives to meet the pH, or any other washwater criteria, then the washwater is required to be further assessed taking into account IMO guidance for ballast water management systems that make use of active substances (G9) under MEPC.169(57).

Alternatively during commissioning of the EGC unit the pH of the discharged water plume can be measured at rest in harbor at a distance of 4m from the scrubber washwater discharge. The corresponding pH value at the overboard monitoring point to achieve the pH value of 6.5 at 4 meters from the overboard discharge is the value that will be recorded in the ETM-A or ETM-B as the discharge limit value to achieve a pH of 6.5 at the plume.

The pH is to be continuously monitored with a pH electrode and meter having a resolution of 0.1 pH units and temperature compensation, with both electrode and meter meeting the standards referenced by the 2009 Guidelines.

Polycyclic Aromatic Hydrocarbons

The washwater discharge is also to be monitored for polycyclic aromatic hydrocarbons (PAH), whereby the maximum continuous PAH concentration is not to be greater than 50μg/L PAHphe (phenanthrene equivalence) above the inlet water PAH concentration. The outlet PAH level is to be measured after any water treatment equipment but before any washwater dilution. This limit value is applicable to an EGC unit washwater flow rate of 45t/MWh and is adjusted up or down in accordance with Table 5 for different flow rates.

The 2009 Guidelines permit a 15-minute deviation of up to 100 percent of this limit value, in any 12-hour period, to account for EGC unit start up. The PAH discharge is to be permanently monitored and the monitoring equipment capable of monitoring PAH in a range twice that given to the applicable limit value as shown in Table 5, using either of the

Table 5: PAH Discharge Concentration Limits

Flow Rate (t/MWh)	Discharge Concentration Limit (μg/L PAH_{phe} equivalents)	Measurement Technology
0-1	2,250	Ultraviolet Light
2.5	900	Ultraviolet Light
5	450	Fluorescence
11.25	200	Fluorescence
22.5	100	Fluorescence
45	50	Fluorescence
90	25	Fluorescence

permitted ultraviolet or fluorescence measuring techniques. The monitoring equipment is to not deviate by more than 5 percent within the applied range.

Turbidity/Suspended Particle Matter

The turbidity of the EGC unit washwater should not exceed 25 formazin nephlometric units (FNUs) or 25 nephlometric turbidity units (NTUs) above the inlet water turbidity. This should be measured over a 15-minute period and measured downstream of any water treatment but before washwater dilution. The treatment system should be designed to minimize suspended particle matter such as ash and heavy metals.

Similar to the criteria for PAH, the 2009 Guidelines permit a 15-minute deviation of up to 20 percent in any 12-hour period. Turbidity monitoring is to be continuous using monitoring equipment meeting the requirements of the standards referenced by the guideline.

Nitrates

Washwater discharge samples are to be taken within three months of an EGC unit renewal survey and analyzed for nitrate discharge data. The analysis certificate is to be retained as part of the EGC Record Book for the purposes of verifying that the washwater treatment system prevents the discharge of nitrates beyond a level equivalent to 12 percent removal of NOx from the exhaust, or 60 mg/l normalized for a discharge flow rate 45t/MWh.

The 2009 Guidelines require that all EGC systems are tested for nitrates in the discharge water and if typical levels are above 80 percent of the upper limit they should be recorded in the ETM-A or ETM-B.

US Environmental Protection Agency

Under the Vessel General Permit (VGP) regulations the US EPA has defined the criteria for the washwater discharged from EGC systems. The proposed new VGP2 regulations, to be issued in 2013, have specific requirements for scrubber water discharge limits that are in general consistent with the IMO 2009 Guidelines. In addition, the VGP2 regulations include additional requirements for monitoring, sampling, testing etc.

The regulations require that the creation of a sheen on the water by any oil like substances in the discharge water should be avoided and necessary pretreatment of the discharge water made to prevent this. The creation of a sheen in operation may cause a vessel to be subject to a penalty. There are further requirements for monitoring, periodic sampling, and record keeping contained in the VGP2 regulations. These regulations, when adopted in their final form, would need to be considered when designing a scrubber system for any ship that will operate in US waters.

Data Monitoring

The 2009 Guidelines require that data recording devices are provided as part of any EGC system installation. The following details some of the basic system data that is to be monitored and recorded automatically:

- When the system is in use, time against Universal Coordinated Time (UTC), and vessel position by Global Navigational Satellite System (GNSS) position
- Washwater pressure and flow rate at the inlet connection
- Exhaust gas pressure before and pressure drop across the scrubber

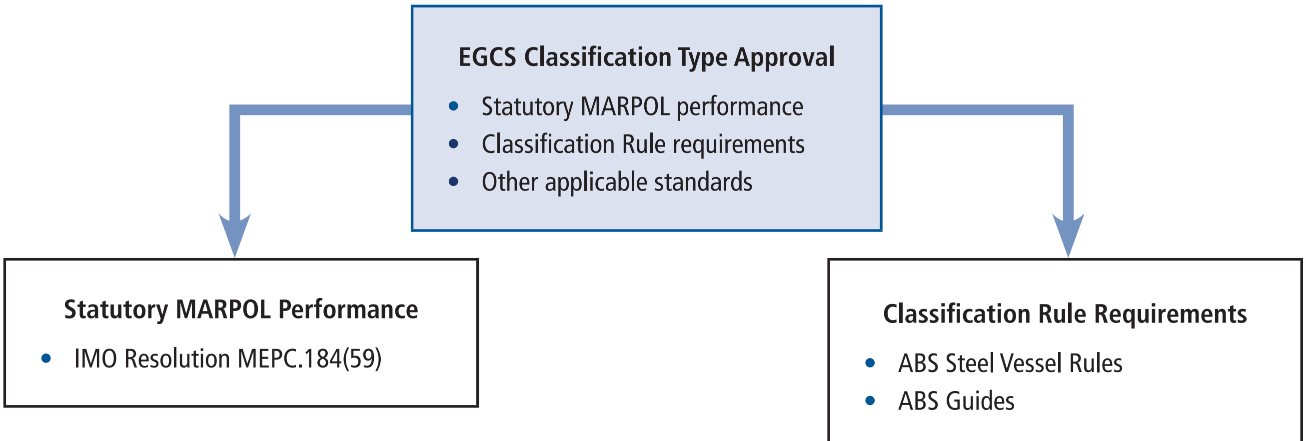


Figure 6: EGCS Classification Type Approval

- Engine or boiler load
- Exhaust temperature before and after the scrubber
- Exhaust gas SO_2 and CO_2 content
- Washwater pH, PAH and turbidity

The data recording device should be robust, tamper-proof and with read-only capability able to record at a rate of 0.0035 Hz. It should be capable of preparing reports and the data should be stored for a period of at least 18 months from the date of recording. If the unit is changed during that time period, the shipowner should ensure that the required data is retained on board and available as may be required. The device should be able to download a copy of the recorded data and reports in a readily usable format and copies of the reports made available to flag Administration or Port State Control (PSC) authorities upon request.

Washwater Residues

The residues collected from the EGC system washwater are to be collected on board and delivered ashore at suitable reception facilities which Administrations are required to provide under Regulation 17 to Annex VI. It is not permitted to discharge these residues at sea or incinerate them on board. It is also mandated by the guidelines that records of the storage and disposal of such residues are to be recorded in the EGC Record Book.

EGC System Approval

There are two basic parts to obtaining full approval of an EGC system – the statutory MARPOL approval process covering the environmental performance aspects; and classification society approval to the individual society's rules. Type approval from a classification society would cover these aspects, in association with any other applicable or voluntary standards to which the EGC system manufacturer wishes to have the product validated against. Full type approval would encompass the design assessment, validation or type testing and manufacturing assessments as per the IMO definition for type approval under MSC.1/Circ.1221.

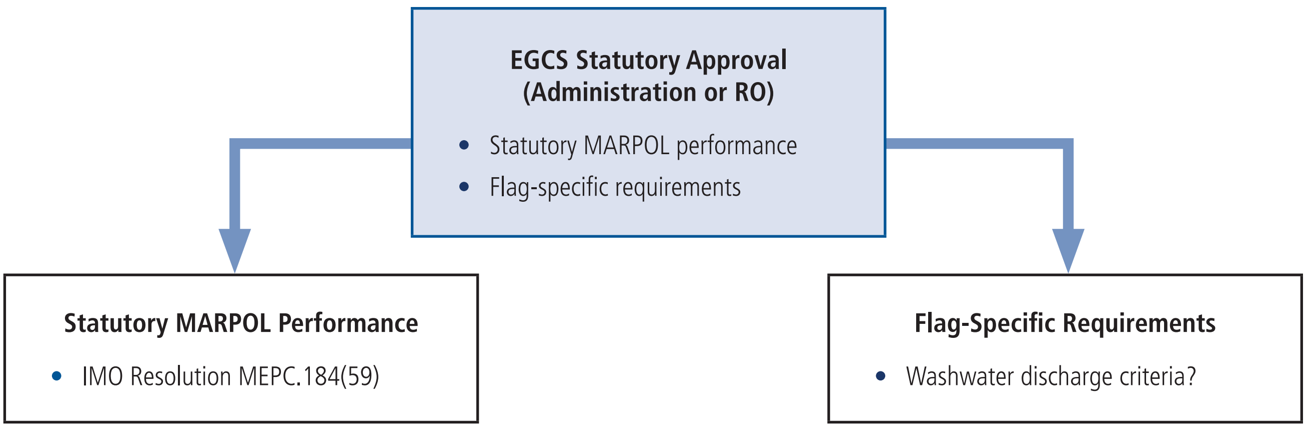


Figure 7: EGCS Statutory Approval

There may also be additional flag Administration requirements covering environmental performance aspects or general EGC system arrangements. Where appropriately authorized a classification society may undertake approvals on behalf of an Administration in its capacity as an RO. Figures 6 and 7 show the building blocks to the statutory and classification approval processes.

The verification that an EGC system meets the MARPOL performance approval criteria of the 2009 Guidelines encompasses a number of elements, as depicted in Figure 8. Application for approval would typically be made by the equipment supplier, in association with the shipowner, since a number of the elements can be assessed during design and manufacture but full verification is vessel-specific and requires in-situ testing after installation.

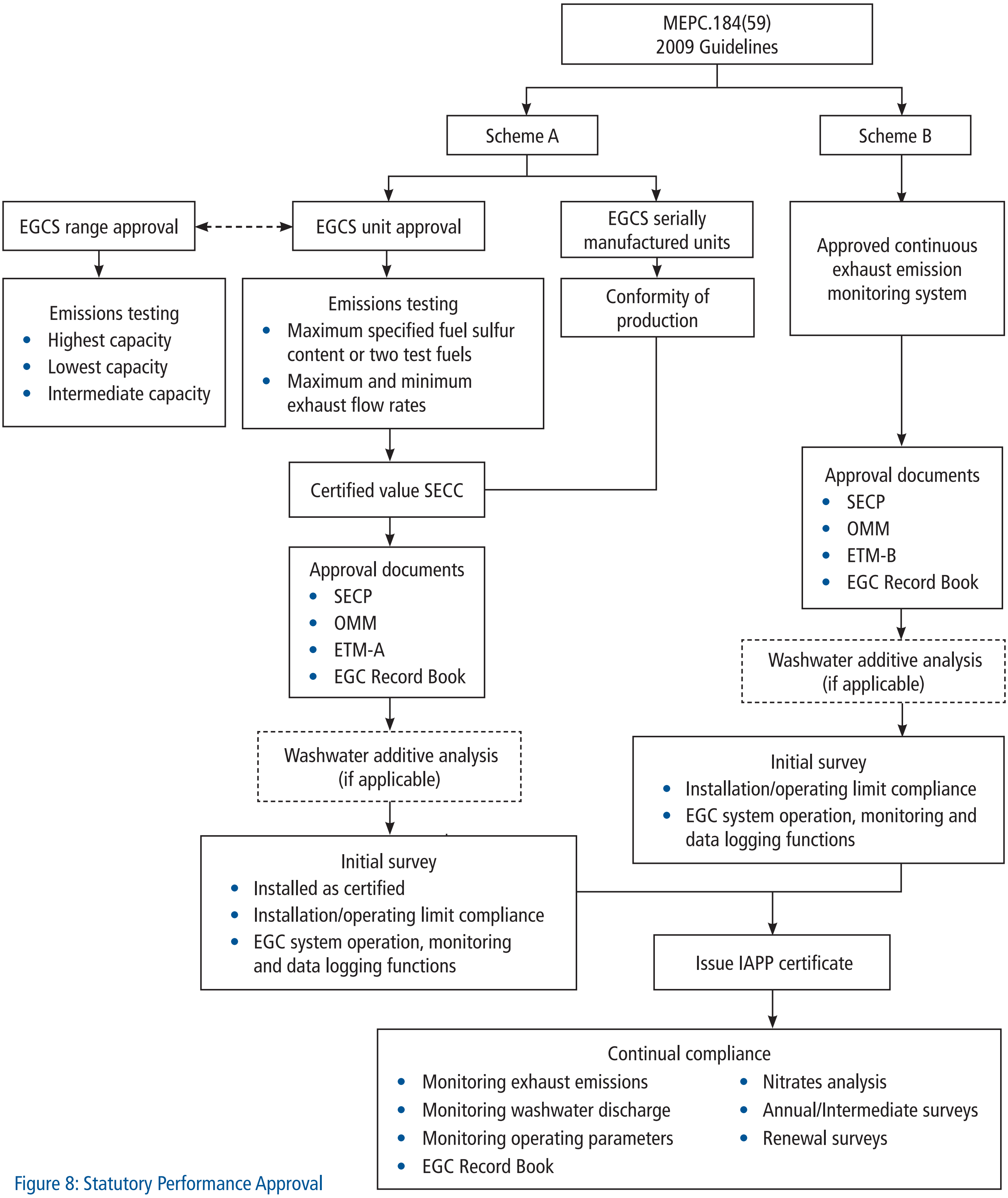


Figure 8: Statutory Performance Approval

EGC System Concepts

General

A scrubber is a device installed in the exhaust system after the engine or boiler that treats the exhaust gas with a variety of substances including sea water, chemically treated fresh water or dry substances, so as to remove most of the SOx from the exhaust and reduce PM to some extent. After scrubbing, the cleaned exhaust is emitted into the atmosphere. All scrubber technologies create a waste stream containing the substance used for the cleaning process plus the SOx and PM removed from the exhaust.

SOx (SO_2 plus SO_3) gases are water soluble. Once dissolved, these gases form strong acids that react with the natural alkalinity of the seawater, or the alkalinity derived from the added substances (normally sodium hydroxide), forming soluble sodium sulfate salt, which is a natural salt in the seas. In addition, the PM in the exhaust will become entrapped in the washwater, adding to the sludge generated by a scrubber. With dry scrubbers calcium hydroxide ($Ca(OH)_2$), or hydrated lime as it is more commonly known, reacts with the SOx and solid calcium sulfate ($CaSO_4$), or gypsum as it is more commonly known, is the product of the reaction. The waste stream and generated sludge has to be processed as per the IMO guidelines before discharge overboard, where allowed, or stored and discharged to shore as a waste substance.

Engine Exhaust Gas Chemistry:
$S + O_2 \rightarrow SO_2$ ~ 95%
$SO_2 + \frac{1}{2}O_2 \rightarrow SO_3$ ~ 5%

SOx Reactions in a Scrubber:
$SO_2 + H_2O \rightarrow H_2SO_3$
(Sulfurous Acid)

$SO_3 + H_2O \rightarrow H_2SO_4$
(Sulfuric Acid)

Sulfurous gases in water are in a state of rapid oxidation: sulfur dioxide (SO_2) oxidizes to sulfur trioxide (SO_3), which dissolves in water to form sulfuric acid (H_2SO_4). Also, upon dissolution in water, SO_2 forms the hydrate $SO_2 + H_2O$ or sulfurous acid H_2SO_3, which dissociates rapidly to form the bisulfate ion HSO_3, which in turn is oxidized to sulfate.

There are two basic concepts commonly proposed for shipboard application of EGC systems, the dry scrubber-type and the wet scrubber-type. The basic principles for each concept are described further in this section.

Dry Scrubbers

A dry scrubber does not use water or any liquid to carry out the scrubbing process but exposes hydrated lime-treated granulates to the exhaust gas to create a chemical reaction that removes the SOx emission compounds. Since the exhaust does not pass through water it is not cooled and therefore dry scrubbers can be placed before an exhaust gas economizer (EGE) or used in conjunction with SCR units, which typically require exhaust gas temperatures above 350°C to enable the catalysts to operate correctly, to reduce both SOx and NOx emissions. At this time, only Couple Systems, based in Germany, offers dry scrubbers to the marine market. They are commonly used on land-based EGC installations. A schematic of a dry scrubber system is shown in Figure 9.

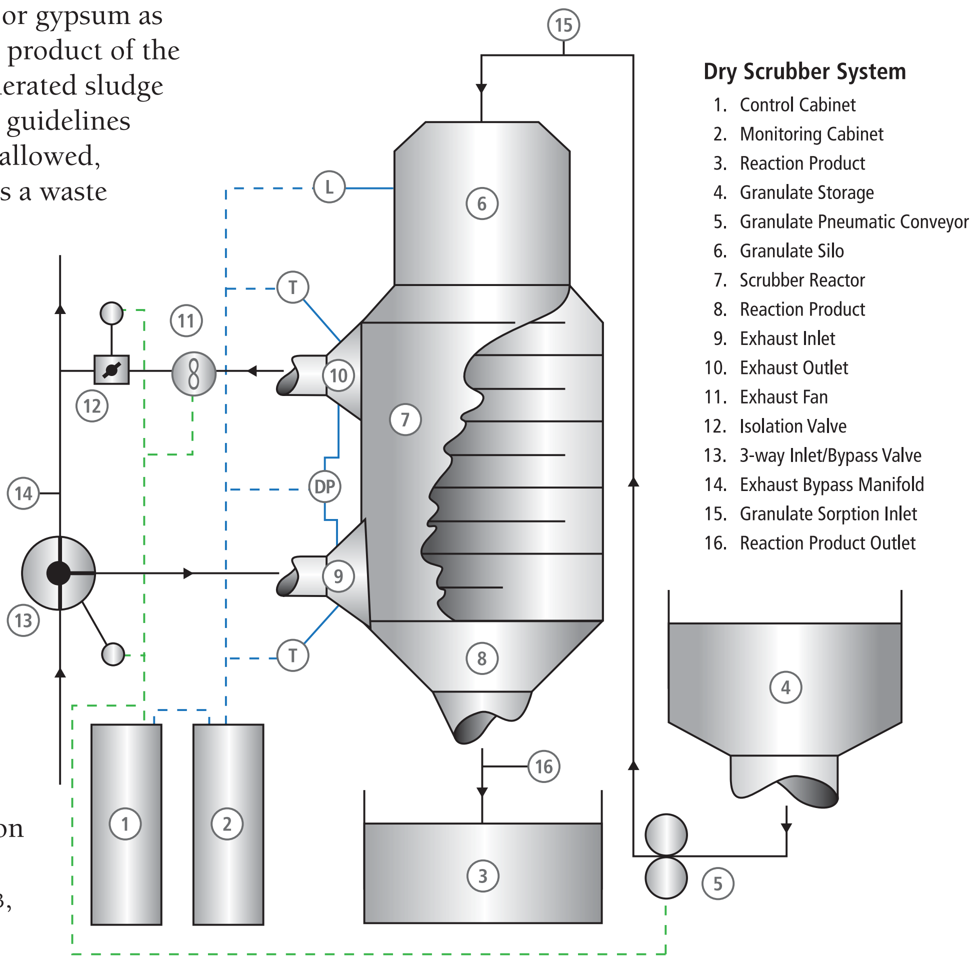


Figure 9: Dry Scrubber System

Dry scrubbers use granulates with caustic lime ($Ca(OH)_2$) which reacts with sulfur dioxide (SO_2) to form calcium sulfite:
$SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O$

Calcium sulfite is then air-oxidized to form calcium sulfate dehydrate or gypsum:
$CaSO_3 + \frac{1}{2}O_2 \rightarrow CaSO_4$

Reaction with sulfur trioxide (SO_3) is:
$SO_3 + Ca(OH)_2 \rightarrow CaSO_4 + H_2O$

Which with water forms:
$CaSO_4 \bullet 2H_2O$ *(Gypsum)*

Hence there is no CO_2 release.

For example, the Couple Systems dry scrubber works by feeding dry pellets of hydrated lime treated granulates through a packed bed absorber. The hydrated lime reacts with the hot exhaust gas and absorbs the SOx components to form pellets of gypsum, a non-toxic harmless substance, commonly used in the manufacture of wallboard which is used in the construction of houses. The gypsum containing pellets are removed from the absorber and stored on board for disposal ashore. Transport of the pellets to and from the absorber is achieved pneumatically. An exhaust gas bypass is required for periods during which the scrubber is not in operation or when its operation is not required. Testing has been carried out so far on one vessel with a medium-speed main propulsion engine. Couple Systems claims a SOx removal effectiveness of up to 99 percent and PM reduction of approximately 60 percent.

Wet Scrubbers

Wet scrubbers pass the exhaust gas through a liquid media in order to remove the SOx compounds from the gas by chemically reacting with parts of the wash liquid. The most common liquids are untreated sea water or chemically treated fresh water. Sea water scrubbers are normally open loop-type, where the water is sourced and discharged from outside the system and the water flows only once through the unit. In a closed loop scrubber, the treatment water is cleaned and recycled back to the scrubber in a continuous closed loop. In a closed loop system particulate matter and other residues have to be removed from the water and the water treated to maintain its pH and then make it suitable for reuse in the scrubber.

Wet Scrubbing Process

While there can be significant differences in the detail design of EGC systems and the liquid media used to carry out the scrubbing process, all wet scrubbers operate using the same basic chemical processes. The objective is to dissolve the water soluble gases contained in the exhaust gas by mixing the exhaust gas with the scrubbing liquid using some combination of water spray or cascading liquid system. Some scrubbers will have a packed bed of various shapes and materials through which the water will flow downward as the exhaust gas passes up through the liquid cascading over the maze-like packing, promoting mixing of the two streams.

Other scrubbers may be a tower like structure with spray nozzles and baffles. In all wet scrubbers the intent is to maximize the surface area of liquid in contact with the exhaust gas to promote SOx absorption in the liquid while not excessively restricting exhaust flow and exceeding the exhaust backpressure limits of the engine or boiler. Once the SOx mixes with the liquid, various chemical reactions such as $SO_2 + H_2O + \frac{1}{2} O_2 \leftrightarrow H_2SO_4$ (sulfuric acid) can take place depending on the chemistry of the liquid. In all cases, alkaline liquid must be provided to neutralize the acidic SOx based constituents.

In an open loop-type scrubber using sea water, the washwater will react with SOx to produce mainly sodium, but also some calcium sulfate and sulfites. When in alkaline (hard) river or estuary water, which contains calcium based and other salts, calcium sulfate or other sulfites may form in the washwater. As there is always free oxygen in the exhaust, SOx will form sulfates (SO_4) from the SO_3 portion of the SOx. Where the SO_2 is further oxidized, the SOx gas can also produce acid sulfate. As the natural alkaline buffer salts are used up in the reactions, the pH of the washwater mixture in the scrubber will be lowered.

In addition, the drop in temperature of the exhaust gas can cause unburned hydrocarbons to condense and the momentum effects of changes in direction will cause larger particles to fall out of the gas stream. These combine and mix in the scrubber to form larger particles in the scrubber effluent. In marine closed loop-type scrubbers, fresh water is treated with an alkaline substance, usually sodium hydroxide (NaOH), or caustic soda as it is more typically known, to create the desired level of alkalinity in the washwater. Some effluent is periodically removed and some fresh water is added to maintain the proper chemistry, and to extract the sodium sulfate salt produced.

Open Loop Scrubbers

An open loop-type scrubber uses sea water as the medium for cleaning or scrubbing the exhaust as shown in Figure 10. Sea water is normally supplied by a dedicated pump.

CO_2 dissolves in seawater forming carbonic acid, bicarbonate or carbonate ions depending on the pH. The positive companion ion can be calcium (Ca^{2+}) or sodium (Na^+) – here the sodium carbonate salt is used as an example. When the carbonate/bicarbonate ion reacts with an acid CO_2 is released.

$Na_2CO_3 + H_2SO_3 \rightarrow Na_2SO_3 + H_2O + CO_2$
(Sodium Sulfite)

$Na_2SO_3 + \frac{1}{2}O_2 \rightarrow Na_2SO_4$ *(Sodium Sulfate)*

$Na_2CO_3 + H_2SO_4 \rightarrow Na_2SO_4 + H_2O + CO_2$
(Sodium Sulfate)

Each EGC system manufacturer has their own techniques for how the scrubber mixes the exhaust gas and the water. As previously mentioned an open loop scrubber is only effective if the source water is alkaline. However, some river water is 'hard' water with significant alkalinity, in some cases higher than seawater, so open loop scrubbers can also work effectively in some port and river areas, but it is necessary to know the alkalinity of the water before this can be determined.

Therefore, the effectiveness of an open loop scrubber very much depends on the chemistry of the water the vessel is operating in. This should be considered at the design and selection stage or when deploying a vessel to new areas. If the water is not alkaline (pH is too low), the scrubber will

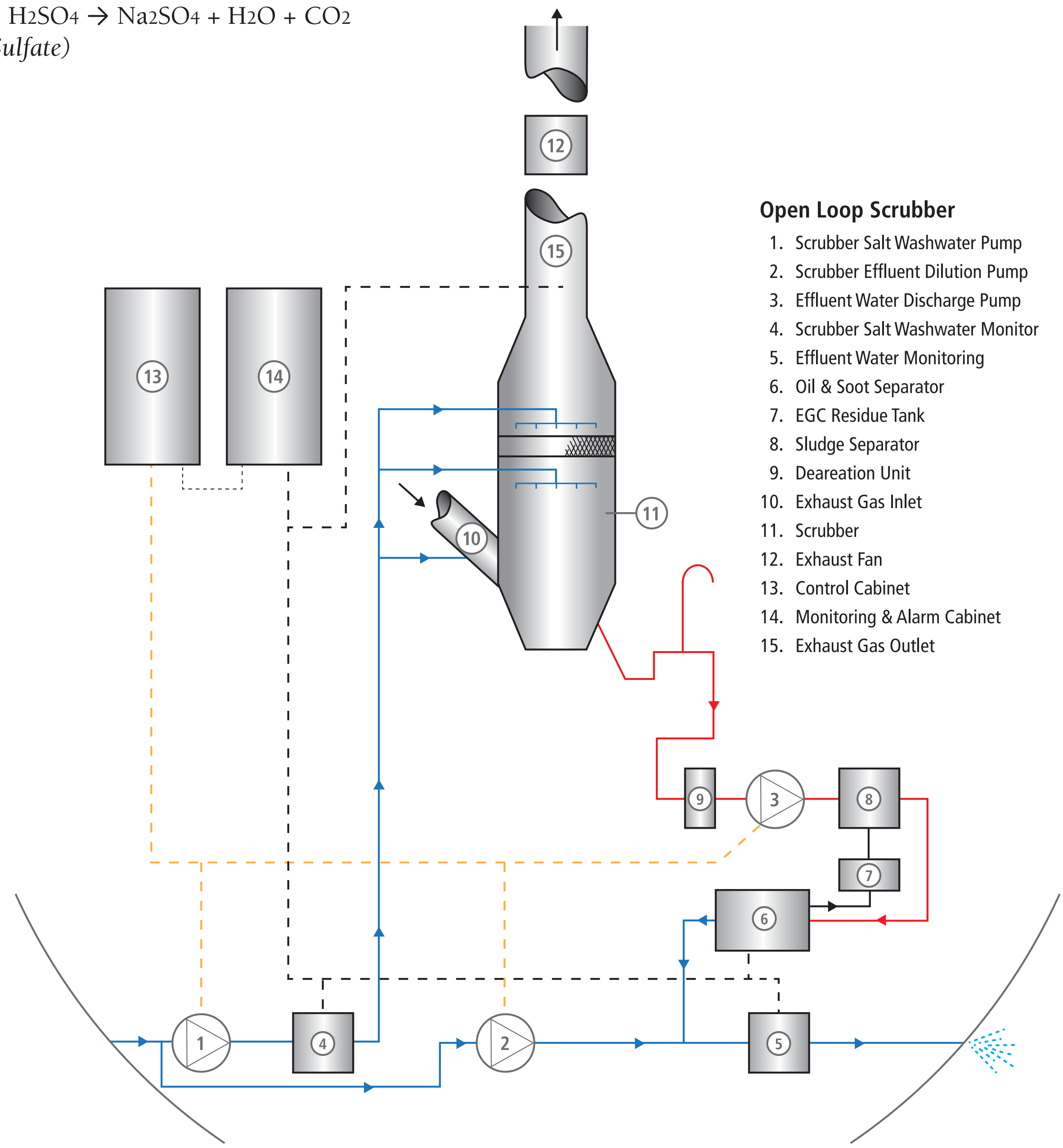


Figure 10: Open Loop Scrubber System

not meet the required performance level and the operator would have to use low sulfur fuel to be in compliance with the applicable SOx emission regulations.

As required by the 2009 Guidelines, scrubber manufacturers must state the operational limits in terms of maximum fuel sulfur content for operation to be in compliance with the Annex VI Regulation 14 requirements. Open loop scrubbers have larger water flow rates than closed loop scrubbers because there is less control over water alkalinity and more water is needed to make the scrubbing process effective when lower alkalinity water is used.

After the basic scrubbing process takes place in the main scrubber tower, the exhaust mixture normally passes through a demister or water droplet separator to remove the water particles from the gas, which reduces the potential for steam generation as the exhaust exists into the atmosphere. While a steam plume is harmless, it creates the appearance of exhaust smoke being emitted, and should be avoided. Many systems incorporate, or have the option to fit, a re-heater after the EGC system unit.

The water mixture generated during the scrubbing process falls to a wet sump at the bottom of the scrubber. This water, called washwater, is removed from the scrubber sump by gravity or by a pump, after passing through a deaerator in some systems, to a hydrocyclone or separator to remove the residuals from the washwater. The removed residuals are discharged to a dedicated residue tank on board. MARPOL Annex VI Regulation 16, Paragraph 2.6 prohibits incineration of sludge generated from a scrubber; it must be disposed of at suitable reception facilities ashore.

The collected residue will contain PM, ash, heavy metals, etc. removed from the fuel together with insoluble calcium sulfate, and silt entrained in the washwater drawn from estuaries, rivers, or harbor waters. Where the source of the washwater has a large amount of silt, this silt can make up the dominant portion of the sludge volume. Sludge generated from substances in the incoming water, such as silt, is an issue only with open loop-type scrubbers.

Once the residuals are cleaned from the washwater it can be discharged overboard or retained on board where discharge of such water is restricted. In most cases, the discharge washwater pH can be adjusted by diluting the acidic substances in the washwater by increasing through-put when using open loop systems or by diluting it with sea water cooling water. However, other local and national restrictions may apply that limit washwater discharge.

Closed Loop Scrubbers

In a closed loop-type scrubber, treated water is circulated through the scrubber to keep the scrubbing process independent of the chemistry of the waters the vessel is sailing in, plus there is little or no water discharged overboard from the scrubbing process, reducing the need for processing the washwater to make it suitable for discharge. Sodium hydroxide as a chemical additive is typically used in marine EGC systems to control the water alkalinity which can also be produced by electrolysis of seawater (see Figure 11).

The closed loop scrubber internals are similar to those of an open loop scrubber, and the chemical processes to remove the SOx emissions are similar. The major difference between the two systems is that rather than going overboard, most of the circulating washwater is processed after it leaves the scrubber to make it suitable for recirculation as the scrubber washwater medium. The washwater can be fresh or salt water depending on the scrubber design. In this treatment process, the residues are removed from the water, and the water is dosed again with caustic soda to restore its alkalinity.

Manufacturers claim a closed loop scrubber requires about half or less of the washwater flow than an open loop scrubber to achieve the same scrubbing efficiency. The reason for this is that higher levels of alkalinity are ensured by the direct control of the alkalinity level using the caustic soda injection process.

In fresh water scrubbers, SO_2 combines with a salt and consequently does not react with the natural bicarbonate of sea water. There is no release of CO_2.

$2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O$ *(Sodium Sulfite)*

$Na_2SO_3 + SO_2 + H_2O \rightarrow 2NaHSO_3$ *(Sodium Hydrogen Sulfite)*

$NaOH + H_2SO_4 \rightarrow NaHSO_4 + H_2O$ *(Sodium Hydrogen Sulfate)*

$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$ *(Sodium Sulfate)*

In a closed loop-type system, the dirty washwater exiting the scrubber goes to a process or circulating tank. A limited quantity of washwater from the bottom of the process tank, where the residuals have collected, is extracted using a low suction, and it goes to a hydrocyclone or separator, similar to an open loop system, where the residuals are removed or for some systems the extracted water can go to a bleed-off treatment unit (BOTU).

From any of the processes, the cleaned bleed off water is discharged overboard or to a holding tank, depending on the ship's location and local regulations. The removed residual sludge goes to a residue tank for disposal ashore. Make up water is added to the process tank to replace the washwater lost in the particulate treatment process, bleed off and evaporation during the scrubbing process. A pump circulates the scrubbing water from the process tank back to the scrubber. The water passes through a sea water cooler before re-injection in the scrubber. A dosing unit adds caustic soda back to the scrubbing water, either in the processing tank or to the water as it leaves the tank, with the amount varied depending on the alkalinity requirements for the water.

Hybrid Scrubbers

There are advantages to open loop type systems, such as the avoidance of purchasing and handling caustic soda, and the avoidance of the need to process washwater. The closed loop system has the advantages that the scrubber works with the same efficiency independently of where the vessel is operating and there is little or no water discharge, making it best

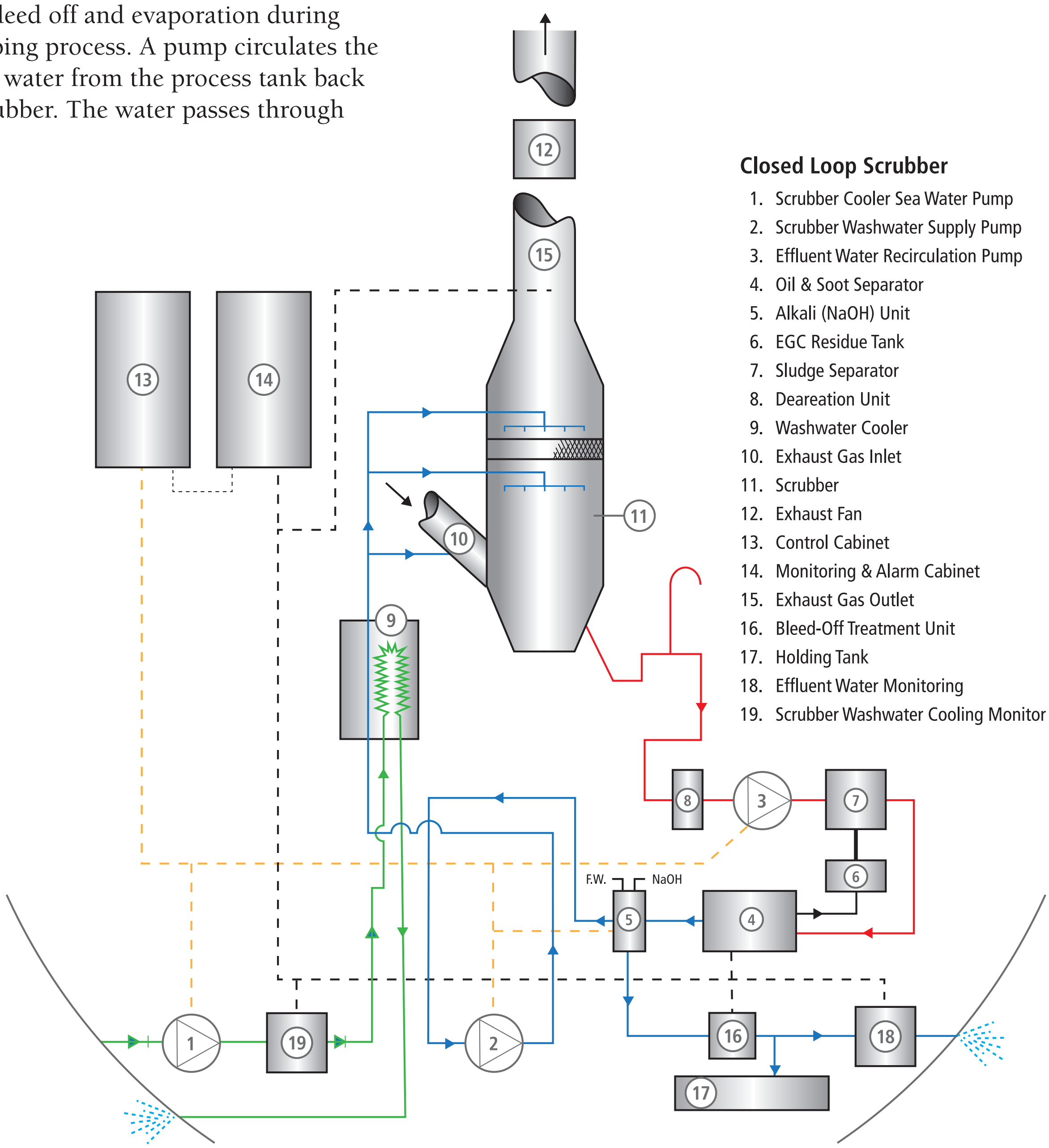


Figure 11: Closed Loop Scrubber System

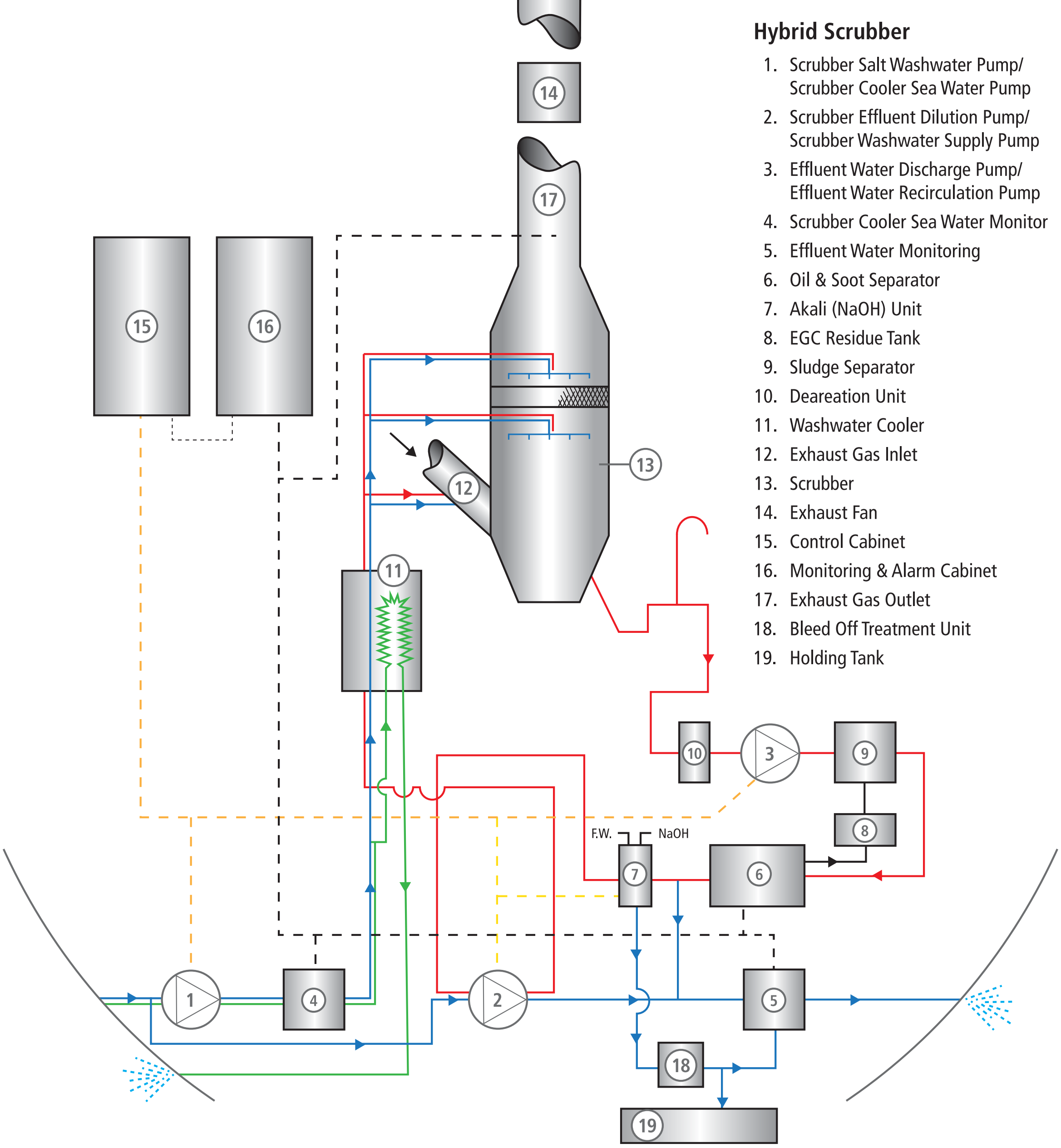
suited for coastal, port and inland waters. In order to utilize the advantages of both systems, some manufacturers have proposed hybrid scrubbing systems. These operate as an open loop system when in the open ocean; and as a closed loop system when in ECA (see Figure 12). The changeover from open to closed loop is done by changing over the circulating pump suction from sea water to the fresh water circulating tank and changing the washwater discharge from the overboard discharge to the circulating tank.

Effectiveness of Wet Scrubbers

Since the primary goal of scrubbers is removal of SOx from the exhaust stream to achieve SOx emission levels equivalent to ships consuming low sulfur fuel, the effectiveness of scrubbers in SOx removal is of great importance and the key measure of their performance. There are a limited number of wet scrubbers in service so there is not a large body of data demonstrating real life marine scrubber effectiveness on a long term basis, however a number of systems have been deployed that have accumulated significant operational hours, notably the Krystallon installations on the *Pride of Kent* and *Zaandam* and the Alfa Laval Aalborg unit on the *Ficaria Seaways*. Appendix II to this Advisory contains further details on specific marine scrubbers.

One key element of wet scrubber performance, particularly open loop-type, is the need for alkaline substances in the water. For closed loop scrubbers the alkalinity is directly controlled

Figure 12: Hybrid Scrubber System



by the dosing process that injects an alkaline material directly into the washwater, so the performance of the scrubber can generally be controlled. For open loop scrubbers, alkalinity of the washwater depends on the characteristics of the water the ship is traveling through, so the effectiveness of an open loop scrubber is significantly reduced if the vessel operates in brackish or soft fresh water with lower pH than normal seawater.

Some river waters are hard, meaning they contain significant amounts of alkaline substances, and can be just as effective for scrubbing as sea water. Alkalinity of water is expressed in units of pH and higher pH washwater improves the removal of SOx. Levels of pH below 7 can significantly reduce scrubber effectiveness. However, washwater throughput volume is another parameter that impacts scrubber effectiveness. Even when using washwater with a lower alkaline pH, a SOx removal rate to the required levels can possibly be achieved if sufficient volume of washwater is used.

Table 6 lists estimates of scrubber effectiveness in the removal of harmful substances from exhaust gases based on minimum levels of alkalinity being present in the washwater.

Considerations for EGC System Selection

Scrubber Installation

On most ships, the EGE is normally installed in the lower engine exhaust system casing, above the main engines or boilers. Placing the scrubber above would then necessitate the location of the scrubber in the upper part of the exhaust system casing, where the casing is normally reduced in size, and may therefore require substantive changes to the engine exhaust system casing design to accommodate both the increased horizontal and vertical space requirements. Figure 13 illustrates the impact of a scrubber on the engine exhaust system casing. It shows a 20 MW scrubber made by Alfa Laval Aalborg Industries being installed in the upper engine exhaust system casing of a ro/ro type vessel, the *Ficaria Seaways*.

The funnel is also impacted by the addition of a scrubber by the need for a second set of exhaust pipes. If the scrubber is provided with an exhaust bypass for each engine or boiler, the existing number of exhaust outlets at the funnel top will be retained for the bypass pipes. Each scrubber will then need a separate exhaust pipe, usually of at least the same diameter as the

Table 6: Wet Scrubber Effectiveness Rates

Scrubber Performance Factor	Rate	Remark
SOx Removal Required	97.10% (1)	Makes 3.5% S fuel equivalent to 0.1% S fuel
Expected SOx Removal Rate	> 96% (2)	Depends on alkalinity of the water
Typical Particulate Removal Rate	30% - 60%	When using heavy fuel, particulates emissions are higher than for 0.1% S distillate diesel fuel

Notes:

(1) If burning fuel with 3.5% sulfur, the scrubber must remove 97.1% of the SOx in the exhaust to achieve emissions similar to 0.1% S fuel.

(2) Scrubbers are expected to have removal rates in excess of 96%, so some of the scrubbers may be able to achieve equivalence with 0.1% S fuel, but not all scrubbers will. Manufacturers should specify the maximum sulfur content in the fuel that the scrubber can reduce to 0.1% S fuel equivalency.

existing exhaust pipe, and larger in diameter than existing pipes if an integrated scrubber is fitted that combines the exhausts from several engines and boilers.

This means there is a need for at least one large new exhaust pipe, and potentially several new exhaust pipes if multiple scrubbers are fitted. In a typical funnel design there is no space for an additional large exhaust pipe so for retrofits, either an exterior exhaust pipe has to be added or the funnel enlarged. For new ships the funnel can be enlarged, as needed, to suit the expanded number of exhaust pipes.

Tankers and bulk carriers generally do not have cargo aft of the deckhouse, so there is space to expand the engine exhaust system casing aft or to one side to install the scrubber. Containerships typically have a short deckhouse with containers stowed aft of the deckhouse (except smaller feeder types that have the deckhouse fully aft). For containerships expanding the engine exhaust system casing may result in reduced container stowage capacity aft of the deckhouse. For new vessels the space for the scrubber, bypass, and auxiliary equipment can be designed into the vessel and may therefore not have as much of an impact on other systems as for retrofits.

For retrofit installations the engine exhaust system casing modifications previously mentioned together with space for new pumps and piping systems, including possibly new sea chests and overboard discharges, plus space for the alkaline material storage (for closed loop scrubbers) and waste-water processing can mean significant conversion work. There may not be space available in existing engine rooms, and other spaces would need to be modified to fit new equipment or an enlargement of the engine room may have to be considered. Retrofitting a scrubber may require a significant out of service period, particularly on larger ships where the scrubber and auxiliary equipment are large.

Dry Scrubber Usage Rates and Dimensions

Hydrated lime usage rates and storage dimensions for the Couple Systems dry scrubber are given in Table 7. As can be seen, a relatively large storage capacity for both lime and gypsum is required and is one of the issues to be considered when selecting a dry scrubber. There is a need for storing both the material used for the scrubbing process and all the output material, requiring significantly more storage and material handling capacity than wet scrubbers. Dry scrubbers also require large material handling systems both on the ship and ashore, for transporting and loading the lime on board and for discharging the gypsum to shore.

Figure 13: Scrubber Installation on the *Ficaria Seaways*.

Table 7: Couple Systems' Dry Scrubber Estimated Lime Usage and Storage Capacity

Engine Size	4 MW	10 MW
Lime specific rate (kg/MWh)	50	50
Usage rate (kg/hr)	200	500
20 days usage at full power (kg)	96,000	240,000
20 days storage capacity – lime, gypsum storage similar (m^3)	75	185

Wet Scrubber Dimensions

Wet scrubbers and their associated auxiliary equipment are large units. They are required to be installed in the exhaust system after any waste heat recovery equipment, such as an Exhaust Gas Economizer (EGE) since the scrubber will cool the exhaust. Table 8 and Figure 14 show the principal dimensions based on engine power rating, for scrubbers produced by Alfa Laval Aalborg Industries. Scrubbers from other manufacturers will have different dimensions, but the size is expected to be of a similar order of magnitude. For more detailed information see Appendix II. For reference, a scrubber will typically be about two to three times the size of a typical EGE or composite boiler.

It is estimated the structure to support the scrubber, including the expanded engine exhaust system casing, will weigh about 50 percent of the scrubber weight, so the weight impact on vessel deadweight and stability will be about 150 percent of the scrubber operational weight.

Vessel Stability

For existing ships a revision of the stability may need to be considered based on the increased wind profile and additional weight of the scrubber. In general, if the change in lightship displacement exceeds 2 percent (excluding any certified weights, if any) of the lightship displacement from the most recent approved lightship data and/or the change in lightship longitudinal center of gravity (LCG), relative to the most recent approved lightship data exceeds 1.0 percent of length between perpendiculars (LBP), a stability test may be required on the vessel and stability calculations may need to be revised to indicate the changes. Where a ship is within these limits, immediate update of the Stability Booklet may not be required if there is sufficient margin in the conditions contained in the booklet. In this case the principal particular page would need to be updated and the ship would be required to use the latest lightship properties when assessing new conditions.

Table 8: Wet Scrubber Principal Dimensions by Engine Power (Courtesy of Alfa Laval Aalborg)

Engine MW	Diameter m	Length m	Height m	Dry Weight tonnes	Operational Weight tonnes
4	2.0	3.5	5.6	11.0	13.0
8	2.9	4.9	7.2	15.0	18.0
12	3.5	5.8	8.1	18.0	22.0
16	4.0	6.7	9.0	22.0	29.0
20	4.6	7.8	10.0	25.0	35.0
24	4.9	8.3	10.4	28.0	41.0
32	5.9	10.6	11.6	38.0	52.0
55	7.7	13.9	14.4	62.0	86.0

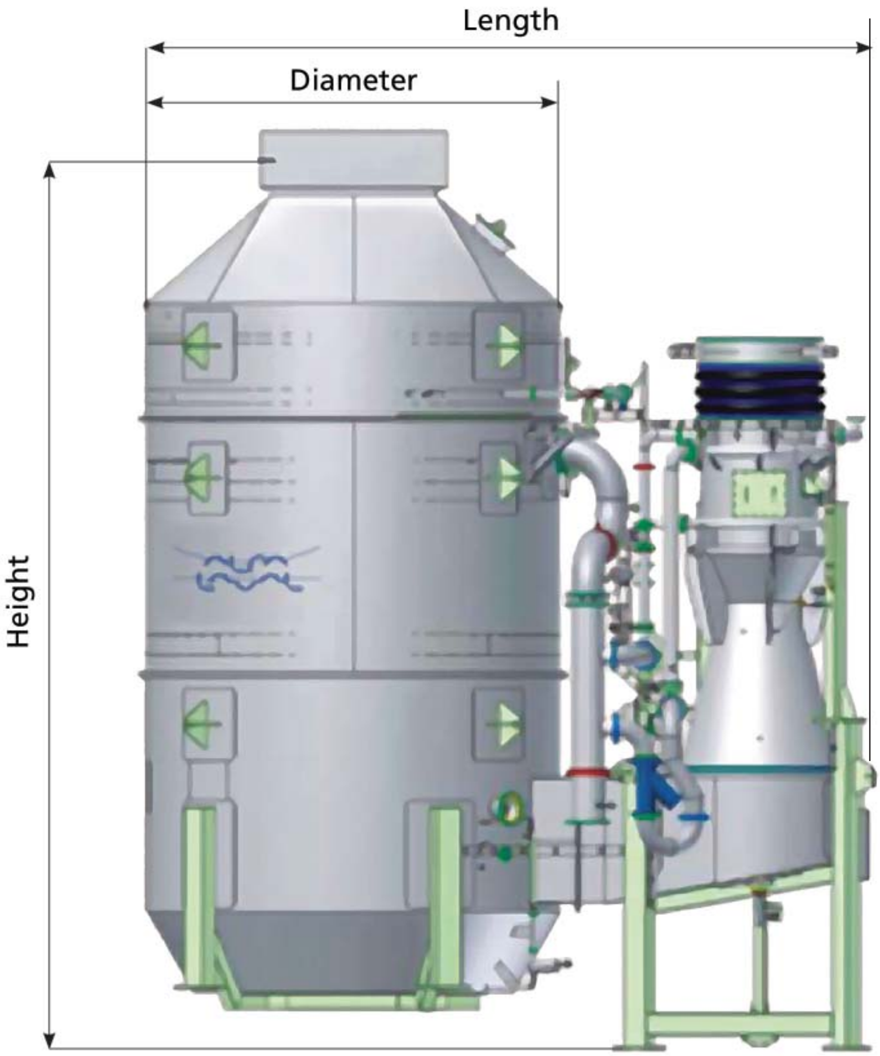


Figure 14: Scrubber Dimension Layout (Courtesy of Alfa Laval Aalborg)

Exhaust Gas Bypass

An exhaust gas bypass for a scrubber allows the exhaust gas to bypass the scrubber and go directly to atmosphere. Unless made with suitable materials for the high exhaust temperatures, wet scrubbers are not normally recommended to be operated dry, i.e. operated with exhaust gas passing through them without washwater flowing. For scrubbers that are suitable for dry operation, a separate bypass will not be required.

For most scrubbers fitting a bypass is a requirement if there is a need to be able to operate the equipment connected to the scrubber when the scrubber is non-operational for any reason. This would apply to engines and boilers considered essential services of a vessel. When the scrubber is not needed, such as when the ship is outside an ECA or low sulfur fuel is being used, the exhaust bypass can be used and the scrubber shut down, saving on EGC system electric power consumption.

Bypass exhaust pipes are as large as the original exhaust pipe and the required space in the engine exhaust system casing for the bypass pipe and the bypass valve can be large. The bypass pipe normally passes alongside the scrubber and requires a separate exhaust outlet at the top of the funnel in addition to the scrubber outlet. The bypass valve, which may be a metal to metal seated butterfly valve, controls the direction of the exhaust flow between the scrubber and atmosphere.

Where the valve is a two-damper design, an interlock would be required to prevent both dampers from being closed at the same time (see Figure 15). Exhaust bypass valves may require frequent maintenance because of the hot gas environment and soot accumulation that occurs. For main engines, an EGE is also frequently provided before the scrubber and for operation with the scrubber bypassed it is recommended to have a silencer fitted in the exhaust system.

Scrubber Material Selection

The lower portions of the scrubber (especially the open loop-type) may have a high concentration of acid and chlorides. Accordingly they must be designed to incorporate acid resistant materials. Scrubbers suitable for dry operation and wet scrubbers without a facility for bypassing exhaust gas when the washwater system is not in operation would experience higher operating temperatures and therefore this limits the materials selection to high temperature acid and chloride resisting alloys; typically nickel alloys. Duplex stainless steel has also been shown to perform well. Above the lower portions of the scrubber unit a less corrosion resistant stainless steel is often used. However the selection of the appropriate stainless steel grades should be considered in detail and should be based accordingly on conservative assumptions.

Figure 15: Exhaust Bypass Valves (Courtesy of Wärtsilä)

Integrated Scrubbers with Multiple Inlets

If it is desired to connect multiple engines or boilers to one scrubber, special features are needed for the scrubber and for the exhaust pipes leading to the scrubber. A scrubber suitable for multiple connections is called an Integrated Scrubber and they are custom designed to suit the specific number and sizes of connected engines or boilers. Each system will need to be evaluated and approved based on its merits with regard to interconnections and safe vessel operations. Any arrangements proposing the interconnection of exhaust systems along with the isolation and control system arrangements involved would require specific ABS approval in accordance with the provisions of 4-6-5/11.5 and 4-6-6/13 of the ABS Steel Vessel Rules.

When using an integrated scrubber, bypasses for each exhaust are required (see Figure 16), and for safety reasons special measures are needed to make sure the bypass valves are positioned and sealed properly when an engine or boiler is out of service so that exhaust will not backflow down the exhaust pipe to the idle engine or boiler. An exhaust fan is also typically needed to keep the exhaust system back pressure low enough and to keep the scrubber exhaust line at lower than atmospheric pressure as a safety measure to prevent the exhaust from leaking back into the exhaust system of an idle engine or boiler.

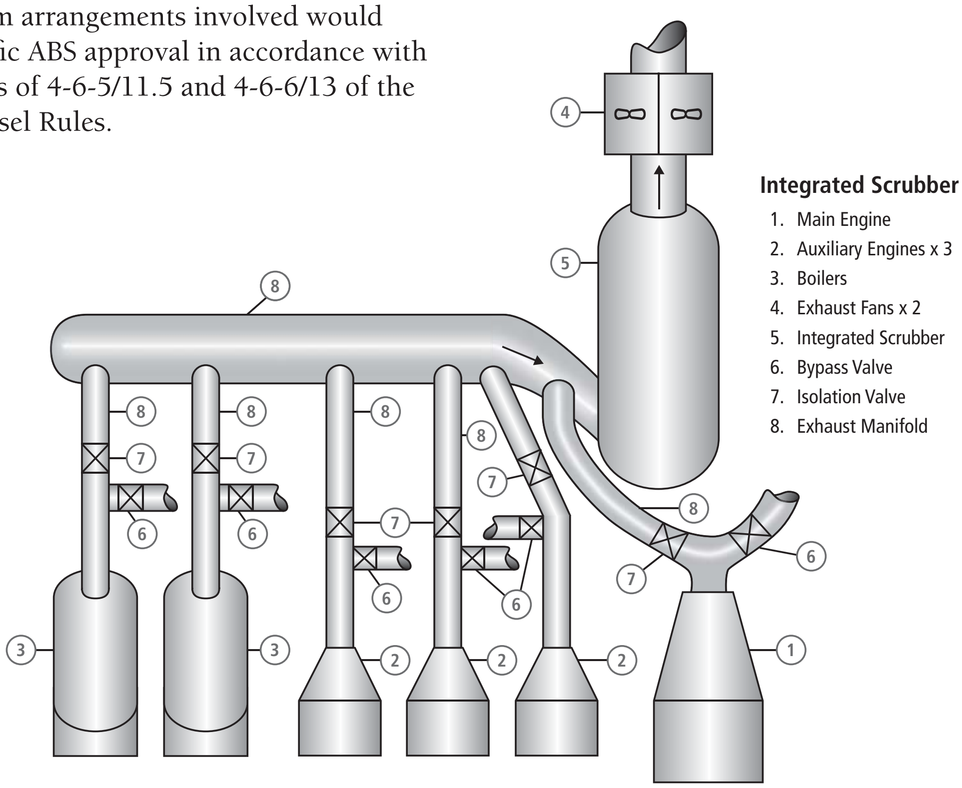


Figure 16: Integrated Scrubber System with Multi-Engine Inlets

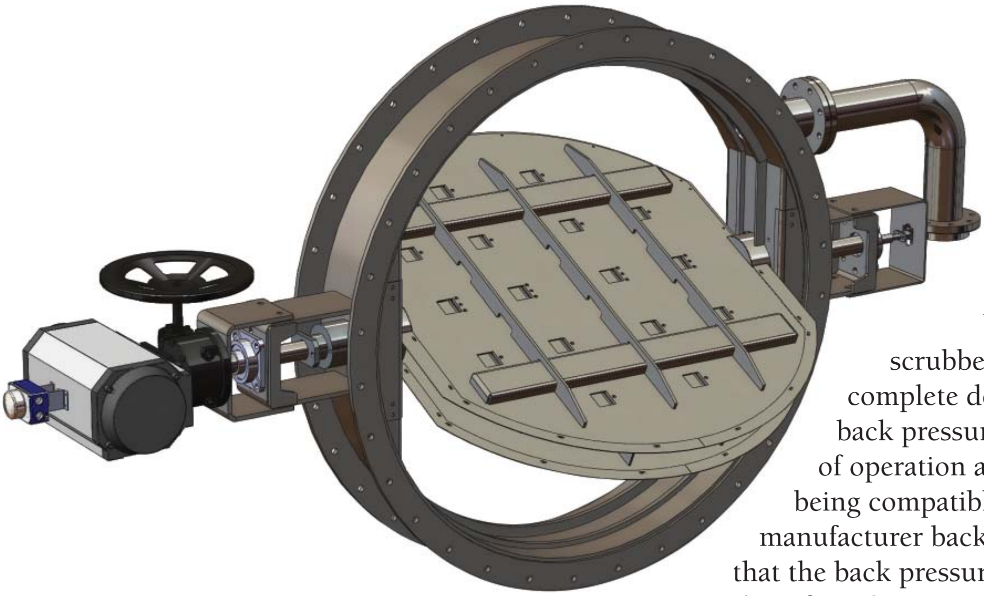


Figure 17: Exhaust Gas Isolation Valve
(Courtesy of Alfa Laval Aalborg)

Due to the potential impacts on engine operation through excessive back pressure and safety concerns of exhaust backflow to idle units, the impact of the scrubber fan failure on safe operation of the fuel burning units should be carefully considered. The scrubber manufacturer should submit complete details related to the anticipated back pressure across the full load range of operation and this should be verified as being compatible with the engine or boiler manufacturer backpressure limits to determine that the back pressure will not create problems for the safe and continued operation of the equipment.

Exhaust bypass valves need to be designed to avoid leakage and some leakage issues have been confirmed by bypass valve difficulties seen during scrubber system testing. One way to address leakage is to use butterfly valves with multiple discs and an extraction fan between the discs that prevents any leakage getting past the discs (see Figure 17).

Back Pressure

It is to be noted that scrubbers may have an impact on the operation of any engine/boiler to which they are added, if they cause excessive exhaust system back pressure. Continual compliance with IMO Annex VI Regulation 13 requirements on NOx emissions may be affected if the engine is operated at an exhaust backpressure outside the approved limits detailed in the Technical File. For this reason, before a scrubber is installed on an exhaust system, it is important to verify that the certified design and operational exhaust backpressure limits will not be exceeded.

If necessary, a fan may be provided on the scrubber outlet to the exhaust pipe to lower the pressure in the scrubber and thereby prevent excessive back pressure in the system. A fan may not normally be required for a scrubber attached to a single engine, but is more common on scrubbers connected to multiple engines and boilers to prevent higher back pressure from one engine or boiler affecting the other interconnected stationary or in operation fuel burning units.

Scrubber Piping Systems

Scrubbers require several piping systems to be installed, each with different material requirements. Considerations for the key piping systems are as follows:

Sea Water Supply

For open loop scrubbers seawater is supplied to the scrubber for the scrubbing process and standard sea water piping material can be used. Typical materials are steel pipe with polyethylene or rubber lining, galvanized piping, or glass reinforced epoxy (GRE) pipe, which will have to be of an approved type for use in machinery spaces. For closed loop scrubbers, sea water is used for cooling purposes and the same pipe material requirements would apply for those pipes.

Fresh Water Supply

For closed loop scrubbers that use treated fresh water for scrubbing, the piping should be of an appropriate material suitable for the particular closed loop chemistry.

Scrubber Drainage Pipe

The water draining out of the scrubber is acidic and corrosive, and special pipe materials are needed. Similar to inert gas scrubbers on tankers, steel pipe with polyethylene or rubber lining can be used. Alternatively, approved GRE piping has been known to perform satisfactorily. Valves should be rubber lined butterfly type or of suitable stainless steel grade. In closed loop systems the washwater will be considered corrosive until the point where the water is dosed with the alkaline material and the pH is raised.

Exhaust Pipe

Exhaust piping before the scrubber would typically match that for standard exhaust systems, however the exhaust gas exiting the scrubber would tend to have a high relative humidity and therefore highly corrosion resistant materials, such as stainless steel, would be preferable.

Sludge Pipe

The sludge generated by the scrubbing process may be acidic, and the associated piping should therefore be of acid corrosion resistance material.

Washwater Processing Tanks

Tanks for storing and processing the washwater (used in closed loop systems) should also be made from corrosion resistant materials. Fiberglass or appropriate approved plastic materials have been found to be practical in this application.

Flooding

One concern with wet scrubber operation is scrubber flooding, which will occur if the washwater drainage from the sump, either by pump or gravity drain, stops or is blocked. This will quickly cause flooding of the scrubber and overflow of the water down the exhaust pipe and subsequent damage to the attached engine/boiler may occur. The scrubber automation system should prevent such critical situations and this may be achieved with a high water level alarm, an automatic stop of the water supply to the scrubber and opening of the exhaust bypass (if fitted), with simultaneous appropriate functions for maintaining the associated fuel burning systems in a safe status.

Auxiliary Equipment

In addition to the scrubber itself, there is a need to consider the space and power requirements of the associated scrubber auxiliary equipment, such as pumps, process tanks, particulate separators, and coolers, which are similar in size to other engine room auxiliary equipment of the same type. The auxiliary equipment can be located lower down in the machinery space than the engine exhaust system casing since they do not have to be directly adjacent to the scrubber.

The main auxiliary equipment and typical sizes for three different scrubber sizes are listed below in Table 9 for both open loop and closed loop scrubbers. For the higher power engines large pumping systems are required that use substantial amounts of electric power because of the high discharge head, particularly for open loop

Table 9: Sample Wet Scrubber Auxiliary Equipment Sizing

Engine Size	5 MW		20 MW		40 MW	
Equipment	Open loop	Closed loop	Open loop	Closed loop	Open loop	Closed loop
Scrubbing water flow (m^3/hr)	225	120	900	480	1,800	960
Pump electric load (kW)	70	15	280	60	560	120
Process tank (m^3)	N/A	12	N/A	30	N/A	60
Sludge generation (liter/hr)	10	10	40	40	80	80
Caustic soda usage – 50% Solution (kg/hr)	N/A	150	N/A	600	N/A	1,200

Notes:

1. Scrubbing water flow rate and power estimates are based on Wartsila data.
2. N/A indicates not applicable.
3. Open loop-type scrubber has higher water flow because sea water is less effective as a scrubbing medium than treated fresh water.
4. Sludge generation rate can be reduced if effective means are used to remove water, and depends on water overboard discharge quality requirements, which affects how much sludge has to be removed.
5. Caustic soda usage rates and storage requirements can vary significantly depending on the engine load and scrubber operation. Indicated values of the expected requirements.

scrubbers (estimated to be about 70 m in the sample analysis) for three main reasons:

- Raise the water up from the lower engine room to the scrubber in the upper engine exhaust system casing,
- Overcome pressure losses in the piping, and
- Supply water at the required pressure to the spray nozzles (about 2 bar).

Multiple water supply or circulating pumps or variable speed pumps are needed so that the water supply to the scrubber can be varied with engine load, otherwise excessive water supply will occur at low engine loads. There is significant difference in the types of auxiliary equipment in use and flow rates dependent on whether a scrubber is an open loop-type or closed loop-type and for hybrid scrubbers in which mode they are operating in.

Scrubber Electrical Systems

Scrubber systems require electrical power and a control and monitoring system. For wet scrubbers, the electric load is primarily for pumping the washwater. For dry scrubbers it is for the pneumatic systems that transport the pellets to and from the scrubber. As can be seen in Table 9, the electrical load for pumping can be substantial, several hundred kW for open loop scrubbers for large engines. There are also other electric loads to consider, such as sludge removal, alkaline dosing, sea water cooling, induced draft fans, and process control. It is expected that the total electric load will be about 115 to 125 percent of the scrubber pumps electric load. These loads can be more than the surplus electric capacity available in an existing vessel's electric power system and may require the addition of a separate generator.

New vessels may be installed with generators designed to accept the scrubber loads as part of normal operating conditions. For retrofit installations, the need to add an electrical distribution system for the scrubber requires modification of the main switchboard to provide feeder circuit breakers. One or more power distribution boards would be added for the scrubber systems and local starters fitted in the vicinity of the motors.

Besides electric power to the scrubber, an automation and control system has to be

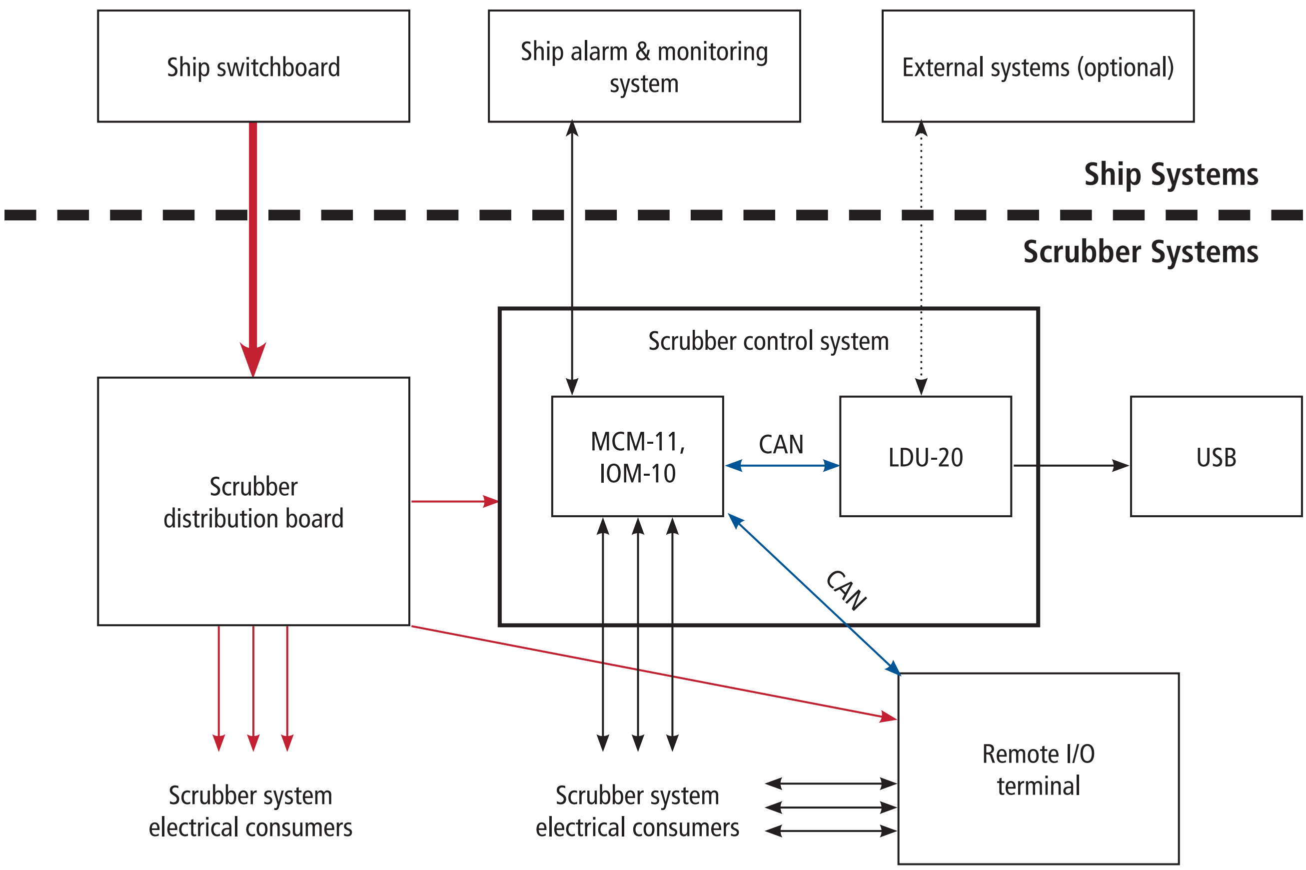


Figure 18: Typical Scrubber Power and Control System Schematic (Courtesy of Wärsilä)

Table 10: Scrubber Automation and Monitoring Requirements

Function	Control Mechanism	Remarks
Water flow rate varied by engine load	Number of pumps or pump speeds	Necessary to reduce water flow rate at low engine power
Alkalinity of water	Control of dosing rate	Applies to closed loop scrubber
Washwater temperature	Control of sea water cooler	Applies to closed loop scrubber
Monitor exhaust emissions	Monitor SO_2/CO_2 ratio (ppm/%) with specialized analyzers	For scrubbers certified under Scheme A, exhaust emissions monitoring is to be undertaken on a periodic basis. For scrubbers certified under Scheme B, the SO_2/CO_2 ratio monitoring is to be continuous.
Monitor scrubber operation	Record key scrubber parameters	Records at required frequency (per Schemes A or B) scrubber usage, washwater pressure and temperature, exhaust pressure and temperature, engine load, rate of chemical usage
Monitor washwater discharge	Record key parameters and adjust them by controlling washwater treatment prior to discharge	Record continuously washwater discharge pH, PAH, and turbidity levels. Temperature is also normally recorded. Nitrates levels (from NOx) should be periodically tested and recorded. Levels of any additives to the washwater discharge should be periodically recorded.

installed. Control panels can be local to the scrubber, but basic scrubber control should be available from the engine control room with a tie in for the scrubber alarms to the ship's central alarm and monitoring system. Figure 18 shows an electrical distribution and control system for a closed loop scrubber system.

Wet Scrubber Automation and Monitoring

EGC units require automation and monitoring of their systems, operation and effectiveness to ensure that the scrubber provides the required level of exhaust gas and washwater discharge cleaning. Some of the key automation and monitoring functions that are required to be provided in a scrubber system are listed in Table 10. The monitoring and data logging system should be tamper-proof and in compliance with MARPOL and any national regulations that may be applicable.

Redundancy

Redundancy of the scrubber, or active scrubber system components, is not currently explicitly required by the implementing regulations for sulfur emissions. However, if it fails while the ship is operating in an area where low-sulfur fuel is required, the ship will no longer be in compliance with the emission regulations. In addition, if there are failures there could be safety related issues that can be of concern to the operator and the classification society. Regulation 3 to Annex VI provides general exceptions and exemptions to the Annex for the purpose of securing life at sea and any emission resulting from damage. In the case of damage this would exempt collision, accidental and heavy weather damage but due diligence in design and operation must be exercised to minimize equipment breakdowns. Accordingly providing redundancy in scrubber systems for components such as water supply pumps and automation will help mitigate the impact of failure on operations and scrubbers may be considered essential services.

Summary

International, regional and local emissions regulations are requiring reductions in exhaust emissions from oil burning equipment. Reducing SOx emissions is typically regulated by mandating reductions on the sulfur content of the fuel but there are question marks over the availability and price of these compliant fuels. Accordingly there is growing interest and application for exhaust gas cleaning systems that can provide alternative means of complying with the emissions regulations.

There are international guidelines covering the testing, survey and certification of exhaust gas cleaning systems in place which generally cover the performance, emissions compliance aspects and there are also additional classification society requirements in place addressing further requirements, primarily relating to safety issues.

There are a number of scrubber types available to suit different vessel types, trading patterns and local conditions; exhaust gas cleaning systems therefore offer a viable alternative means of compliance that may have significant operational cost saving benefits.

The operating pattern of a ship will influence the process of determining which type of scrubber system is to be considered for a particular application. If the ship has a minimum port stay or minimum transit time in ECAs operating profile, or there are no restrictions on the discharge water by local or regional regulations, an open loop scrubber may be considered appropriate. However, if the vessel has long port stays with an appreciable time spent transiting in ECAs and with minimum time at sea, a hybrid or closed loop scrubber system could be considered. The global IMO fuel sulfur limits scheduled to be reduced to 0.5 percent sulfur in 2020 will influence this decision making process.

The total cost of a scrubber system includes the initial cost of the scrubber, installation expenses, additional miscellaneous auxiliary equipment, off hire, ship modifications, etc. together with the cost of the additional fuel consumption to operate the scrubber system and the cost of consumables where applicable. Based on these factors, a comparison could be made to the cost of operating the ship's fuel combustion units on low sulfur fuel.

The Appendices to this Advisory provide more information on a number of scrubber systems that are on the market and reference should be made to the accompanying check lists for owners. It is advisable to consult with the flag Administration of the vessel and the classification society at an early stage to determine applicability, current regulations and any specific requirements that may need to be applied.

References

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15. European Council Directive 2005/33/EC – Amending Directive 1999/32/EC; 6 July 2005

16. European Council Directive 2009/30/EC – Amending Directive 1999/32/EC; 23 April 2009

17. European Council Directive 2012/33/EC – Amending Directive 1999/32/EC; 21 November 2012

18. US Code of Federal Regulations – Title 40: Protection of Environment , Part 1043, Control of NOx, SOx and PM emissions from marine engines and vessels subject to the MARPOL protocol

19. US Code of Federal Regulations – Title 40: Protection of Environment, Part 94, Control of emissions from marine compression ignition engines

20. US Code of Federal Regulations – Title 40: Protection of Environment, Part 1042, Control of emissions from new and in-use marine compression ignition engines and vessels

21. California Code of Regulations (CCR) 13 CCR 2299.2 – Fuel sulfur and other operational requirements for oceangoing vessels within California waters and 24 nautical miles of the California baseline

22. CARB Marine Notice 2012-1 – Advisory to owners and operators of oceangoing vessels or ships visiting California ports; 2 July 2012

23. IMO Resolution MEPC.130(53) – Guidelines for Onboard Exhaust Gas-SOx Cleaning Systems; 22 July 2005

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26. IMO Protocol of 1997 to MARPOL 73/78 – Annex VI, Regulations for the Prevention of Air Pollution from Ships – Resolution 2, the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines (NOx Technical Code); September 1997

27. IMO Resolution MEPC.169(57) – Procedure for Approval of Ballast Water Management Systems that make use of Active Substances (G9); 4 April 2008

28. IMO Circular MSC.1/Circ.1221 – Validity of Type Approval Certification for Marine Products; 11 December 2006

FREQUENTLY ASKED QUESTIONS

The following are a sample of questions taken from a recent MARTECMA meeting:

When transiting an ECA, what would be the status of a vessel in the case of failure of an installed scrubber system?

MARPOL Annex VI Regulation 3.1 considers exemptions and exceptions for vessels that experience noncompliance with the emission standards set forth in MARPOL Annex VI Regulation 14 as a result of damage to a ship or its equipment. The acceptance or non-acceptance of an exemption would be in the realm of the concerned flag Administrations. For the exemption to be granted, the owner would need to exhibit that due diligence had been exercised in both design and operation, i.e. sufficient redundancy, has been incorporated in the system.

ABS has determined that miscellaneous electrical equipment such as the scrubber washwater pumps and/or other rotating, reciprocating components, together with the power supply to these components essential for the operation of the scrubber, are to be provided with redundancy arrangements. Therefore, continuous operation of the fuel combustion units and scrubber systems is ensured to maintain the vessel's propulsion and maneuvering capability, together with continual compliance with MARPOL Annex VI Regulation 14.

How does the scrubber washwater fluid (sea water or fresh water) feed rate influence the back pressure of the main and D/G engines?

Height, diameter and water mass all influence the back pressure. The biggest effect on back pressure comes from the design of the internal scrubber itself. The scrubbing efficiency is guided by the intimacy of the molecular contact between the washwater and the exhaust gas. Typical exhaust backpressure has been quoted as approximately 100 mmWc though scrubber designs and arrangements may necessitate the use of a fan to keep system backpressure within the limits specified by an engine manufacturer.

What might be the added electrical load of forced fan ventilation to recover the back pressure of the main engine?

Scrubber manufacturer's specifications vary from 10kW to 38kW or 0.5 percent of the MCR of the main engine.

When caustic soda is used in a closed loop system, what is the relationship between engine size, sulfur content in the fuel, and the use of caustic soda?

As an example, Wartsila quotes caustic soda consumption as approximately 18 liters/MWh when scrubbing 3.5 percent S HFO to 0.1 percent S exhaust equivalence. Or, 1.25 kg NaOH per kg SOx removed. The cost of caustic soda can vary by a factor of up to 300 percent ($200 to $600 was a suggested price/range by one scrubber manufacturer), so the purchase of this consumable needs to be considered and the storage capacity designed around the particular scrubber manufacturers usage rate.

What are the primary safety concerns for using caustic soda in scrubbers?

Appropriate safety measures must be taken to ensure safe storage, handling and use of toxic or corrosive chemicals. Caustic soda has a pH of 14, is hazardous, can cause severe skin burns, respiratory damage and eye injury. Robust procedures are required for handling caustic soda, including the use of appropriate personal protective equipment when there is risk of exposure. Reference should be made to material safety datasheets (MSDS). Safety showers in the vicinity of bunkering stations and storage tanks, and protective shields over all pumps handling caustic soda are needed (caustic soda tends to wear seals, etc. which can cause caustic spray).

ABS requires the submittal of additional details for any proposed arrangement that would use caustic soda. For ship's domestic use there is no special statutory regulatory approval. Since caustic fluids are considered to represent a hazard to personnel, the following protective measures shall be provided:

1) Eye wash and showers shall be provided in the vicinity of the treatment fluid bunker manifold as well as in the vicinity of, but at a safe distance from, treatment fluid pumps.

2) Three sets of protective equipment, covering all skin so that no part of the body is unprotected (large aprons, special gloves with long sleeves, suitable footwear, overalls of chemical resistant material, tight-fitting goggles or face shields or both). The equipment shall be resistant to the treatment fluid in question. The equipment shall be used by personnel during bunkering and in operations which may entail danger to personnel.

3) The protective equipment shall be provided in easily accessible lockers outside the accommodation area.

Are scrubber systems acceptable for use in the state of California, the EU and other port States in lieu of low sulfur fuel?

California does not currently accept SOx scrubbers as an alternative means for using low sulfur distillate fuel, unless it is being used for the purpose of testing. The EPA has issued an "Interim Guidance on the Non-Availability of Compliant Fuel Oil for the North American Emission Control Area" dated 26 June 2012 which states that vessels may either use Annex VI ECA compliant fuel oil when operating within the designated North American ECA or install and use an equivalent method as approved and allowed under MARPOL Annex VI Regulation 4, and 40 CFR. § 1043.55 (e.g., exhaust gas cleaning device).

After 2015, when sulfur limits are harmonized with the North American ECA requirement of 0.1percent, California's CARB will fall in under the US ECA rules, and thereafter it would be the intent of the Californian CARB to allow the use of SOx scrubbers as an alternative.

The EU requires the monitoring system to be of the continuous type. In addition, the Council of the European Union has adopted a directive amending directive 1999/32/EC in regards to the sulfur content of marine fuels (PE-CONS 31/12) with one of the key elements being to allow the use of alternative exhaust gas cleaning systems such as scrubbers, provided they are operated in closed mode.

How will Port State Control verify the cleaning rate of the scrubbers?

Guidelines for PSC associated with MARPOL Annex VI are described in IMO Res. MEPC.181(59), where it is stated that the PSC officer should examine the "approved documentation relating to any installed exhaust gas cleaning systems, or equivalent means, to reduce SOx emissions (Reg. VI/4)." Furthermore, as per 4.2.3.2 and 5.3.2 of the Annex to Res. MEPC.184(59), EGC units and their monitoring systems may also be subject to inspection by Port State Control. Section 7.5 also requires that a copy of the recorded data and reports should be made available to the Administration or Port State Authority as requested.

With regard to nitrates, according to 10.1.5.2 of the Resolution "at each renewal survey nitrate discharge data is to be available in respect of sample overboard discharge drawn from each EGC system within the previous three months prior to the survey." However, the Administration may require an additional sample to be drawn and analyzed at their discretion. The nitrate discharge data and analysis certificate is to be retained on board the ship as part of the EGC Record Book and is to be made available for inspection as required by Port State Control or other parties.

How will the calculated Energy Efficiency Design Index (EEDI) be influenced by a scrubber?

It is not envisioned that the EEDI would be impacted by the installation of a scrubber.

Which monitoring devices are needed for an EGC and what is the marine service experience of these devices?

The requirements for monitoring are described in MEPC.184(59) and there are installations that have substantial marine experience. The monitoring devices in general are types that have been in use for several years on onshore installations. The type and extent of monitoring depends on the certification Scheme (A or B) of Resolution MEPC.184(59) and the details of these monitoring devices are required to be specified in the Onboard Monitoring Manual (OMM).

Scheme A – MEPC.184(59) recommends, where a continuous exhaust monitoring system is not fitted a daily spot check of exhaust emissions together with a continuous monitoring of certain prescribed parameters is required. If continuous monitoring is installed then only spot checks of the prescribed parameters may be carried out.

Scheme B requires continuous monitoring of exhaust emissions using an approved monitoring system together with daily spot checks of certain prescribed parameters is required. In both the cases Scheme A or Scheme B the washwater is required to be continuously monitored for pH, PAH and turbidity.

The pH electrode and pH meter should have a resolution of 0.1 pH units and temperature compensation. The electrode should comply with the requirements defined in BS 2586 or of equivalent or better performance and the meter should meet or exceed BS EN ISO 60746-2:2003.

The PAH monitoring equipment should be capable to monitor PAH in water in a range to at least twice the applicable discharge concentration limit. The equipment should be demonstrated to operate correctly and not deviate more than 5 percent in washwater with turbidity within the working range of the application. And the turbidity monitoring equipment should meet requirements defined in ISO 7027:1999 or USEPA 180.1.

Are there any requirements on particulate matter (PM) monitoring by the IMO, US EPA or other such organizations?

IMO does not specifically limit PM but regulates the sulfate portion of PM formation through the fuel sulfur content requirements of Regulation 14 to Annex VI. The US EPA defines PM limits for Category 1 and 2 marine engines (up to 30 liters displacement). The EPA emission measurement requirements for Category 3 engines (over 30 liters displacement) require test bed monitoring of particulate matter. In response to a query put forth regarding the requirements for PM limits the EPA advised that at this point in time there is no official guidance regarding the PM limits by substitution with exhaust gas scrubbers in lieu of using low sulfur fuel.

However as specified in the EPA's Final Rule for Control of Emissions From New Marine Compression-Ignition Engines at or Above 30 Liters per Cylinder, significant PM emissions control will be achieved through the ECA fuel sulfur requirements. During its 62nd session, the Marine Environment Protection Committee adopted a work plan to address the impact on the Arctic of emissions of black carbon from international shipping and instructed the Sub-Committee on Bulk Liquids and Gases (BLG) to develop a definition for black carbon emissions from international shipping; consider measurement methods for black carbon; identify the most appropriate method for measuring black carbon emissions from international shipping; investigate appropriate control measures to reduce the impacts of black carbon emissions from international shipping in the Arctic; and submit a final report to MEPC 65 (in 2014).

What are the IMO and regional regulations governing discharge water?

Washwater criteria limits for pH, polycyclic aromatic hydrocarbons (PAH), turbidity/suspended particulate matter and nitrates are defined in 10.1 of Resolution MEPC.184(59). The US EPA washwater discharge limits are consistent with the IMO requirements in the VGP2 for 2013. However, the EPA has added some additional requirements for washwater sampling and analytical monitoring for all 16 PAHs; while the IMO requires monitoring by measuring of the most common phenanthrene equivalents, shipowners/operators must submit all monitoring data to the US EPA's e-reporting system unless specifically exempted from electronic reporting. Monitoring data must be submitted at least once per calendar year, no later than 28 February of the following year, on the vessel's annual report. In addition to those requirements, the EPA is in the process of drafting a water quality certification to the VGP that would be adding other conditions related to vessels in general.

Please elaborate on the washwater discharge criteria in the draft 2013 VGP.

As per 2.2.26.2.2 of the proposed 2013 VGP, in addition to the continuous monitoring, owners and operators must collect and analyze one sample per quarter for each of the constituents analyzed in 2.2.26.2.3 to demonstrate treatment equipment maintenance, probe accuracy, and compliance with the permit. Records of the sampling and testing results must be retained on board for a period of three years in the vessel's recordkeeping documentation. The EPA compiles and analyzes information to be assured that scrubber systems are not likely to result in adverse impacts to aquatic environments, particularly if these systems are adopted on a wide scale. According to the EPA, they have received comments on these sections of the permit, and may consider whether to incorporate any changes.

Are SOx scrubbers compatible with selective catalytic reduction (SCR) systems for NOx removal, considering post-2016 Tier III requirements?

Vessels built after 1 January 2016 will need to consider how the vessel arrangements meet both NOx and SOx requirements, but the degree of impact would appear to depend on the NOx reduction method being utilized. EGR arrangements would typically also involve the use of scrubbers and would not be in conflict. However, SCR systems need high exhaust inlet temperatures to work and hence must be deployed upstream of the scrubber. This in turn means the SCR needs to deal with the fuel sulfur content, which may be a problem for some SCRs. Most SCR manufacturers have catalyst technologies that can operate at a higher SOx content. The shipowner is well advised to inquire about catalyst cost, and service life expectancy, at higher SOx exhaust levels, and what the upper sulfur limit is for the specific SCR. The use of an SCR in addition to a scrubber in the exhaust stream will increase back pressure, which has to be considered.

What are the considerations that may be required to address (lightship changes), the effect on stability and tonnage?

The tonnage certificate may need to be revised. In general, the effect on the lightship characteristics should be determined after installing a scrubber. If this calculation indicates a change of about 2 percent or more in the ship's lightweight, or a change in the longitudinal center of gravity of 1 percent or more of the ship's length, then a full inclining experiment should be carried out after the completion of the work. If the change is expected to be less than these limits then a lightweight survey should be carried out on completion of the work to confirm the effect of the changes.

Can more than one fuel combustion unit be accommodated by a single SOx scrubber?

Yes, several fuel combustion units may be connected to a single scrubber. Please refer to the section of the Advisory titled Integrated Scrubbers (Multiple Inlets).

The installation of an SCR in addition to an EGCS in way of the exhaust gas piping is an additional abatement system that may lead to an increase in the MCR of the engine in order to withstand the effect of increased back pressure. In this case the measures taken for NOx reductions would also increase the SOx emissions (by increasing the MCR of the engine and thus the fuel consumption). The EGCS cools down the exhaust gas whereas the SCR requiring an exhaust gas with a relatively higher temperature for operation. With the first acting against the second, what would be the solution for such installations?

Typically wet EGC systems use water spray in the exhaust for cleaning and therefore may require demisters for drying and re-heaters for increasing the temperature of the exhaust gas that may be necessary for use with SCRs. However, some slow-speed engines may incorporate SCR systems before the scrubber, even before the turbocharger, and will not be impacted by the drop in the scrubber outlet exhaust gas temperature associated with the installation of a scrubber. Where excessive back pressures are anticipated, some scrubber system designs reduce the resulting back pressure by the installation of auxiliary fans.

Are new stability calculations required after installation of a scrubber, considering the height and the weight of a scrubber?

Depending on the weight of the scrubber, the vessel's lightship weight characteristic may have to be revised by weights and centers calculation. Further, based on this weight increase, a deadweight survey may be required to confirm revised lightship weight vertical center of gravity. As applicable a revised lightship data is to be indicated on the existing trim and stability booklet, loading manual and loading computer program.

Is a new damage stability calculation needed?

Revision of the damage stability will need to be considered on a case-by-case basis. If the designer can prove that the effect on the damage stability can be easily confirmed by comparison with the original damage stability, it may not be necessary to run the damage stability analysis again.

Are all scrubber installations provided with exhaust by pass ducts/valves allowing operation on low sulfur fuel oil for areas where the scrubber might not be allowed?

It is expected that most exhaust gas scrubbers would be provided with exhaust gas bypasses.

Do scrubber systems require modifications to existing exhaust gas piping?

Modifications will be required to the existing exhaust piping. In addition, a demister unit might be required after the scrubber to ensure sufficient exhaust temperature to prevent condensation. It is however recommended that the exhaust pipe material after the scrubber is of a corrosion resistant type. If the velocity of the exhaust plume is slowed in the scrubber, the exhaust velocity may need to be accelerated by the design of exhaust pipe terminal to move the exhaust plume away from the ship. Some scrubber system designs may also accelerate the flow by the installation of auxiliary fans to reduce the backpressure of the scrubber system.

Can scrubbers be positioned as a substitute for exhaust silencers?

Scrubbers typically have a sound damping effect (e.g. 35 dB) and they can eliminate the need for a silencer. However, this depends on the internal design of the scrubber and it is always advisable that the scrubber manufacturer is consulted.

Will the scrubber function as designed at all loads?

Scrubbers are to be designed to reduce emissions to equal, or less than, the required fuel S equivalence at any load point when operating within the range of operational limits for which the unit is approved. The maximum HFO sulfur content for which this is achievable is to be stated by the manufacturer.

How can the system ensure that sulfuric acid mist and condensation generating an undesired plume will not cause corrosion in the exhaust pipes?

A de-plume exhaust gas re-heater can be used to prevent both pluming and acidic gas condensation. This is anticipated to be addressed by the makers. Re-heaters may have to be used for condensation reduction.

In case of a dry run, and the scrubber being affected by full heat of the exhaust, what are the likely consequences? Are there scrubbers that can sustain exposure to hot exhaust in a dry mode without requiring bypass arrangements?

If dry-running of a scrubber is envisaged, then the scrubber must have been designed as such with appropriate materials.

Can the SOx scrubber be combined with an Exhaust Gas Recirculation system for NOx reduction?

The use of EGR as an engine primary NOx emission reduction technique in association with a scrubber aftertreatment system is possible. For marine applications the use of EGR will likely necessitate the integration of some form of scrubber within the EGR system to treat the exhaust gases for the effects of the relatively high fuel sulfur content.

Are there any particular sludge disposal restrictions in place? Can the sludge produced be incinerated on board?

The residues from the exhaust scrubbing processes may not be incinerated on board and must be disposed of ashore In accordance with MARPOL Annex VI Regulation 16, Paragraph 2.6, which prohibits incineration of sludge generated from a scrubber. Even if all major ports are expected to have approximate capacities by 2015 the shipowner is well advised to investigate sludge reception facilities where the ship will trade to avoid deviations. Where reception facilities are found to be inadequate the Administration is to notify the IMO (as per document MEPC/Circ.469 Rev.1, which contains an entry for exhaust gas cleaning residues) based on information sent by a ship having encountered difficulties in discharging waste to reception facilities – see MARPOL Regulation VI/17.2 and 17.3.

Checklist for Owners

Baseline for Compliance with ECA Low Sulfur Requirements

1. Does the vessel have a fuel system suitable for switching to low sulfur fuel and, if so, does it have adequate capacity for operation for the full period of time the vessel will be in an ECA? Currently ECA operation requires 1 percent sulfur fuel, but starting in January 2015 this will reduce to 0.1 percent sulfur fuel.
2. If the vessel does not currently have an adequate capacity for the accommodation of compliant low sulfur fuel or a proper fuel system for operation on low sulfur fuel, the shipowner/operator should develop a list of required modifications and determine the cost for these. This will be the baseline for comparisons to the costs associated with installing a scrubber.
3. The shipowner/operator should estimate the annual additional operating cost for operation in ECAs using low sulfur fuel compared to using standard, typically HFO, fuel oils. This cost will be the baseline for comparison to the operating costs if a scrubber is installed.

Scrubber Installation Feasibility – New Vessels

1. Determine what will be the operating ports and coastal areas the ship will be calling at over its expected life. Do any of these areas have low alkaline fresh or brackish water? If so, determine how often the ship would be in these waters as this will limit the effectiveness of open loop-type scrubbers.
2. Determine the ship's operating profile, including percent of time at near full power and partial and low powers, including maneuvering and port times. This is useful information for scrubber design.
3. Determine which engines/boilers would need to be considered for the installation of scrubbers – main propulsion engines, auxiliary engines, boilers etc. Consider whether an integrated scrubber will be suitable for all engines/ boilers or whether each fuel burning unit should have an individual scrubber.
4. Based on the operating pattern of a ship a determination would need to be made to select the type of scrubber system to be considered. If the ship has minimum port stay or minimum transit time in ECAs the open loop may be considered. However, if the vessel has long port stays with an appreciable time spent in transiting in ECAs with minimum time at sea a hybrid or closed loop could be considered. Also consider the suitability of the installation of a dry scrubber. Ask the ship's designer (which could be the shipyard) or scrubber vendors directly for proposals on suitable scrubbers for the ship's propulsion plant and intended operating profile.
5. After the ship's design has been updated to include a scrubber, a review is to be made as to the acceptability of the impact on the general arrangement, machinery arrangement and accommodation arrangement or impact on cargo or vessel operations from expanding the engine exhaust system casing to include the scrubber and any exhaust bypasses.
6. The proposal should list the special requirements for bypass valves to avoid leakage. For an integrated scrubber, details are available on how exhaust gas will be prevented from entering offline engines. The scrubber proposal should include or indicate the following items:
    a. Weight and size of the scrubber
    b. Need for bypass, bypass valve and silencer
    c. Expected back pressure over a range of loads
    d. Exhaust fan requirements and redundancy measures
    e. Washwater flow requirements over the range of operating powers and piping diagrams of the water-washing system including pump sizes, flow rates, pressures and system redundancy

For closed loop systems, the proposal should include the amount of washwater bleed-off expected.

f. Method of processing the water to make it acceptable for discharge or re-use and details of required equipment. For discharged washwater, the proposal should specify the method to adjust pH and other characteristics to meet permitted limits.

g. Estimated quantities of sludge accumulation and the need for storage arrangements and offloading. Total storage capacity should allow for possible silt accumulation from open loop systems.

h. Required chemicals, dosing equipment, usage rate, source for chemicals on worldwide basis, frequency of resupply, method of handling on board and costs

i. Details of electrical loads and power supply requirements for the ship

j. Details of required automation and monitoring equipment to be supplied. Confirm all the monitoring equipment requirements contained in the regulations will be provided.

k. Details of allowable fuels, sulfur levels, expected scrubbing performance, operating parameters, restrictions on operation, firefighting requirements, emergency operations and other guidance on the use of the scrubber should be provided by the vendor.

l. Details on how the scrubber will help meet emission requirements in all areas the vessel will operate in and, if not at all times (such as in low alkaline waters for an open loop scrubber), the owner/operator should determine how to otherwise meet emission requirements when the scrubber does not, such as use of low sulfur fuel. Determination should be made on whether the scrubber will be operated when outside ECAs or other areas where low emissions are required.

m. Details of Type Approvals received for the scrubber equipment and approvals and certification that the scrubber vendor will obtain from the ship's class society and flag Administration (as needed) for the unit and supporting auxiliary equipment and controls.

n. Are all the Manuals listed in Table 4 of the Advisory to be supplied by the scrubber vendor? If not, who will develop them?

7. Decide on the level of redundancy in the scrubber systems that will be required in order to provide emission compliance reliability. The probability of the need to enhance system design and specifications to suit needs.

8. Has the engine/boiler maker been consulted regarding the impact of the proposed scrubber on the engine/boiler and its operation and certification?

9. Details of the cost for the scrubber and all vendor-supplied auxiliary equipment and manuals should be made available. Transport costs to the shipyard are to be determined and all installation costs are to be provided by the shipyard/installation contractor. Cost for supply and installation of any additional equipment beyond the vendor supply to be determined. Cost for design changes and any structural modifications of the ship and its machinery systems should be determined. A total installed cost should be determined.

10. The vendor should supply estimates for the operating cost of the scrubber and expected maintenance costs. The shipowner/operator should determine the method and cost for disposing ashore sludge produced by the scrubber.

11. The shipowner/operator should determine the crew training requirements and crew labor hours and costs for scrubber operation on an annual basis.

12. A comparison should be made of the total cost that would be expected for the owner/operator by using a scrubber, considering the value of capital costs for the scrubber purchase and installation, and annual operating costs, versus the costs for alternative means of compliance (see Baseline for Compliance).

Scrubber Installation Feasibility – Existing Ships

1. Is there adequate space on the existing ship to add one or more scrubbers? If not, how can the space be created?
2. How will the additional required space and weight of the scrubber(s) affect the operation of the ship, including its accommodation spaces, cargo loading and stability?
3. A comparison should be made of plans submitted by more than one designer to evaluate the most acceptable changes to the ship's arrangement, structure and machinery systems to install the scrubber(s).
4. Have the costs associated with the design changes to the ship's arrangement and structure been estimated and later developed if the installation goes forward?
5. Has the engine/boiler maker confirmed a scrubber can be added to the exhaust system and what will be its impact on the engine's operation and certification?
6. Determine all the associated changes to the existing machinery and systems, whether it is practical to make these changes, and how the changes will be executed.
7. Determine the out-of-service time for the scrubber installation and when and how this will be done. Determine the cost for the changes to the ship, berthing and shipyard costs and the lost revenue for the out-of-service period. Can the work be done in conjunction with other repair or drydocking work?
8. Determine who will obtain the necessary class and other regulatory approvals for the changes to the existing vessel and its systems to install the scrubber(s).

Appendix I

Exhaust Gas Cleaning System Association Members

While EGC systems have been in widespread use on land and in inert gas systems on tankers, the use of scrubbers for the purpose of cleaning engine exhausts on commercial ships is a relatively new application. A number of manufacturers have formed an association, the Exhaust Gas Cleaning Systems Association (EGCSA), to promote the development, design and approval of scrubbers. The association is located in the UK and further information is available at www.egcsa.com.

The following scrubber and engine manufacturers are members of the association:

- Alfa Laval Aalborg
- Clean Marine
- Couple Systems
- Dupont BELCO Clean Air Technologies
- Green Tech Marine
- MAN Diesel and Turbo[1]
- Marine Exhaust Solutions
- Wartsila Hamworthy Krystallon

All members of the EGCSA produce wet scrubbers, using processes similar to those described in this Advisory, except for Couple Systems, which produces the dry scrubber described in this Advisory. The EGCSA periodically offers instruction courses and workshops and can be a good source of information on the latest types of scrubbers being marketed and developed, technical details, performance and how EGC systems impact the environment. The EGCSA members have agreed to follow a Code of Conduct that promotes ethical and responsible actions by the member companies. The EGCSA members are of course not the only companies offering EGC system solutions to the marine community.

[1]MAN does not offer scrubbers independently. They have developed a scrubber as an integrated part of their Tier III EGR system for NOx control.

Appendix II

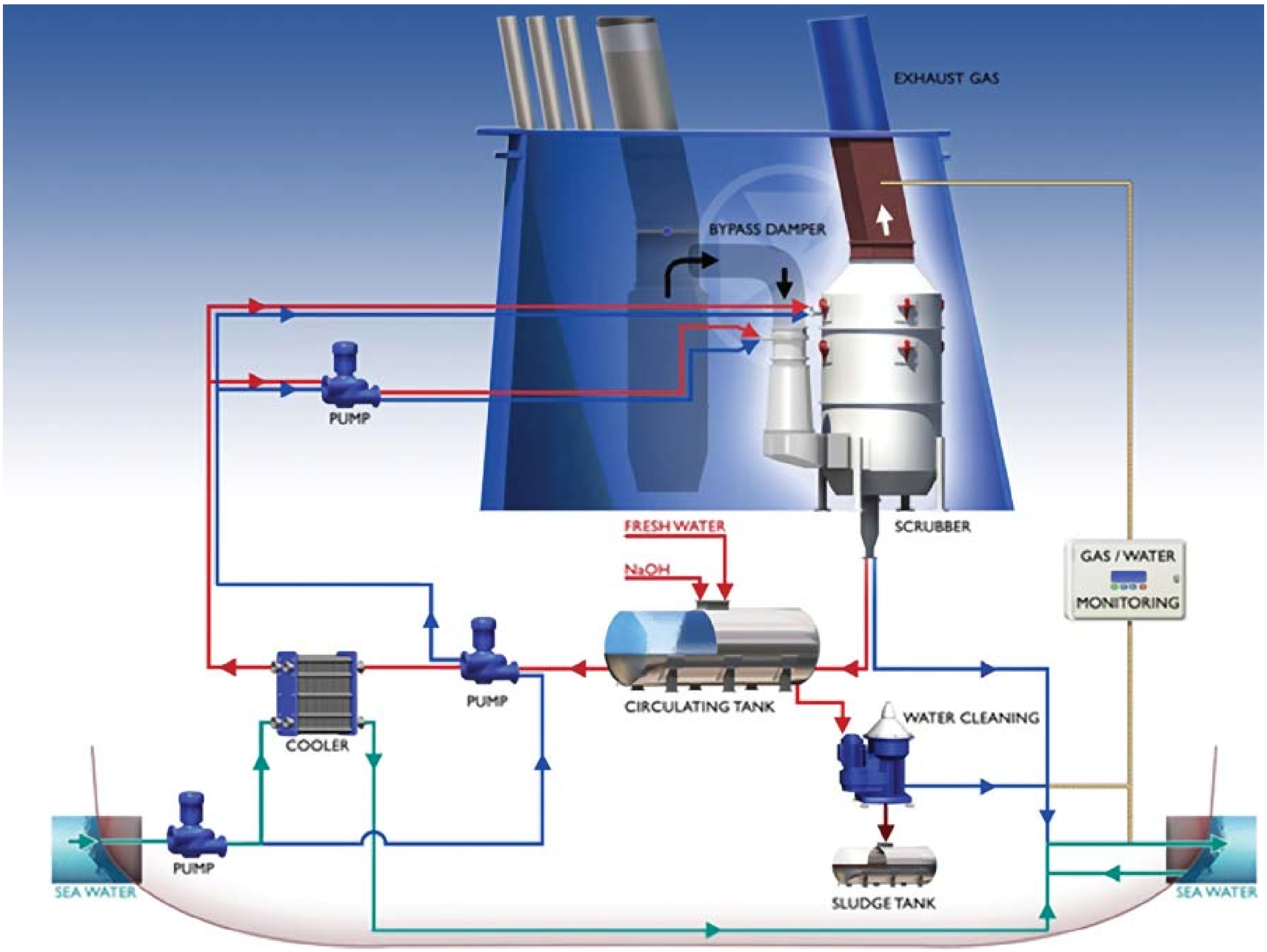
Technical Information for Exhaust Gas Cleaning Systems

Alfa Laval Aalborg

For engine size (MW)	5			25			50		
System	Open loop	Closed loop	Hybrid system	Open loop	Closed loop	Hybrid system	Open loop	Closed loop	Hybrid system
Performance	98% S removal			98% S removal			98% S removal		
Sources	Main engine (ME), auxillary engine (AE) and boiler								
Size of Equipment (length x width x heigth)	3.9 x 2.2 x 6.4 m	3.8 x 2.1 x 6.6 m	3.9 x 2.2 x 6.4 m	8.6 x 5.0 x 11.0 m	8.2 x 4.6 x 10.8 m	8.6 x 5.0 x 11.0 m	12.1 x 7.0 x 14.3 m	11.6 x 6.5 x 14.0 m	12.1 x 7.0 x 14.3 m
Power need	59 kW	31 kW	59 kW/ 31 kW	296 kW	154 kW	296 kW/ 154 kW	593 kW	308 kW	593 kW/ 308 kW
Footprint	The total footprint (including scrubber unit and the related auxiliaries) is estimated on a project.								
Bypassed when scrubber is not in use?	Yes, a bypass has been foreseen in the system.								
Can exhaust pass through scrubber while dry/not cooled?	Exhaust gas is not permitted to pass through the scrubber without washwater.								
Chemicals used (caustic, etc.)	NaOH, 50% aqueous solution. Consumption depends on mode of operation, cleaning rate and alkalinity of ambient water.								
Residuals produced (amount of sludge per kWhr), silt	None (SW)	Caustic (FW)	None (SW)/ Caustic (FW)	None	Caustic (FW)	None (SW)/ Caustic (FW)	None	Caustic (FW)	None (SW)/ Caustic (FW)
Residuals produced (amount of sludge per kWhr), silt	None	1/5,000 l/kWhr	None/ 1/5,000 l/kWhr	None	1/5,000 l/kWhr	None/ 1/5,000 l/kWhr	None	1/5,000 l/kWhr	None/ 1/5,000 l/kWhr
Volume of flow	348 m^3/hr (SW)	156 m^3/ hr (FW)	348 m^3/ hr (SW)/ 160 m^3/ hr (FW)	1,740 m^3/ hr (SW)	780 m^3/ hr (FW)	1,740 m^3/ hr (SW)/ 780 m^3/ hr (FW)	3,483 m^3/hr (SW)	1,560 m^3/ hr (FW)	3,483 m^3/ hr (SW)/ 1,560 m^3/ hr (FW)

Operational Note: PureSOx is a highly effective sulfur-removal system, and it's the first installed and operated as a main engine (21 MW) exhaust gas scrubber. The system promises compliance with the new IMO legislation restricting sulfur emissions, which will begin taking effect in 2015. Sulfur is scrubbed from the vessel's exhaust gas in an open loop with sea water or in a closed loop with fresh water. The ability to switch between these two modes gives PureSOx unique operational flexibility, while its modular construction – which includes options for multiple inlets – ensures a compact and energy-efficient scrubber installation.

Link/Reference: www.alfalaval.com

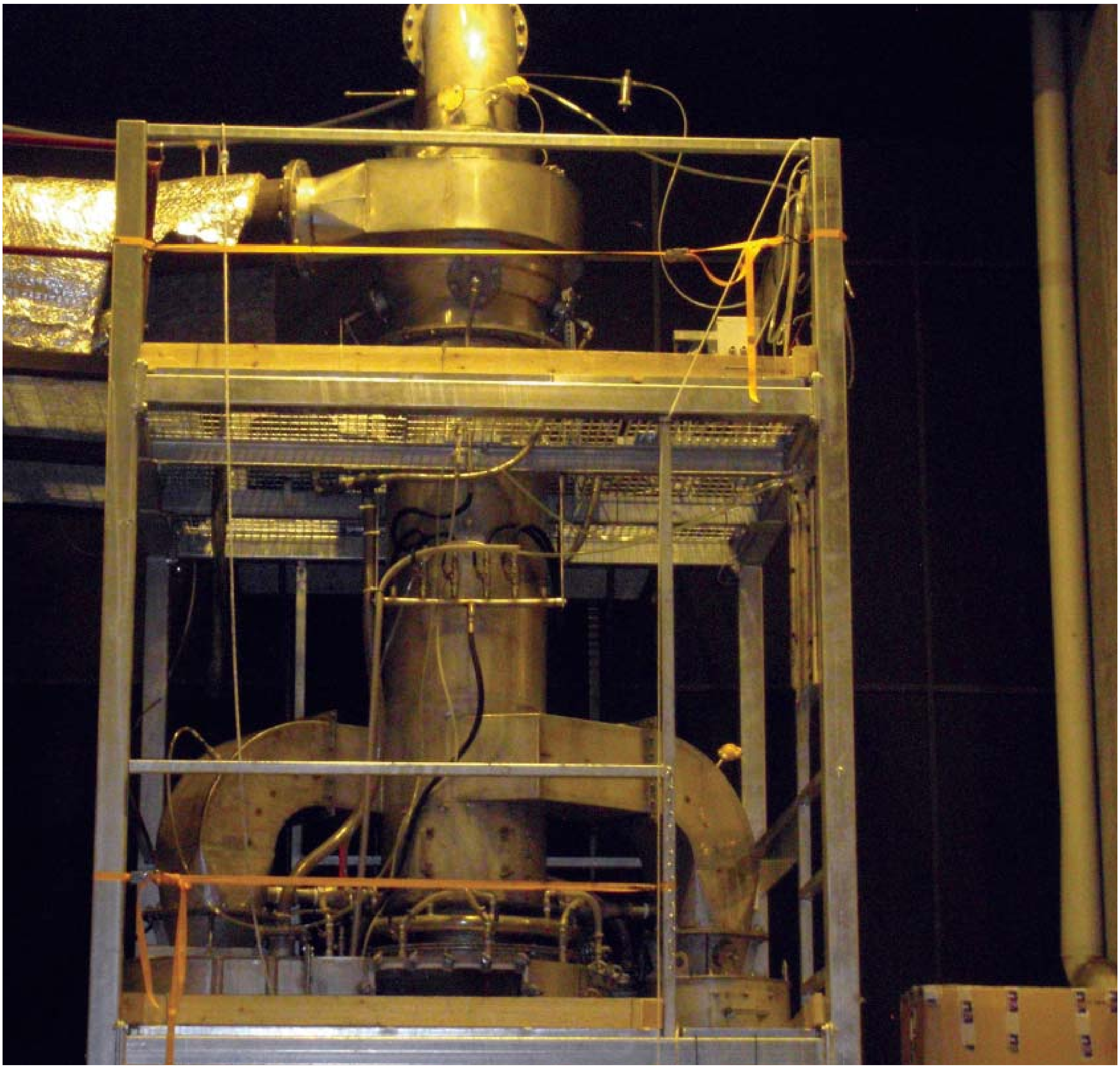


Clean Marine

For engine size (MW)	5	25	50
Performance	Based on 2.5% S reduction to 0.1% S		
Sources	Main engine (ME), auxillary engine (AE) and boiler		
Open loop, closed loop or hybrid system	CM offers an "integrated multi stream" (handling multiple exhaust sources by one EGC unit). EGCS incorporates fans to ensure minimal backpressure in exhaust meeting point. Open and closed loop operation is available as a standard. It is a hybrid system where NaOH (50% solution) is used to boost cleaning efficiency in both closed and open loop mode.		
Size of equipment (dimensions) (HxWxD)	Approx. 10 x 5.5 x 2.5 m, Weight approx. 12 mt	Approx. 19 x 9 x 6.3 m, Weight approx. 35 mt	Approx. 20 x 11 x 8 m Weight approx. 45 mt
Power need (kW)	Approx. 2% of treated power (calculated as maximum practical exhaust production – for instance ME at NCR plus one auxillary engine at 600-1,000 kWh)		
Footprint	5.5 x 2.5 m	9 x 6.3 m	11 x 8 m
Bypassed when scrubber is not in use?	Yes, separate bypass for propulsion and boiler; common bypass for auxilliary engines		
Can exhaust pass through scrubber while dry and not cooled?	Scrubber can sustain hot, dry gas through the system should water fail		
Chemicals used (l/h)	NaOH, 50% aqueous solution. Consumption depends on mode of operation, cleaning rate and alkalinity of ambient water.		
Residuals produced (amount of sludge, kg/kWh)	Approx. 3 kg/mt fuel oil. 0.2 g/kWh for all sizes		
Volume of flow (in circulation, m^3/MWh)	Approx. 40 m^3/MW water consumption for the open loop and about 10 m^3/day per MWh bleed stream in closed loop		

Operational Note: Clean Marine is one of the pioneers within the maritime exhaust gas cleaning system (EGCS) industry. Its sole business is emission cleaning. Since 2004, Clean Marine has focused on developing an EGCS product that can easily be adapted to both newbuildings and existing ships. Recognizing that the IMO sulfur requirement reflects a demand to minimize human exposure to harmful particulate matter, a PM trapping feature, that also removes non-sulfur related PM, has been incorporated into the product. Clean Marine EGCS allows continued operation on HFO with 3.5 percent sulfur content when the ECA requirements are tightened.

Link/Reference: www.cleanmarine.no



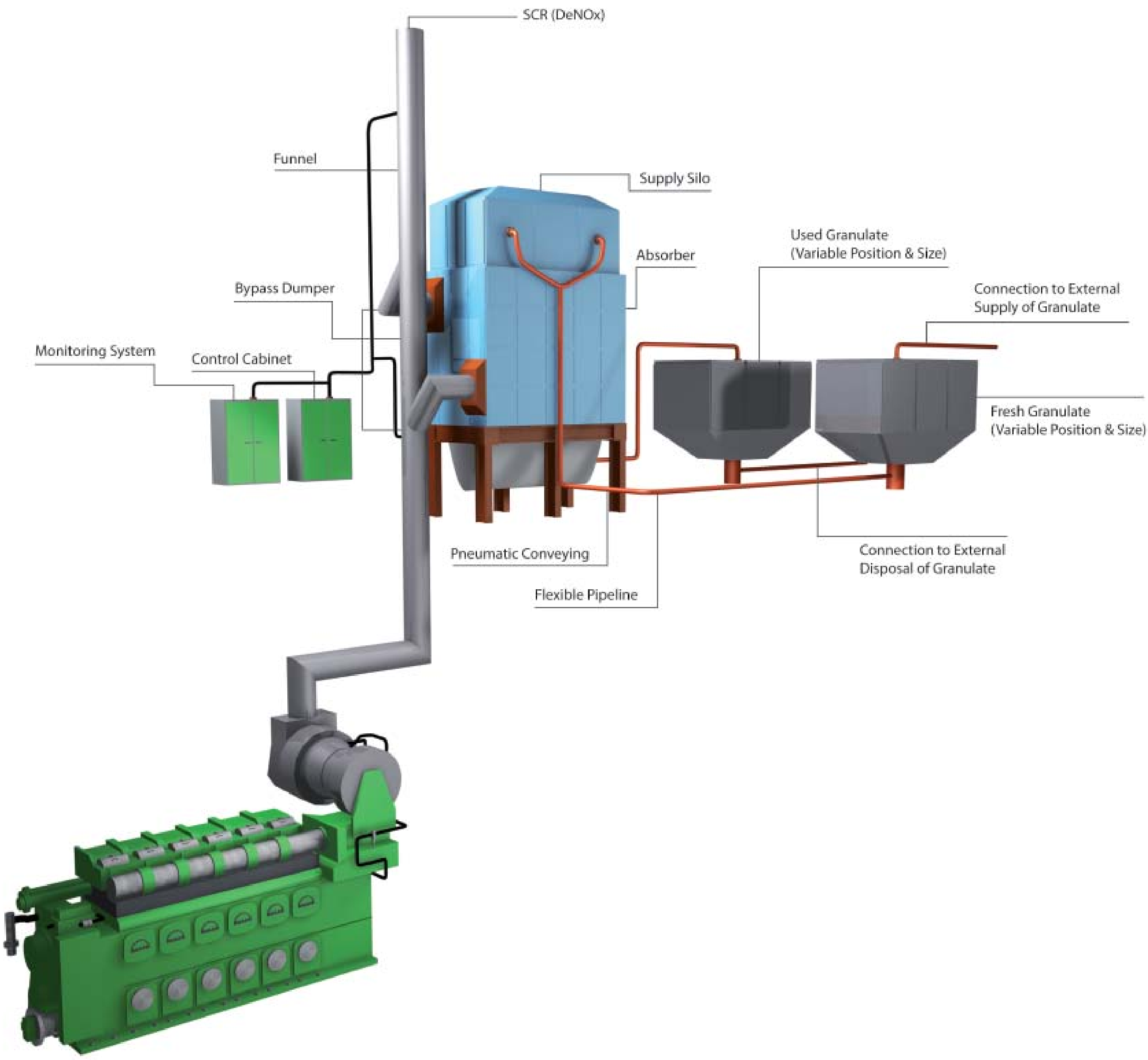
Couple Systems

For engine size (MW)	5	25	50
Performance	99% sulfur reduction + 85% PM		
Sources	Main engine (ME), auxillary engine (AE) and boiler		
Open loop, closed loop or hybrid system	Dry		
Size of equipment (scrubber unit dimensions: diameter x height in mm)	W = 4,680 mm L = 3,300 mm H = 9,350 mm	W = 10,280 mm L = 3,700 mm H = 14,350	2x W = 10,280 mm L = 3,700 mm H = 14,350
Power need (kW)	80 kW	150kW	300kW
Footprint	4,680 mm x 3,300 mm	10,280 mm x 3,700 mm	2 x 10,280 mm x 3,700 mm
Bypassed when scrubber is not in use?	Yes, a bypass is required		
Can exhaust pass through scrubber while dry and not cooled?	Scrubber is a dry system; washwater is not needed.		
Chemicals used (l/h)	Calcium Hydroxide Granulate $Ca(OH_2)$		
Residuals produced (amount of sludge, g/kWh)	36		
Volume of flow (in circulation, m^3/MWh)	NA		

** Total footprint (including scrubber unit and the related auxiliaries) is estimated on a project

Operational Note: The size of the Dry Exhaust Gas Cleaning System (DryEGCS) depends on several conditions including engine load MCR, sulfur content and the partition of power to several engines. The DryEGCS has very low energy consumption and is considered a robust and proven system. Couple Systems indicates that the return on investment can be achieved in less than one year if operating in ECAs. An installation of a small-sized SCR catalyst is possible because there is no loss of temperature. The use of calcium hydroxide granulate is exploitable as there will be no discharge to the sea. The size of the DryEGCS has to be designed in accordance to the GA-Plan of the vessel. For example, it would make sense to install two DryEGCS as a multi-streaming concept on a vessel with 25 MW to make use of the empty space on board the vessel.

Link/Reference: www.couple-systems.com



DuPont BELCO Clean Air Technologies

For engine size (MW)	5	25	50
Performance	97.14% reduction from 3.5% S to 0.1% equivalent	97.14% reduction from 3.5% S to 0.1% equivalent	97.14% reduction from 3.5% S to 0.1% equivalent
Sources	Main engine (ME), auxillary engine (AE) and boiler		
Open loop, closed loop or hybrid system	All three designs available		
Size of equipment (scrubber unit dimensions: diameter x height in mm)	1.8 m x 9.5 m	4.6 m x 10.5 m	6.1 m x 11.5 m
Power need (kW)	108	722	1,444
Footprint (m)	3 x 5	6 x 10	8 x 12
Bypassed when scrubber is not in use?	No bypass required		
Can exhaust pass through scrubber while dry/not cooled?	Can be operated dry at the exhaust gas temperatures		
Chemicals used (l/h)	Seawater/caustic soda		
Residuals produced (amount of sludge, g/kWh)	Minimal		
Volume of flow (in circulation, m^3/MWh)	548	3,269	6,805

Operational Note: DuPont™ Belco Technologies Corporation (BELCO®) is a world leader in air pollution control equipment for the refining industry where reliability and safety are highly regarded. BELCO provides wet scrubbers to this industry where four to five year periods are required between equipment shutdowns, similar to drydockings required by ships. The scrubbing equipment engineered, designed and built by BELCO is used to reduce SOx. BELCO has various technologies available which can also reduce NOx and PM. BELCO has over 250 land-based scrubbing systems for a variety of combustion processes where highly reliable systems are required. The BELCO Marine Scrubbing System can be configured as an open loop using seawater, a closed loop using caustic soda or as a hybrid with the capability of operating in a closed loop or open loop mode. The scrubber can also be operated in a "dry mode" when operating outside of ECA zones.

Link/Reference: www2.dupont.com/sustainable-solutions/en-us/dss/belco-clean-air.html

Wärtsilä

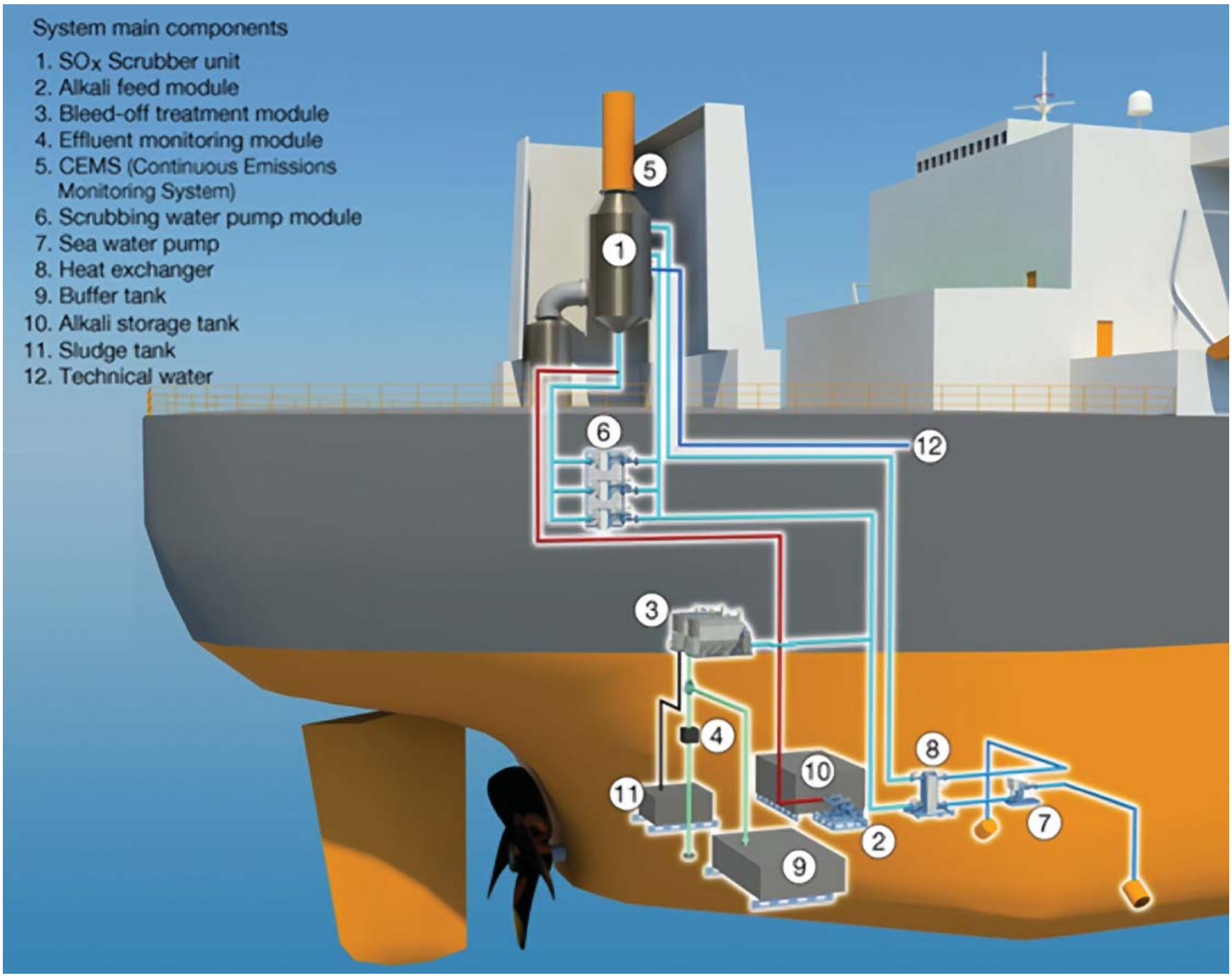
For engine size (MW)	5	25	50
Performance	Values presented are for scrubbing from 3.5% S to < 0.1% S equivalent with 100% engine power		
Sources	Main engine (ME), auxillary engine (AE) and boiler		
Open loop, closed loop or hybrid system	Closed loop	Closed loop	Closed loop
Size of equipment (scrubber unit dimensions: diameter x height in mm)	2,460 x 6,500	5,500 x 10,600	7,920 x 13,900
Power need (kW)	35 - 70*	150 - 390*	290 - 740*
Footprint	**	**	**
Bypassed when scrubber is not in use?	Standard design has bypass with scrubber offline		
Can exhaust pass through scrubber while dry/not cooled?	Dry running is not allowed		
Chemicals used (l/h)	50% caustic 88, fresh water 875, small amounts of water treatment chemicals	50% caustic 438, fresh water 4,375, small amounts of water treatment chemicals	50% caustic 875, fresh water 8,750, small amounts of water treatment chemicals
Residuals produced (amount of sludge, kg/kWh)	0.0004	0.0004	0.0004
Volume of flow (in circulation, m^3/MWh)	25	25	25

* Minimum value is for a main stream scrubber without exhaust gas fans. Maximum value is for an integrated scrubber having exhaust gas fans.

** Total footprint (including scrubber unit and the related auxiliaries) is estimated on a project basis.

Operational Note: When using the Wärtsilä Freshwater Scrubber (FWS) one is always in control of the scrubber efficiency, regardless of the sea water quality. The system can be operated in a "zero-discharge mode" – with no discharge to the sea. Wärtsilä indicates that the impact on vessel stability is lower and the payload is greater as the FWS is smaller and weighs less than comparable competing systems. Reagent flow is also smaller than with a sea water scrubber, which means that water treatment is easier with notably small amounts of discharge into the sea. Other important features are small power demand, low pressure drop, and easier to manage corrosion and scaling issues.

Link/Reference: www.wartsila.com



Wärtsilä Hamworthy Krystallon

For engine size (MW)	5	25	50
Associated scrubber size (MW)	6	25	2x25
Sources	Main engine (ME), auxillary engine (AE) and boiler		
Open loop, closed loop or hybrid system	Open loop and hybrid system		
Size of equipment (scrubber unit dimensions: diameter x height in mm)	2,000 mm x 8,485 mm	4,500 mm x 12,200 mm	2 x 25
Power need (kW)	1.5 - 2% of energy produced by scrubbed equipment		
Footprint (length including 1 inlet section)	3,915 mm	7,520 mm	2 x 25
Bypassed when scrubber is not in use?	Bypass is optional fitting		
Can exhaust pass thru scrubber while dry/not cooled?	System can run dry		
Chemicals used (l/h)	For hybrid systems, caustic soda is required when in closed loop mode		
Residuals produced (amount of sludge, g/kWh)	0.1g/kWhr, silt will depending on the amount in seawater		
Volume of flow (in circulation, m^3/MWh)	45 m^3/MWhr at 3.5% sulfur HFO		

Operational Note: Wärtsilä Hamworthy Krystallon's exhaust gas cleaning system complies with all currently adopted and proposed regulations, removing up to 98 percent of the sulfur and 70 to 90 percent of the particulate matter from exhaust gas emissions. With Hamworthy Krystallon's exhaust gas cleaning system, owners and operators are able to avoid the additional costs of switching, sourcing and using cleaner fuels, allowing continued use of low cost, environmentally friendly residual fuel. The system is designed in a modular way to provide both flexibility and reliable operations. A variety of features can easily be added to account for different operating preferences or requirements.

Link/Reference: www.hamworthy.com

Appendix III

Low Sulfur Fuel Availability

The IMO and EPA requirements for reducing sulfur emissions have been in the process of being aligned for oceangoing vessels. The following table summarizes the low sulfur phase-in dates specified for different areas. The gray highlighted fuel limits indicates 0.5 percent sulfur and less.

Low Sulfur Phase-In Dates

Low Sulfur Fuel		Operating Areas			
Requirements	**Outside ECAs**	**Inside ECAs**	**EU Ports**	**California Coastal**	**US EPA Category 1 and 2 Vessels**
Starting Year 1 January	**% Sulfur in Fuel**	**% Sulfur in Fuel**	**% Sulfur in Fuel**	**% Sulfur in Fuel**	**% Sulfur in Fuel**
2010	4.5	1.0	0.1	1.5 (0.5)*	0.0500 (500 ppm)
2012	3.5	1.0†	0.1	1.0 (0.5)**	0.0015 (15 ppm)
2014	3.5	1.0	0.1	0.1	0.0015 (15 ppm)
2015	3.5	0.1	0.1	0.1	0.0015 (15 ppm)
2020 (2025)††	0.5	0.1	0.1	0.1	0.0015 (15 ppm)

* California allowed 1.5% Marine Gas Oil (DMA) or 0.5% Marine Diesel Oil (DMB)

(Courtesy of The Glosten Associates)

** California allowed 1.0% Marine Gas Oil (DMA) or 0.5% Marine Diesel Oil (DMB) on 1 August 2012

† North American ECA took effect on 1 August 2012

†† Implementation of Ocean Limits at 0.5% Sulfur subject to results of review to be completed in 2018

Notes:

a. For ECA waters under Canadian jurisdiction: Transport Canada (TC) issued Ship Safety Bulletin 03/2012 addressing interim measures with respect to the North American Emission Control Areas (ECA) requirements which became enforceable on 1 August 2012 and other matters. The TC Bulletin advises that until required national regulations are published, if a vessel is found in Canadian waters of the North American ECA after 1 August 2012 to have fuel on board with sulfur content greater than 1 percent, Marine Safety Inspectors may verbally advise the master of the pending air emissions standards and the fact that they will soon be enforceable.

   For ECA waters under US jurisdiction: Reference is to be made to the "Interim Guidance on the Non-Availability of Compliant Fuel Oil for the North American Emission Control Area" dated 26 June 2012. In order to minimize disruptions to commerce and avoid delays, vessels should submit a Fuel Oil Non-Availability Report as soon as it is determined or the vessel becomes aware, that it would be unable to procure and use compliant fuel oil in the North American ECA, but no later than 96 hours prior to entering the North American ECA.

The US EPA has clarified that while it is expected that distillate fuels of various grades to be used as blending agents to produce 1 percent m/m (10,000 ppm) sulfur fuel oil, vessels will not be expected to use a fuel oil with viscosity less than 11 centistokes in order to meet the 1 percent m/m (10,000 ppm) fuel sulfur standard. See http://www.epa.gov/otaq/oceanvessels.htm then select Guidance and Publications. Therefore, consistent with this clarification, prior to January 1, 2015, when the 0.1 percent m/m (1,000 ppm) sulfur standard begins, the EPA will not give consideration to the availability of distillate fuel oil, other than as a blending agent, when an evaluation is made of the circumstances described in the submitted Fuel Oil Non-Availability Report.

b. California Coastal Zone: The state of California requires the use of low sulfur marine distillate fuel while operating within its 24 nautical mile coastal zone, including 24 nautical miles from the shoreline of each of the Channel and Farrallon Islands. California does not specifically allow scrubbers as an alternative to burning low sulfur marine distillate fuels. However, there is a temporary experimental or research exemption that provides for their use during development and testing of scrubber technology. Also, it is the intent of California to sunset the state program once the North American ECA provides equivalent emissions reductions, which is expected when the ECA fuel sulfur limit is lowered to 0.1 percent in 2015."

The introduction of a fuel availability provision under Regulation 18 Fuel Oil Availability and Quality outlines what actions are appropriate should a ship be unable to obtain the fuel necessary to comply with a given requirement under Regulation 14.

Fuel Oil Availability as mandated in Regulation 18 of Annex VI MARPOL 73/78 is as follows:

1.0 Each party shall take all reasonable steps to promote the availability of fuel oils which comply with this Annex and inform the organization of the availability of compliant fuel oils in its ports and terminals.

2.1 If a ship is found by a party not to be in compliance with the standards for compliant fuel oils set forth in this Annex VI, the competent authority of the party is entitled to require the ship to:

.1 Present a record of the actions taken to attempt to achieve compliance; and

.2 Provide evidence that it attempted to purchase compliant fuel oil in accordance with its voyage plan and, if it was not made available where planned, that attempts were made to locate alternative sources for such fuel oil and that despite best efforts to obtain compliant fuel oil, no such fuel oil was made available for purchase.

2.2 The ship should not be required to deviate from its intended voyage or to delay unduly the voyage in order to achieve compliance.

2.3 If a ship provides the information set forth in paragraph 2.1 of this regulation, a party shall take in to account all relevant circumstances and the evidence presented to determine the appropriate action to take including not taking control measures.

2.4 A ship shall notify its Administration and the competent authority of the relevant port of destination when it cannot purchase compliant fuel oil.

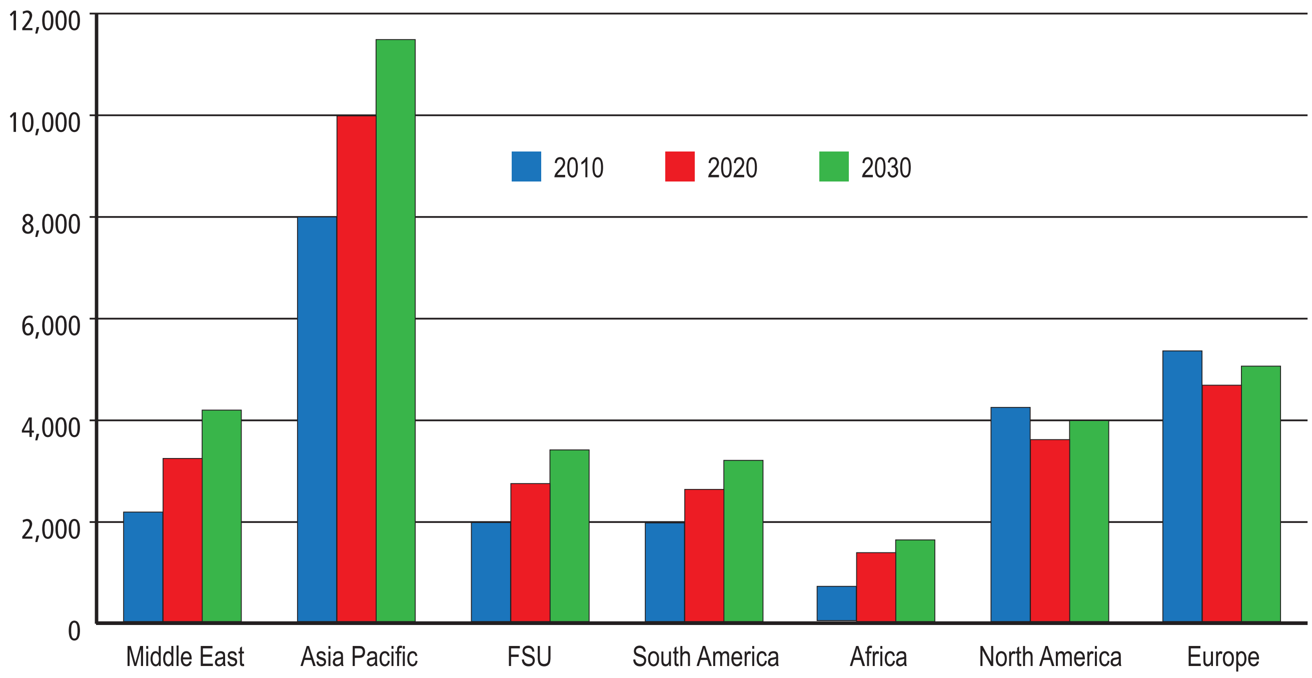
2.5 A party shall notify the organization when a ship has presented evidence of the non-availability of compliant fuel oil.

Projections of Future Supply and Demand of Distillate Fuels

Several organizations worldwide are involved in research and projections on the subject of supply and demand which change on a daily basis. A sample of a projection dated 18 July 2012 by Robin Meech, Marine and Energy Consulting Ltd., relates to distillate fuels on the basis of the present designated ECAs Emission Control Areas. The latest estimates for future demand assuming the global cap of 0.50 percent S fuel is introduced in 2025 is as follows:

- There will be insufficient distillates available to introduce the 0.50 percent S fuel cap in 2020
- There will be sufficient 0.10 percent S fuel to meet the demands from the European (ECA and in ports) and North American ECA between 2015 and 2025 assuming there are no significant new ECA introduced in the decade.

Projections for Regional Demands for Distillates – 1,000 bpd



Global Supply & Demand

Middle Distillates million MT pa	Year								
	2010	2011	2012	2013	2014	2015	2020	2025	2030
Total Consumption	1,141	1,165	1,184	1,205	1,225	1,246	1,357	1,468	1,585
Inland	1,052	1,079	1,095	1,114	1,134	1,125	1,234	1,277	1,357
Bunkers - Lower Sulfur < 0.50%	10	10	15	18	19	50	48	164	221
Bunkers - Higher Sulfur	79	76	74	73	72	71	75	27	7
Total Bunker	89	86	89	91	91	121	123	191	228
Supply	1,125	1,140	1,160	1,179	1,199	1,226	1,336	1,426	1,530

Marine Distillate Fuels: ISO 8217:2010 Marine Fuel Specifications

Parameter	Unit	Limit	DMX	DMA	DMZ	DMB
Viscosity at 40°C	mm^2/s	Max	5.500	6.000	6.000	11.000
Viscosity at 40°C	mm^2/s	Min	1.400	2.000	3.000	2.000
Micro-carbon residue at 10% residue	% m/m	Max	0.30	0.30	0.30	–
Density at 15°C	kg/m^3	Max	–	890.0	890.0	900.0
Micro-carbon residue	% m/m	Max	–	–	–	0.30
Sulfur[A]	% m/m	Max	1.00	1.50	1.50	2.00
Water	% V/V	Max	–	–	–	0.30[B]
Total sediment by hot filtration	% m/m	Max	–	–	–	0.10[B]
Ash	% m/m	Max	0.010	0.010	0.010	0.010
Flash point	0°C	Min	43.0	60.0	60.0	60.0
Pour point, summer	0°C	Max	–	0	0	6
Pour point, winter	°C	Max	–	-6	-6	0
Cloud point	°C	Max	-16	–	–	–
Calculated cetane index		Min	45	40	40	35
Acid number	mgKOH/g	Max	0.5	0.5	0.5	0.5
Oxidation stability	g/m^3	Max	25	25	25	25[C]
Lubricity, corrected wear scar diameter (wsd 1.4 at 60°C[D])	µm	Max	520	520	520	520[C]
Hydrogen sulfide[E]	mg/kg	Max	2.00	2.00	2.00	2.00
Appearance				Clear & Bright[F]		B, C

A A sulfur limit of 1% m/m applies in the Emission Control Areas designated by the IMO. As there may be local variations, the purchaser shall define the maximum sulfur content according to the relevant statutory requirements, notwithstanding the limits given in this table.

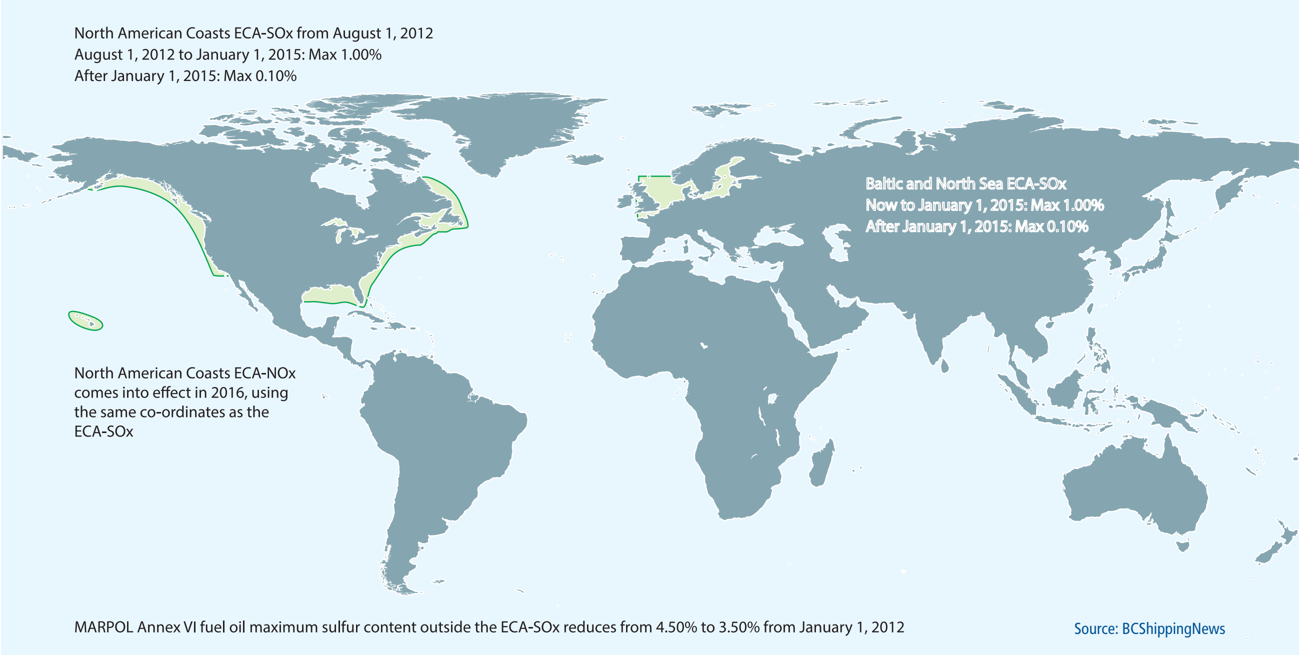
B If the sample is not clear and bright, total sediment by hot filtration and water test shall be required.

C Oxidation stability and lubricity tests are not applicable if the sample is not clear and bright.

D Applicable if sulfur is less than 0.05% m/m.

E Effective only from 1 July 2012.

F If the sample is dyed and not transparent, water testing shall be required. The water content shall not exceed 200 mg/kg (0.02% m/m).

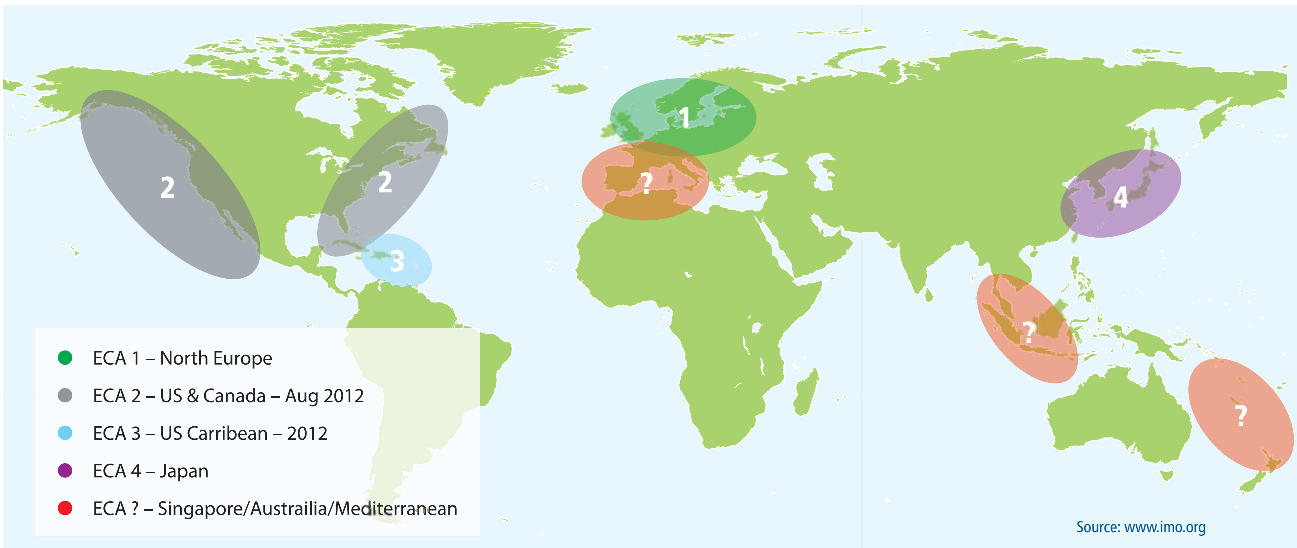


Future Designation of Emission Control Areas

The primary provisions of the revised Annex VI are for a progressive global reduction in emissions of SOx and other products and provides for national governments to individually and/or collectively seek approval for the introduction of ECAs to reduce emissions in designated geographical coastal areas. In the future it is foreseen that more areas are expected to be designated as ECAs. An increase in the designated ECAs would require further research and projections of the availability of distillate fuel.

Shipowners would require their vessels to operate with 0.10 percent maximum sulfur content fuel oil in ECAs on and after 1 January 2015; in addition, on or after 1 January 2020, Regulation 18 of Annex VI MARPOL 73/78 requires all vessels globally to operate with fuel that would have a sulfur content of less than 0.50 percent in areas outside the ECAs. The capability of the world's refineries to match this global market demand and the price of bunker fuel oil at that point in time in 2020 will be difficult to predict.

The IMO requirements for low sulfur fuels could ultimately restrict the use of residual fuel (without the use of sulfur abatement technologies). This, in turn, may cause shortages of distillate fuels over the next 12 to 15 years, as refineries worldwide attempt to meet the market demand while maintaining the specifications associated with the required regulations.



International Chamber of Shipping

The ICS International Chamber of Shipping has drafted a submission MEPC 64/4/17 dated 29 June 2012 for consideration of the IMO at the Marine Environmental protection Committee 64th session.

For the proposal of the need to have a preliminary study on fuel availability and for an appropriate decision to be taken accordingly the following are the issues put forward by the ICS to the IMO for consideration:

1. It is the contention of the ICS that there are compelling reasons for carrying out a preliminary study. This is to ensure that the proposed model is capable of providing reliable data that can be used with confidence by the Committee when considering the timely and efficient implementation of the provisions of Annex VI. It is essential that the assessment model is verified and proven to provide data that leads to accurate and reliable predictions of fuel availability including the effects of regulatory step changes such as the introduction of new ECAs and mandatory changes in fuel specification.

2. At MEPC 62, the ICS proposed a preliminary study of the availability of compliant fuel taking into account the introduction of the Baltic, North Sea and North American ECAs in 2015 would provide a suitable test case. Such a study would provide a projection of possible scenarios resulting from the introduction of the 2015 0.10 percent ECA standard, against the background of the world market. This could then be considered in comparison with the real situation encountered in 2015.

3. Due to the global nature of both the International Oil Industry and International Shipping, such a study would provide valuable insights into the possible impacts of the regulatory requirements on the global availability of compliant fuel oil.

4. This approach would enable validation of the projections for global oil demand along with possible demand for distillate fuels, taking into account the influences related to refining capacity. The knowledge gained would enable any necessary refinement of the model to be carried out in good time prior to the critical assessment of the availability of fuel in 2020 to be completed by 2018.

5. Furthermore, the ICS believes that it is essential to work backwards from the target date for the global 0.5 percent sulfur standard in 2020 for a sufficient period so that refiners have time to invest and react as appropriate. In this regard, it is important to remember that major upgrading projects – such as would be required by the regulation – will take a minimum four to five years to implement. Therefore, the ICS considers that 2018 may be too late to provide the required assessment of fuel availability for a 2020 deadline if preliminary verification and refinement of the model has not taken place.

6. The possibility of conversion of very large volumes of residual fuels to distillates will be a significant undertaking for refiners. Without a reliable indication of requirements that could be provided by an early study it is possible that the required lead times for refinery construction and conversion to provide the necessary availability will not be met. It should be noted that the MARPOL regulation requires the study to be completed by 2018, but does not stipulate the date to commence the fuel availability study.

7. ICS therefore urges that during the period 2012 to 2014 the fuel availability model proposed by the Correspondence Group is be used to carry out a preliminary study to provide fuel availability scenarios for the period 2015 to 2016. This will provide essential information for the validation and refinement of the model prior to the critical review.

Economic Effects of Bunkering Low Sulfur Fuel Oil

Suppliers initially will study the demand of low sulfur fuel oil before committing to its availability. When supplied the distillate fuel may be supplied for a premium. It is expected that once the initial phase is over the premiums would diminish.

A factor to consider is that suppliers may have a minimum quantity requirement for supplying low sulfur fuel oil, the quantity being such which a vessel may not be able to accommodate. It should be expected that each port will have a unique situation prevailing for fuel oil bunkering.

Compliance with ECA Regulations will cause supplier rates to rise. The operators of vessel would need to expect additional time for loading bunkers due to the delivery of two or three products which would entail additional time for hose connections, sampling, sounding tanks, etc.

If blending is required the product would cost more as suppliers would need to consider additional tank storage space to blend and store products as well as segregate piping for receiving and loading barges.

Conclusion

Shipowners are advised to ensure that after considering the latest projections of the status of the availability of the required low sulfur marine fuel oil from recognized sources advance measures are to be taken to bunker adequate low sulfur fuel well in advance of arriving ports where the supply of appropriate low sulfur fuel may not be possible.

List of Acronyms

BC	Black Carbon
BLG	IMO Bulk Liquids and Gases Sub-committee
BOTU	Bleed Off Treatment Unit
CARB	California Air Resources Board
$Ca(OH)_2$	Calcium Hydroxide (Hydrated Lime)
$CaSO_4$	Calcium Sulfate (Gypsum)
CFR	Code of Federal Regulations
CO	Carbon Monoxide
CO_2	Carbon Dioxide
DWT	Deadweight Tonnage
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EEZ	Exclusive Economic Zone
EGCS	Exhaust Gas Cleaning System
EGCSA	Exhaust Gas Cleaning Systems Association
EGE	Exhaust Gas Economizer
EGR	Exhaust Gas Recirculation
EPA	Environmental Protection Agency
ETM-A	EGC Technical Manual Scheme A
ETM-B	EGC Technical Manual Scheme B
EU	European Union
FNU	Formazin Nephlometric Units
FW	Fresh Water
GESAMP	Group of Experts on the Scientific Aspect of Marine Environmental Protection
GNSS	Global Navigational Satellite System
GRE	Glass Reinforced Epoxy
HC	Hydrocarbons
HFO	Heavy Fuel Oil
IGS	Inert Gas System
IAPP	International Air Pollution Prevention
IMO	International Maritime Organization
ISO	International Organization for Standardization
LBP	Length Between Perpendiculars
LCG	Longitudinal Centre Gravity
LNG	Liquefied Natural Gas
LSFO	Low Sulfur Fuel Oil
MARPOL	IMO International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978
MARTECMA	Marine Technical Managers
MCR	Maximum Continuous Rating
MDO	Marine Diesel Oil
MEPC	Marine Environment Protection Committee
MGO	Marine Gas Oil
MSDS	Material Safety Data Sheet
NaOH	Sodium Hydroxide (Caustic Soda)
NOx	Nitrogen Oxides
NTU	Nephlometric Turbidity Units
NTC	NOx Technical Code
NTE	Not to Exceed
OMM	Onboard Monitoring Manual
PAH	Polycyclic Aromatic Hydrocarbons
PM	Particulate Matter
PPM	Parts per Million
PSC	Port State Control
RO	Recognized Organization
SECA	SOx Emission Control Area
SECC	SOx Emission Compliance Certificate
SECP	SOx Emission Compliance Plan
SO_2	Sulfur Dioxide
SO_3	Sulfur Trioxide
SO_4	Sulfate
SOx	Sulfur Oxides
UTC	Universal Coordinated Time
VGP	Vessel General Permit

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