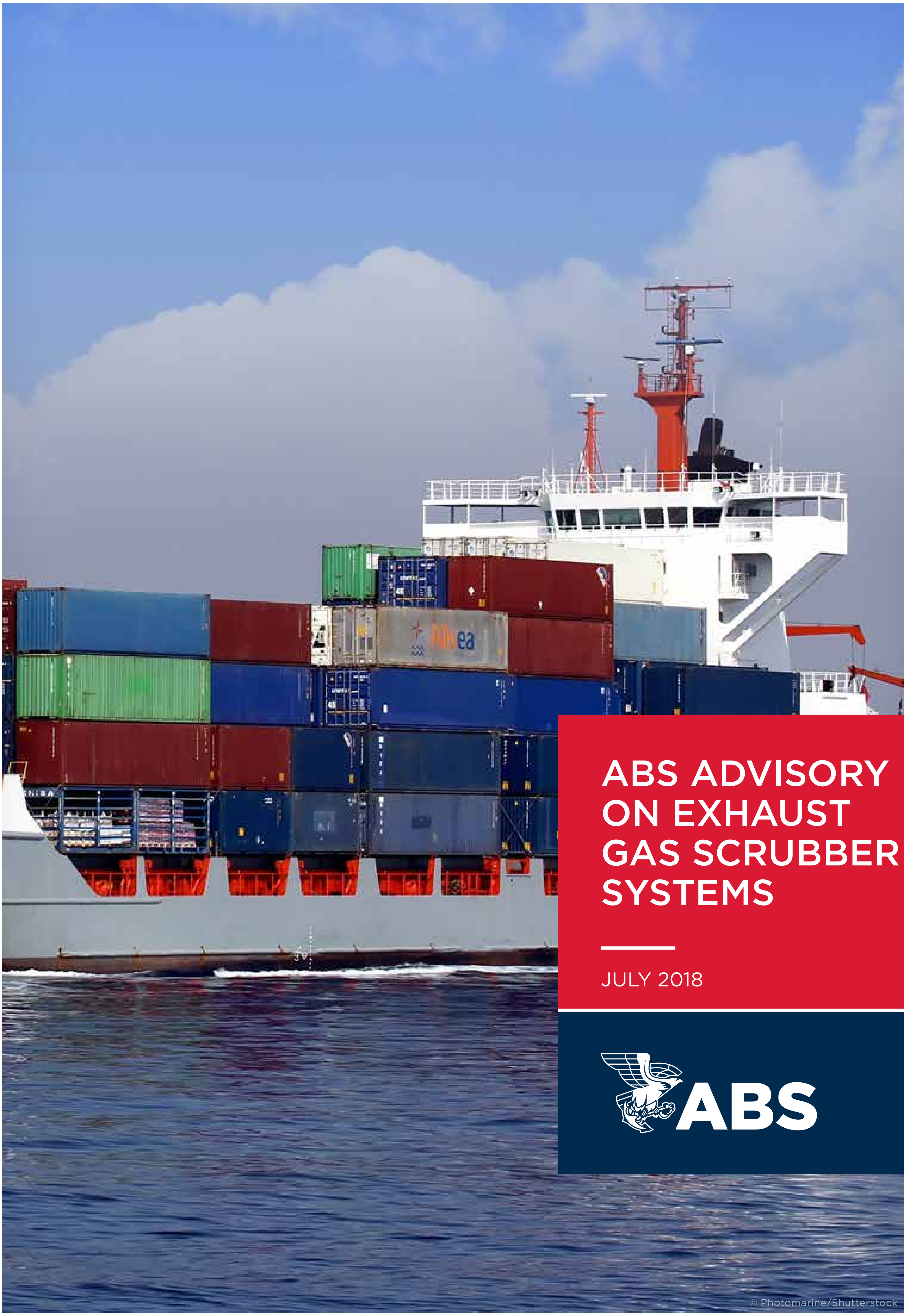

ABS ADVISORY ON EXHAUST GAS SCRUBBER SYSTEMS

JULY 2018

ABS

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INTRODUCTION

The marine industry faces the challenge of adopting new technologies and operational practices to comply with stricter international, regional, national and local regulations to reduce exhaust emissions from ships. The adverse effects of exhaust emissions from internal combustion engines and boiler exhaust gases on humans and sensitive ecosystems are well documented. The objective of exhaust emissions regulations introduced by various organizations including the International Maritime Organization (IMO), the European Union (EU), the U.S. Environmental Protection Agency (EPA), the People's Republic of China (PRC), the Government of the Hong Kong Special Administrative region of the PRC and the California Air Resources Board (CARB) is the reduction of the impact shipping has on global and local air quality.

Critical amongst these regulations are the measures to reduce sulfur oxide (SOx) emissions inherent to the relatively high sulfur content of traditional marine fuels. Ship designers, owners and operators have a number of different routes to achieve SOx regulatory compliance including

- Use of low-sulfur marine fuels in existing machinery
- Installation of new machinery (or conversion of existing machinery where possible) designed to operate on a low- sulfur alternative fuel, such as liquefied natural gas (LNG)
- Installation of an Exhaust Gas Cleaning System (EGCS) as an after treatment device

This Advisory, which was first published in 2013, summarizes the regulatory requirements applicable to SOx EGCS, often referred to as scrubbers, and to provide an overview of available technologies, as well as highlight some of the selection, installation and operational issues that need to be considered when selecting EGCS as a means of compliance with current and future exhaust gas emission regulations. The current edition adds Appendix I to address the retrofitting of existing ships with EGCS, along with updates to the section on Regional and Local 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. However, the use of EGCS technology is generally permitted as an effective alternative means for compliance with regulations that require the use of 0.1 percent and 0.5 percent sulfur fuel.

In addition to meeting SOx emission requirements, vessels built after 1 January 2016, if operated within the North American and US Caribbean ECAs, or vessels built after 1 January 2021 and operated within North Sea and Baltic Sea ECAs, will need to meet NOx Tier III requirements. Compatibility of options for SOx emission compliance and technologies (e.g., EGR/SCR) for NOx Tier III compliance need to be evaluated carefully. Please refer to the Frequently Asked Questions section of this Advisory for details about SOx scrubber compatibility with Selective Catalytic Reduction (SCR) systems or Exhaust Gas Recirculation (EGR) systems.

While scrubbers offer the potential for lower operating costs by permitting the use of less expensive high-sulfur fuels, capital costs, installation cost and operational costs associated with scrubbers must be considered on a vessel-specific basis. These costs should be assessed against the alternatives of operating a ship on low-sulfur fuel or an alternative low-sulfur fuel, such as LNG. Fuel switching, an operational practice in which higher sulfur fuel is used where permitted and lower sulfur fuel is used where mandated, has its own complications and risks, but should also be considered during an evaluation of fuel compliance options. The *ABS Marine Fuel Oil Advisory*, 2018 offers guidance for fuel switching operations.

The operating profile of the ship will often dictate which compliance option offers the best capital expenditure versus operational benefit. The total cost of ownership for that particular ship should be determined to help reach the best decision. It is the intent of this Advisory to highlight the relevant regulatory and technical issues to assist shipowners and operators in making an informed decision when selecting SOx EGCS technologies as a means to meet SOx emission regulations.

REGULATORY BACKGROUND AND REQUIREMENTS

IMO REGULATIONS

The Marine Environment Protection Committee (MEPC) of IMO adopted the 1997 Protocol to the MARPOL Convention which added Annex VI, Regulations for the Prevention of Air Pollution from Ships. This Annex entered into force on May 19, 2005. To reduce the harmful effects of SOx emissions on human health and the environment, Regulation 14 to Annex VI introduced a worldwide limit on the sulfur content of 4.5 percent to marine fuels and a limit of 1.5 percent in designated SOx emission control areas (SECA). The Baltic Sea was the inaugural SECA adopted under the Annex and was followed by the North Sea/English Channel SECA (see Figure 1) on November 22, 2007.

Figure 1: Baltic and North Sea/English Channel SECA

In October 2008 the 58th IMO MEPC session adopted significant changes to Annex VI under Resolution MEPC.176 (58). A global sulfur fuel limit of 3.5 percent became effective January 1, 2012, and introduced further reductions in the fuel sulfur limits within SECAs, with a limit of 1.0 percent applicable from July 1, 2010, and 0.1 percent from January 1, 2015. In the 70th MEPC session, held in October 2016, member states agreed that a 0.5 percent global sulfur cap on marine fuel would be implemented in 2020 based on the studies that identified the availability of compliant fuel (0.5%S). See Table 1 for IMO fuel oil sulfur limits.

Table 1: IMO Fuel Oil Sulfur Limits

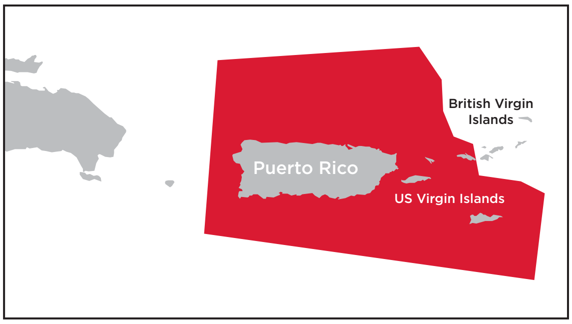
IMO Global		SECA/ECA	
Date	**Sulfur %**	**Date**	**Sulfur %**
Initial limits	4.5	Initial limits	1.5
Jan 1, 2012	3.5	Jul 1, 2010	1.0
Jan 1, 2020	0.5	Jan 1, 2015	0.1

The revised Annex VI included a change 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. Currently IMO does not define PM limits, 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 EGCS.

IMO Resolution MEPC.190 (60) and IMO Resolution MEPC.202 (62) added two new ECAs, the North American ECA (see Figure 2) and the U.S. Caribbean waters, including Puerto Rico and the U.S. Virgin Islands ECA (see Figure 3).

Figure 2: North American ECA

Figure 3: U.S. Caribbean Waters ECA



REGIONAL AND LOCAL REGULATIONS

EUROPEAN UNION

In addition to the global and local controls implemented through the IMO MARPOL Annex VI Regulations, further regional requirements for the use of low-sulfur fuel are in effect. The EU Sulfur Directive 1999/32/EC, as amended by Directives 2005/33/EC and 2009/30/EC, mandated for all ships the use fuel with a maximum sulfur content of 0.10 percent m/m when 'at berth' (including at anchor) in EU ports. This requirement became effective January 1, 2010.

The Sulfur Directive was further amended by Directive 2012/33/EU to align with the revised IMO regulations and included the reduction of the sulfur limit to 0.5 percent for operation in EU waters (outside SECAs) beginning January 1, 2020. The EU has issued Directive (EU) 2016/802 which codifies the original 1999 Directive and subsequent amendments into a single regulation.

The Sulfur Directive also permits trials of emission abatement technology for a period of 18 months or the fitting of EGCS meeting the requirements of the IMO guidelines by providing emission reductions equivalent to the use of low-sulfur fuels and equipped with continuous emission monitoring equipment.

The EU Marine Equipment Directive (MED) 96/98/EC, as amended and replaced by 2014/90/EU, has identified onboard EGCS under Annex A.1/2.10 (now MED/2.10 as per Commission Implementing Regulation (EU) 2017/306) as equipment that requires Type Approval certification in accordance with the MED. Therefore, SOx EGCS installed on EU flagged vessels are to be certified to the MED, typically Module G, in addition to the statutory MARPOL certification. The MED refers to the relevant IMO EGCS guidelines (currently MEPC.259(68)) as the applicable technical standard.

The EU has established a number of expert groups under the European Sustainable Shipping Forum (ESSF) to facilitate the implementation of the Sulfur Directive and particularly, the application of alternative technologies such as EGCS. The EGCS sub-group has a mandate to look at all areas hampering the implementation of EGCS technologies and has been instrumental in developing submissions to IMO to revise existing regulations and guidelines for the purpose of providing harmonized application of the requirements. As part of the efforts the ESSF has encouraged the EU Member States to publish their policy on the discharge of washwater from EGCS units within their territorial waters.

EU Water Framework Directive (WFD) puts an obligation for compliance with water quality standards on the Member States. Many Member States have passed this responsibility down to local ports and areas. Washwater discharge acceptability refer to Agenda item 6c of ESSF of 26 January 2016. As of date of publication, the following EU member states prohibit discharge of washwater from SOx scrubber system:

- **Germany:** inland waters rivers and certain ports such as Kiel Canal
- **Belgium:** within three nautical miles of its coast
- **Lithuania:** port water area
- **Latvia:** territorial waters and ports

It is advisable to contact the intended ports for any potential adoption of additional requirements or change of their current position if the vessel intends to call at those ports.

UNITED STATES

The U.S. has adopted MARPOL Annex VI through Title 40 of the Code of Federal Regulations (CFR) Part 1043, Control of NOx, SOx and PM Emissions from Marine Engines, which is applicable to all U.S. flagged vessels wherever they operate plus foreign flagged vessels while operating in U.S. navigable waters and the U.S. Exclusive Economic Zone (EEZ). The use of EGCS technology is permitted; however, additional requirements or prohibitions by other statutes or regulations, mainly with respect to water pollution, apply.

The U.S. EPA Vessel General Permit (VGP) is a separate regulation required for operation 3 nautical miles from US shores. The requirements are broadly aligned with IMO. The notable differences are on pH discharge and the recording, monitoring and reporting obligations. The pH of the washwater discharged from the scrubbing process is to be no less than 6.0 measured at the ship's overboard discharge and no other methodology of pH determination would be acceptable. For more detailed and specific requirements, including reporting procedures, reference may be made to the specific sections of the VGP 2013, such as 2.2.26 Exhaust Gas Scrubber Washwater Discharge and other associated sections.

Beyond the 3 nautical mile range, the U.S. Coast Guard may consider on a case-by-case basis the alternate calculation-based methodology and/or computational fluid dynamics or other established empirical formulae for verification of washwater discharge criteria for the pH of exhaust gas cleaning systems, which is in accordance with Section 10.1.2.1.2 of the 2015 IMO Guidelines.

For the discharge of washwater from EGCS in the US waters (3 nautical miles from shore), the vessel needs to obtain Authorization to discharge under EPA 2013 VGP. The application starts with the submission of Notices of Intent (NOIs), using EPA's Electronic Notice of Intent (eNOI) system at https://www.epa.gov/npdes/electronic-notice-intent-enoi. Refer to 1.5.1.1 of 2013 VGP. Appendix E of the VGP provides the detailed requirements regarding the deadline and information to be included.

As per Section 6 of EPA 2013 VGP, the following States impose additional discharge restrictions:

Connecticut: Discharge of exhaust gas scrubber washwater into Connecticut waters from any vessel covered under the VGP is prohibited as per 2013 6.5.9 of VGP.

Hawaii: Reporting of specific information regarding the onboard treatment system is to be in accordance with 6.7.1 of the 2013 VGP

Due to the above EPA requirements, an EGCS that meets the IMO requirements on washwater discharge will not necessarily meet the VGP requirements.

Additionally, the sulfur content of fuels available for use in locomotives, ships and non-road equipment in the U.S. is determined by the EPA Non-road Diesel Equipment Regulatory Program. This program is aimed at regulating the supply of available fuels, with an eventual goal to reduce the sulfur level to meet an ultra-low sulfur diesel (ULSD) limit of 15 ppm (0.0015 percent), enabling the implementation of advanced emission control strategies.

Currently, the EPA diesel fuel program restricts the production and sale of 1,000 ppm (0.1 percent) sulfur marine fuel oil for use on vessels with Category 3 engines. The EPA emissions requirements are complex; a complete explanation of its applicability is outside the scope of this Advisory, but it is important 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.

In addition to Federal regulations, vessels must also comply with State regulations; individual U.S. States have set additional air emission limits. For example, California's Fuel Sulfur and Other Operation Requirements for Ocean-Going Vessels within California Waters and 24 Nautical Miles of the California Baseline (or, the Ocean Going Vessel (OGV) Fuel Regulation) has been enforced since July 2009 and was designed to provide significant air quality benefits by requiring ships to use cleaner, low-sulfur marine distillate fuel in ship main engines, auxiliary engines and auxiliary boilers. The OGV Fuel Regulation does not apply to propulsion boilers.

Amendments were made to align California's OGV Fuel Regulation requirements with the North American ECA, including the addition of the 1.0 percent sulfur limit effective August 1, 2012. The original regulation required the use of 0.1 percent sulfur distillate fuel, beginning January 1, 2012, but was amended on June 23, 2011, extending the effective date for Phase II by two years, to January 1, 2014 (see Table 2 where DMA and DMB are marine distillate fuel designations). The California Air Resource Board (CARB) regulations do not allow the use of any fuel other than 0.1 percent sulfur distillate fuel for compliance in Regulated California Waters.

SOx scrubbers are not allowed under the OGV fuel rule as an equivalency to 0.1% sulfur distillate fuel. There is an exemption provided for research projects in accordance with Marine Notice 2017-1. This exemption is very limited, allowing for the temporary use of noncompliant fuel (e.g. high sulfur heavy fuel oil) when necessary for a research project. For example, a research project could involve the emissions testing of a new scrubber design with high sulfur fuel. In this example, the use of the scrubber with high sulfur fuel would only be allowed for the duration needed to conduct the emissions testing. After that, the vessel would again need to use 0.1 percent sulfur distillate fuel (even if the scrubber performed well). Also note the research would need to use rigorous emissions testing protocols, and there would need to be a research report provided to ARB that is also made available to the public.

Vessel operators need to apply at least 30 days before the vessel enters Regulated California Waters, and receive approval in advance for the project in the form of an Executive Order. During the exemption period, the vessel operator must submit annual progress reports detailing any vessel modifications and interim test data or results to the Executive Officer. At the conclusion of the project, all official test data and other results must be provided in final form to the Executive Officer within 90 days of the expiration of the exemption period. The application procedure and required information can be found in Marine Notice 2017-1 https://www.arb.ca.gov/ports/marinevess/documents/marinenote2017_1.pdf

Table 2: CARB Fuel Requirements for Ocean-Going Vessels (OGV)

Fuel Requirement	Effective Date	ARB's California OGV Fuel Requirement Sulfur Content Limit
Phase I	January 1, 2000	Marine gas oil (DMA) at or below 1.5% sulfur; or Marine diesel oil (DMB) at or below 0.50% sulfur
	August 1, 2012	Marine gas oil (DMA) at or below 1.0% sulfur; or Marine diesel oil (DMB) at or below 0.50% sulfur
Phase II	January 1, 2014	Marine gas oil (DMA) at or below 0.10% sulfur; or Marine diesel oil (DMB) at or below 0.10% sulfur

THE PEOPLE'S REPUBLIC OF CHINA

China has also developed local air emissions regulations, the Marine Emission Control Area Plan, applicable to the Pearl River Delta, Yangtze River Delta and Bohai Rim Area (see Figure 4) under the "The People's Republic of China Air Pollution Prevention Law". The regulations apply to ships navigating, at berth and operating within the ECAs that extend up to 12 nautical miles from the coastlines. The special administrative regions, Hong Kong and Macau, are excluded from this Plan. Military vessels, sports boats and fishing vessels are exempt from this regulation.

Figure 4: Chinese ECA

The regulation applies a phased date approach that is initially focused on application of international requirements and controlling emissions from ships at berth in core ports for more than two hours. The requirement will extend and progress as follows:

1. Beginning January 1, 2018, ships at berth in all ports within the ECA should use fuel with ≤0.5 percent sulfur content.
2. Starting January 1, 2019, ships operating within the ECA should use fuel with ≤0.5 percent sulfur content.
3. Before December 31, 2019, an assessment of the effectiveness is to be made for the above-mentioned measures, and a decision made whether or not to impose the following actions:
    a. Ships operating within the ECA mandated to use fuel with ≤0.1 percent sulfur content
    b. Expand the ECA
    c. Other further action
4. Ships can use shore power connection, clean energy, exhaust after-treatment or take alternative equivalent measures for emission control.

HONG KONG SPECIAL ADMINISTRATIVE REGION OF THE PRC

As of July 1, 2015, the Air Pollution Control (Ocean Going Vessels) (Fuel at Berth) Regulation, mandatorily requires ocean-going vessels to use compliant fuels while berthing in Hong Kong. Compliant fuels, defined by the regulation, are marine fuels with a sulfur content of ≤0.5 percent, liquefied natural gas and any other fuels approved by the air pollution control authority.

The new Regulation requires vessels to:

- Switch to compliant fuel within one hour of arriving at their berth and burn only compliant fuel until one hour prior to departure
- Record the dates and times of the vessel's arrival, departure and of commencement and completion of fuel change-over operations as soon as practicable after each occurrence
- Keep records onboard the vessel for a period of at least three years, readily available for inspection at all reasonable times

Approved technologies such as SOx scrubbers may be used subject to their ability to achieve a reduction of sulfur dioxide, which could be considered at least as effective as the use of low-sulfur marine fuel. Ocean going vessels installed with such approved technologies may be exempt from switching to one of the compliant fuels. Written applications for exemptions on the basis of the use of approved technologies must be made to the authorities at least 14 days before the date on which the vessel intends to make its first exempted call at Hong Kong.

Additional information may be obtained from "Air Pollution Control (Ocean Going Vessels) (Fuel at Berth) Regulation" Chapter 311AA, gazette Number E.R. 2 of 2015.

AUSTRALIA

Effective on 1 July 2016, all cruise ships are required to use low sulfur marine fuel (fuel with a sulfur content of 0.1 percent or less by weight) at all times while within Sydney Harbor. Cruise ships will be required to switch to low sulfur fuel before entering Sydney Harbor as per the document EPA 2015/0695; October 2015 issued by New South Wales EPA.

The master or owner of a cruise ship can apply to the EPA for approval to use alternative methods that will achieve sulfur oxide and fine particle emissions that are equal to or below the levels that would have been achieved if the ship used low sulfur fuel.

Information on the application process can be obtained from the EPA's website. Cruise ships must continue to use low sulfur fuel until any approval has been granted. Approvals may be subject to conditions that must be complied with for the approval to remain valid.

TAIWAN

Starting from 1st, January 2019, foreign flag ships and Taiwan flag ships sailing in international routes are required to use low sulfur fuel oil (sulfur content less than 0.5% by weight), or equipment or alternative fuels that achieve the equivalent effect of emission reduction when entering ports and offshore terminals under the jurisdiction of the Republic of China.

IMO EXHAUST GAS CLEANING SYSTEM (EGCS) GUIDELINES

The IMO Guidelines are based on wet scrubbing technologies and therefore are not applicable to other abatement techniques.

The development of EGCS for use onboard ships has been driven by the aforementioned IMO, national, and local regulations. These EGCS were envisaged by the original Regulation 14.4 (b) to MARPOL Annex VI, whereby SOx emissions were limited to 6.0g/kWh for systems that met the requirements in the subsequently developed guidelines of IMO Resolutions MEPC.130 (53), MEPC.170 (57), MEPC.184 (59) 2009 and MEPC.259 (68) 2015 Guidelines for Exhaust Gas Cleaning Systems (adopted on May 15, 2015, and hereafter referred to as the '2015 Guidelines'). These 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 MARPOL Annex VI removed the specific reference to EGCS from Regulation 14, and approval of an EGCS is now undertaken in accordance with the requirements under Regulation 4 of the Annex as an 'equivalent'. Flag Administrations must take into account any relevant guidelines developed by IMO when assessing the equipment and notify IMO (for circulation to all Administration parties) of the details of that assessment. It is important to note that the 2015 Guidelines are not regulations. However, it is understood that EGCS installations meeting these guidelines will be accepted as equivalent by the Administrations. This equivalence needs to be confirmed by the flag Administration of each vessel onto which the equipment is to be installed on a case-by-case basis.

The 2015 Guidelines identify the method of determination of the pH value from the discharge washwater. The pH can be determined either by direct measurement or by using a calculation-based methodology (computational fluid dynamics or other equally scientifically established empirical formulae) to be left to the approval by the Administration.

Among other sections, the following provisions were retained:

The recommendation to IMO Administrations to collect data on washwater discharges in accordance with Appendix 3 of the 2015 Guidelines enables this criterion to be subsequently reviewed by the IMO, taking into account any advice from the Joint Group of Experts on the Scientific Aspects of Marine Environmental Pollution (GESAMP).

Provision of two basic Schemes for compliance to be used for EGCS 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 guidelines by, or on behalf of, a flag Administration, typically by a class society recognized by the Administration (as a Recognized Organization or RO). Refer to EGCS Approval for the approval process

The two EGCS schemes apply the following concepts:

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

In both cases, the condition of discharged washwater used in the scrubbing process is to be monitored and recorded.

SCHEME A

For Scheme A approvals, the EGCS 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 rates. Mechanisms are in place 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 onboard and is approved by the issue of a serial number-based SOx Emissions Compliance Certificate (SECC) on behalf of the vessel's flag Administration. The basis of the approval and the EGCS operating and maintenance parameters, together with survey procedures, are to be contained within the EGCS - Technical Manual for Scheme A (ETM-A), which is also to be approved by the Administration, or RO acting on its behalf.

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

The shipowner is required to maintain an EGCS Record Book, in which the maintenance and service of the EGCS is to be recorded and made available for inspection at EGCS 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

The Scheme B EGCS does not require pre-certification to meet 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 MARPOL Annex VI Regulation 14 at any load point, including during transient operation, by verification of the SO_2/CO_2 ratio after the scrubber is in accordance with Table 3. This must be undertaken on a continual basis by the use of a continuous exhaust gas monitoring system that is approved by the Administration, and which records data at a rate not less than 0.0035 Hz.

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

REQUIRED EGCS DOCUMENTATION

For ships intending to use an EGCS in part or in full to comply with Regulation 14 of MARPOL Annex VI, a SOx Emissions Compliance Plan (SECP) must be approved on behalf of the Administration and is required 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 EGCS.

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

- Data on the sensors used in the EGCS emissions and washwater monitoring system, including service, maintenance and calibration
- 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 EGCS documentation that needs to be on board a ship utilizing EGCS under Scheme A or B of the 2015 Guidelines.

Table 3: EGCS 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
1.0	43.3
0.5	21.7
0.1	4.3

Table 4: List of Required EGCS Documentation

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

EMISSIONS MONITORING

For EGCS 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 2015 IMO 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 where fuel of a maximum of 0.1 percent sulfur is 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 in Appendix 2 of the 2015 IMO Guidelines and demonstrates the correspondence between the 6.0g/kWh prescribed by the original MARPOL Annex VI requirements based on a brake-specific fuel consumption of 200g/kWh.

For those scrubbers where 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 2015 IMO Guidelines specify the discharge washwater quality criteria and monitoring requirements for a number of parameters. Additional washwater limitations may be set by regional, federal or state regulations. Shipowners and vessel managers are encouraged to verify the requirements for each of the intended ports in a vessel's voyage.

PH CRITERIA

The 2015 IMO Guidelines require a limit of pH 6.5 using one of the following two methods:

The pH of the washwater discharged from the scrubbing process at the overboard discharge should be no lower than 6.5 except during maneuvering or transit where the pH difference between the ship's inlet and overboard discharge can be up to 2 pH units measured at the ship's inlet and overboard discharge.

The overboard pH discharge limit applicable to the overboard discharge monitoring position can be determined either by means of direct measurement or by using a calculation- based methodology (computational fluid dynamics or other equally scientifically established empirical formulae) subject to the approval of the Administration to achieve with the ship stationary a pH of 6.5 at a distance of 4 m from the overboard discharge point, and in accordance with the following conditions to be recorded in the ETM-A or ETM-B:

1. EGC units connected to the same outlets and operating at their full loads, (or highest practicable load) and with the fuel oil of a maximum sulfur content for which the units are to be certified (Scheme A), or used with (Scheme B)
2. If a lower sulfur content test fuel and/or test load lower than maximum sufficient for demonstrating the behavior of the washwater plume is used, the plume's mixing ratio must be established based on the titration curve of seawater. The mixing ratio would be used to demonstrate the behavior of the washwater plume and that the overboard pH discharge limit has been met if the EGCS is operated at the highest fuel sulfur content and load for which the EGCS is certified (Scheme A) or used with (Scheme B)
3. Where the washwater flow rate is varied in accordance with the EGCS gas flow rate, the implications of this for the part load performance should also be evaluated to confirm that the overboard pH discharge limit is met under any load
4. Reference should be made to a seawater alkalinity of 2,200 mol/litre and pH 8.2; an amended titration curve should be applied where the testing conditions differ from the reference seawater, as agreed by the Administration
5. If a calculation-based methodology is to be used, details to allow its verification such as, but not limited to, supporting scientific formulae, discharge point specification, washwater discharge flow rates, designed pH values (at both the discharge and 4 m location), titration, and dilution data should be submitted

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 Guidelines.

The washwater discharge may be diluted by mixing with other sources of seawater, such as cooling water discharges, to achieve the required pH level. Furthermore, the pH at the washwater discharge may be adjusted by controlling the flow of reactive water to the EGC unit. For those EGC units using chemicals or additives to meet the pH, or any other washwater criteria, the washwater is required to be further assessed for those agents, taking into account IMO guidance for ballast water management systems that make use of active substances (G9 under MEPC.169 (57)).

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 50 g/L PAHphe (phenanthrene equivalence) above the inlet water PAH concentration. The PAH concentration should be measured downstream of the water treatment equipment (i.e. after any water treatment equipment), but upstream of any washwater dilution or other reactant dosing unit, if used, prior to discharge. This limit value is applicable to EGCS washwater flow rates normalized to 45t/MWh, where MW refers to the maximum continuous rating (MCR) or 80 percent of the power rating of the fuel oil combustion unit. This limit may be adjusted up or down in accordance with Table 5 for different flow rates.

Table 5: PAH Discharge Concentration Limits

Flow Rate (t/MWh)	Discharge Concentration limit (µg/L PAHphe 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

* For any flow rate greater than 2.5 t/MWh fluorescence technology should be used.

The 2015 IMO Guidelines permit a 15-minute deviation of up to 100 percent of this limit value, in any 12-hour period, to account for EGCS startup. The PAH discharge is to be continuously monitored and the monitoring equipment must be capable of monitoring PAH in a range twice that given to the applicable limit value as shown in Table 5, using either the permitted ultraviolet or fluorescence measuring techniques. The monitoring equipment must not deviate by more than 5 percent within the working range of the application.

TURBIDITY/SUSPENDED PARTICLE MATTER

The turbidity of the EGCS washwater should not exceed 25 FNU (formazin nephlometric units) or 25 NTU (nephlometric turbidity units) above the inlet water turbidity. This should be measured continuously using equipment meeting the requirements of the standards referenced by the 2015 IMO Guidelines. During periods of high turbidity, the time lapse between inlet and outlet measurements may be such that the acceptable limiting difference may be unreliable. Therefore, all turbidity readings must be a rolling average over a 15-minute period to a maximum of 25 FNU.

The turbidity in the washwater must be measured downstream of any water treatment equipment, but upstream of washwater dilution (or other reactant dosing) prior to discharge. The treatment system should be designed to minimize suspended particle matter such as ash and heavy metals. Similar to the criteria for PAH, the Guidelines permit a 15-minute deviation of up to 20 percent in any 12-hour period.

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 purpose 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 Guidelines require that all EGCS be 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.

DATA MONITORING

The 2015 IMO Guidelines require that data recording devices are provided as part of any EGCS installation. The following details some of the basic system data that is to be continuously monitored and recorded automatically against Universal Coordinated Time (UTC) and vessel position by Global Navigational Satellite System (GNSS):

- Washwater pressure and flow rate at the at the EGC unit's inlet connection
- Exhaust gas pressure before and pressure drop across the EGC unit
- Engine and/or boiler load(s)
- Exhaust temperature before and after the EGC unit
- Exhaust gas SO_2 (ppm) and CO_2 (%)
- Washwater pH, PAH and turbidity
- Temperature

The data recording device should be robust, tamper-proof, read-only and able to record at a rate not less than 0.0035 Hz. It should be capable of preparing reports over specified time periods and the data should be retained for a period of not less than 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 onboard 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. The copy of the data and reports should be made available to the flag Administration or Port State Control (PSC) authorities upon request.

The emission and discharge measurement are summarized as follows.

Table 6

	Design Requirements	Measurement Method
SO_2/CO_2	• CO_2 analyser is to be operating on non-dispersive infrared (NDIR) principle • SO_2 analyser is to be operating on non-dispersive infrared (NDIR) or non-dispersive ultraviolet (NDUV) principle	• Sampling probe is to be at least 10 pipe diameters downstream of the EGC unit, and 0.5 m or 3 pipe diameters, whichever is greater, upstream of the exit of exhaust gas system • Temperature at the sample gas probe is to be at least 70 deg C Alternative sample probe location is subject to approval by Administration
pH	• The pH electrode and pH meter are to have a resolution of 0.1 pH units and temperature compensation • The electrode is to meet requirements in BS 2586 or equivalent • The meter is to meet the requirements in BS EN ISO 60746-2:2003 or equivalent	• The overboard pH discharge limit can be determined by the following means: i. direct measurement at overboard discharge monitoring position (i.e. the pH at the overboard discharge monitoring position is to be a minimum of 6.5 pH units), or ii. calculation-based methodology (computational fluid dynamics or other scientifically established empirical formula). This involves the use of calculations or modeling to simulate the dilution and neutralisation of the acidic washwater when it is discharged into the sea. The minimum pH value that will be required at the overboard monitoring discharge position in order to meet the pH discharge limit of 6.5 pH at 4 m from the discharge point with the ship stationary, can then be determined. Such calculations are to be based on sea water alkalinity of 2200 μmol/litre and pH of 8.2

	Design Requirements	Measurement Method
PAH	• PAH measurement is to use ultraviolet light technology for washwater flow rates not greater than 2.5 t/MWh • For washwater flow rates greater than 2.5 t/MWh, fluorescence technology is to be used	To be measured downstream of the water treatment equipment, but upstream of any washwater dilution or other reactant dosing unit, if used, prior to discharge
Turbidity	Turbidity monitoring equipment is to meet requirements in ISO 7027:1999 or USEPA 180.1	To be measured downstream of the water treatment equipment but upstream of washwater dilution (or other reactant dosing) prior to discharge
Nitrates	Analysis of nitrates is to be based on methods of seawater analysis by Klaus Grasshoff, et al	The washwater sample for analysis of nitrate concentration is to be taken downstream of the water treatment equipment, but upstream of any washwater dilution or other reactant dosing unit, if used, prior to discharge

WASHWATER RESIDUES

Residues from the EGCS washwater are to be collected onboard and delivered ashore at suitable reception facilities that administrations are required to provide under Regulation 17 to MARPOL Annex VI. Discharging these residues at sea or incinerating them onboard is prohibited. It is also mandated by the Guidelines that storage and disposal of such residues are to be recorded in an EGC log, including the date, time and location of delivery. The EGC log may form a part of an existing logbook or electronic recording system as approved by the Administration.

EGCS APPROVAL

There are two basic parts to obtaining full approval of an EGCS:

1. The statutory MARPOL approval process covering the environmental performance aspects, and
2. The classification society approval to the individual society's rules.

Type approval from a classification society acting as a R.O. on behalf of the ship's Flag Administration covers both these aspects, in association with any other applicable or voluntary standards to which the EGCS 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 5 : EGCS Classification Type Approval

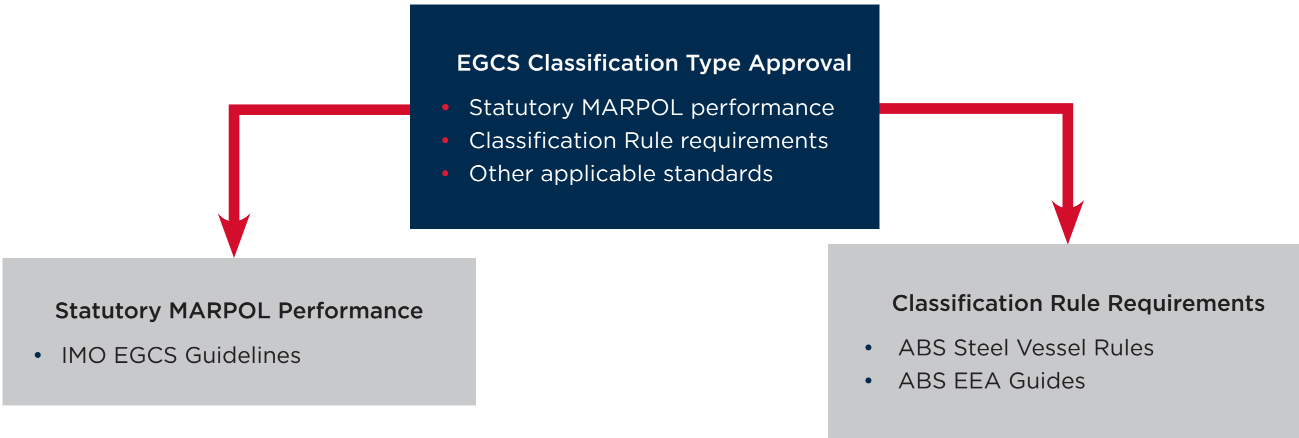
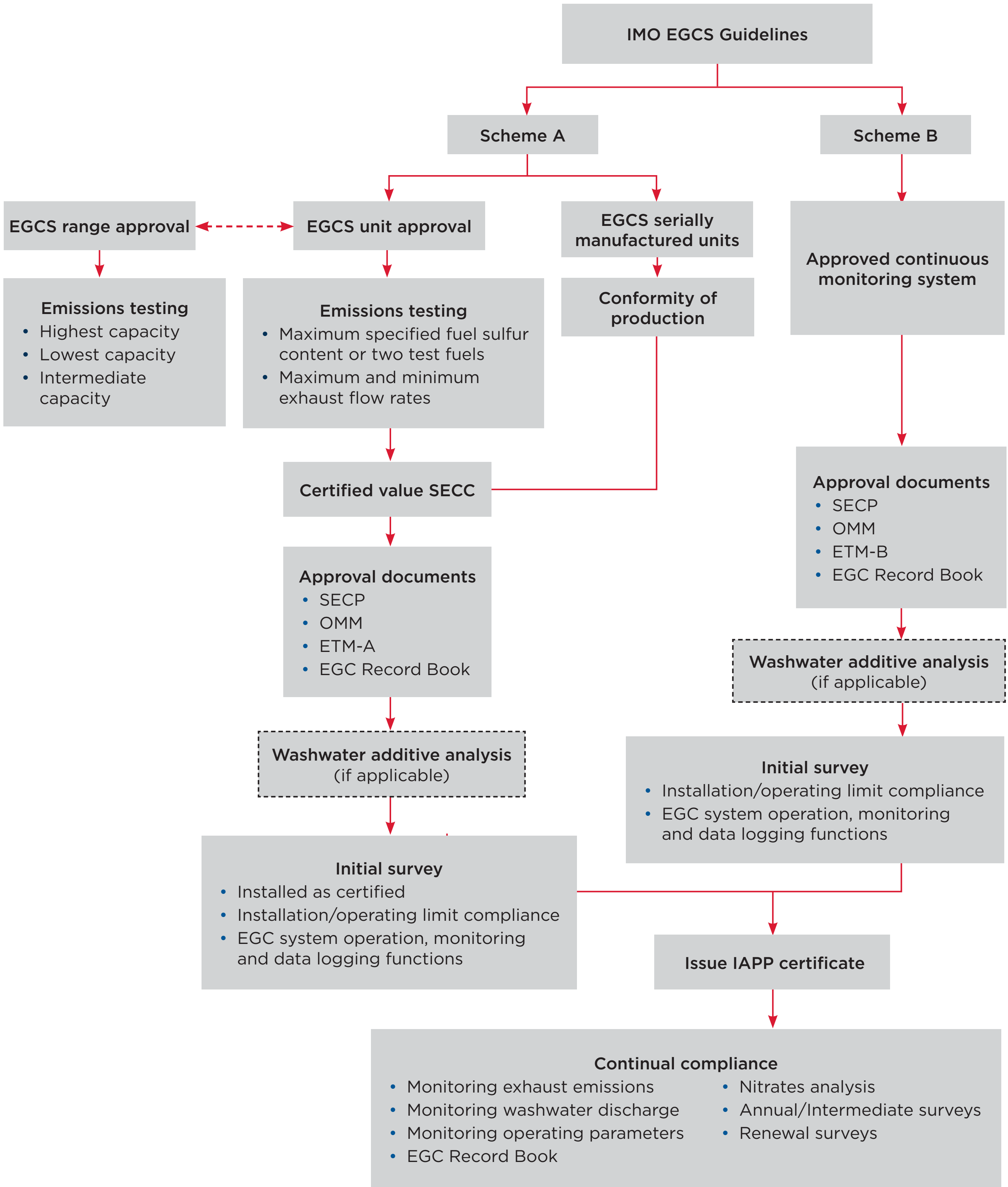


Figure 6: EGCS Statutory Approval

There may also be additional flag Administration requirements covering environmental performance aspects or general EGCS arrangements. Where appropriately authorized, a classification society may undertake approvals on behalf of an Administration in its capacity as an R.O. ABS can provide the review and approval for a majority of the flag Administrations. Figures 5 and 6 show the building blocks to the classification and statutory approval processes.

The verification that an EGCS meets the MARPOL performance approval criteria defined in the 2015 IMO Guidelines requires a number of steps, as depicted in Figure 7.

Figure 7: Statutory Performance Approval



As illustrated in Figure 7, the approval options under the IMO EGCS Guidelines consist of Scheme A and Scheme B.

In principle, the Scheme A route provides a way to deliver a pre-certified EGCS to the ship. In practice there have been challenges in pursuing the Scheme A approval route because of the difficulties of providing representative test bed testing. There are also verification aspects associated with the washwater monitoring that are not directly covered by the air emissions certification under Scheme A that are difficult to replicate.

Due to the challenges of Scheme A, the preferred approach for the EGCS approval has historically been the Scheme B option.

Under Scheme B, the EGCS is considered as a 'black box' with only the monitoring system and the EGCS documentation approved prior to installation. The responsibility of continuous compliance is with the operator. ABS is involved in the approval by inspecting the EGCS and monitoring installation to ensure compliance with the approved documentation and by verifying air emissions and water quality during sea trial operations. ABS will inform the flag Administration of the approval and update the ship's IAPP certificate upon confirmation by flag Administration of their acceptance of EGCS. The flag Administration will then notify IMO the acceptance of EGCS as an equivalent method for meeting Regulation 14 under Regulation 4. The same will be registered in the IMO Global Integrated Shipping Information System (GISIS):

https://gisis.imo.org/Public/MARPOL6/Notifications.aspx?Reg=4.2

Application for approval is typically made by the equipment supplier, in association with the shipowner, since several elements can be assessed during design and manufacturing, but full verification is vessel-specific and requires in-situ testing after installation.

ABS also offers optional class notation EGC-SOx in accordance with the ABS *Exhaust Emission Abatement (EEA) Guide*. For ships requesting such notation, the installation of the scrubber system is to comply with the class requirements in addition to the requirements of IMO Guidelines. Class applies additional requirements through plan review and survey process for system redundancy, material suitability, monitoring, alarm and emergency shutdown system, electrical power and computer-based systems and equipment certification. Such ABS involvement will help to enhance the operability, reliability and safety of the EGCS. Refer to Section 2 of the ABS EEA Guide for more details on class requirements.

For ships not assigned the optional class notation, the scrubber system is to comply with the minimum requirements prescribed under 1/9.11 of the ABS *EEA Guide* in addition to the statutory requirements.

EGCS CONCEPTS

GENERAL

A scrubber is a device installed in the exhaust system after the engine or boiler that treats exhaust gas with a variety of substances, which may include seawater, chemically treated fresh water or dry substances, with the goal of removing most of the SOx from the exhaust and reducing PM. After passing through the scrubber system, the compliant exhaust is released to 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.

WET SCRUBBERS

The exhaust gas passes through a liquid medium in order to remove the SOx compounds from gas by chemically reacting with the wash liquid. Systems are identified as either an open loop or closed loop system. Hybrid systems offer both methods of scrubbing.

The most common liquids are untreated seawater and chemically treated freshwater. In open loop operation, water is sourced, discharged from outside the vessel and passed through the tower. The source water generally must be seawater with a high sodium chloride content. In a closed loop scrubber, the water is generally treated freshwater with the exception of a few closed loop systems that use seawater. Additives are used to react with the washwater after each pass through the scrubbing tower for water treatment and recycling back into the scrubber in a continuous closed cycle. Additional additives and freshwater/seawater (as designed) are added as needed to maintain effective water levels and correct chemical composition.

Due to washwater discharge limitations set by the IMO and various regional and U.S. Federal regulations, the pH of the washwater discharge must be measured prior to overboard discharge. Monitoring of turbidity and PAH are also mandatory.

WET SCRUBBING PROCESS

While there can be significant differences in the detailed design of EGCS and the liquid medium 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 employ a packed bed of various shapes and materials through which the water flows downward, cascading over a maze-like packing as the exhaust gas travels through the liquid, promoting mixing of the two streams.

Other scrubbers may have a tower-like structure with spray nozzles and baffles to create a turbulent environment and mix the streams. 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 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.

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 found naturally in in the ocean. In addition, the PM in the exhaust will become entrapped in the washwater, adding to the sludge generated by a scrubber. The waste stream and generated sludge has to be processed as per the 2015 IMO Guidelines before discharge overboard, where allowed, or stored and discharged to a shore reception facility as a waste substance.

Engine Exhaust Gas Chemistry:
$S + O_2 \rightarrow SO_2$ ~ 95%
$SO_2 + ½O_2 \rightarrow SO_3$ ~ 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.

The basic principles for the scrubbing concept are described further in this section.

In an open loop scrubber using seawater, 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. Since 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, The washwater 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 freshwater/seawater is added to maintain the proper chemistry, as well as to extract the sodium sulfate salt produced.

OPEN LOOP SCRUBBERS

An open loop scrubber uses seawater as the medium for cleaning or scrubbing the exhaust, as shown in Figure 8. Seawater is normally supplied by a dedicated pump.

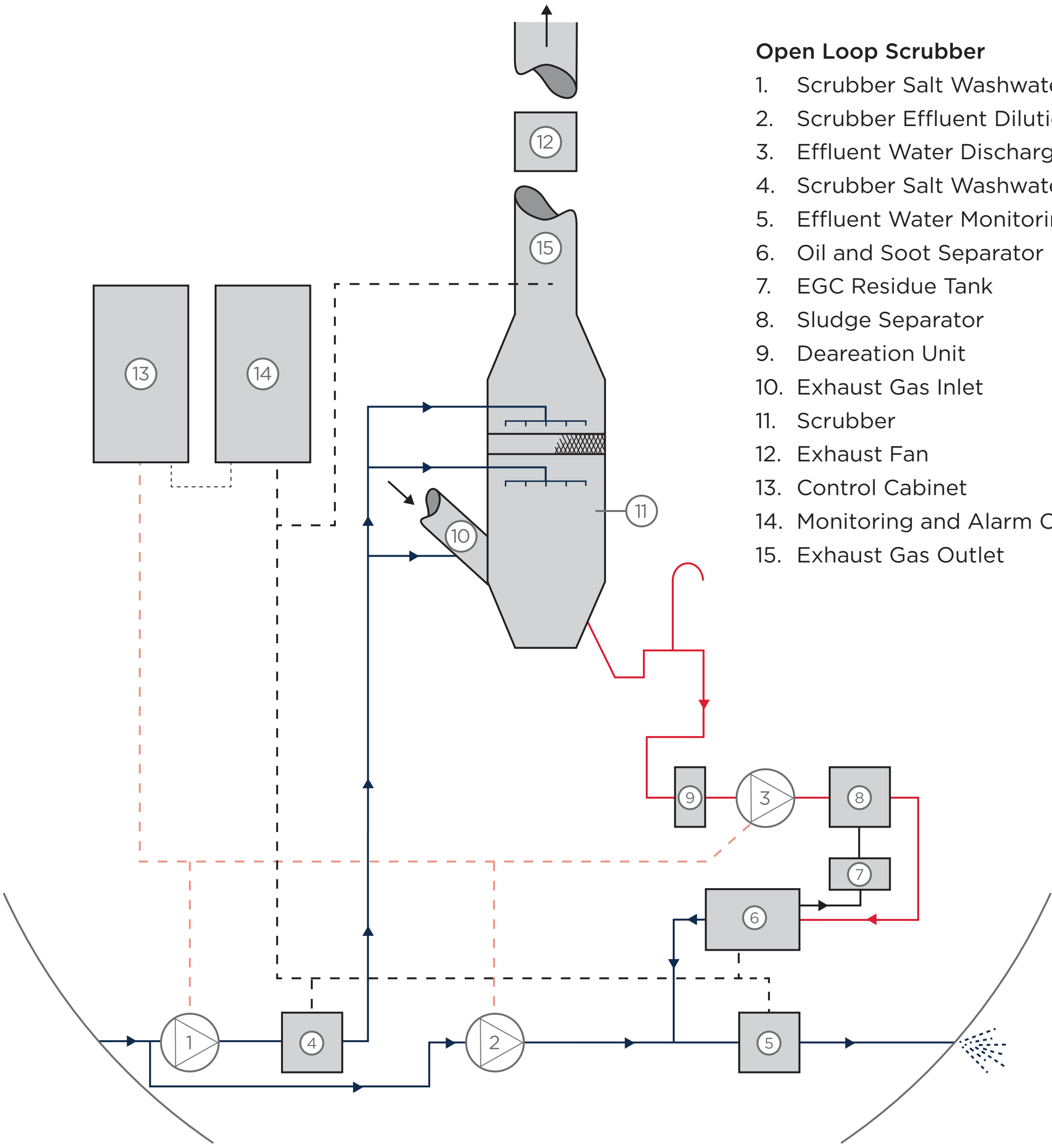
CO_2 dissolves in seawater forming carbonic acid, bicarbonate or carbonate ions depending on the pH. The positive companion ion can be calcium (Ca2+) or sodium (Na+), here the sodium carbonate salt is used as an example.

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)
$Na_2SO_3 + ½O_2 \rightarrow Na_2SO_4$ (Sodium Sulfate)
$Na_2CO_3 + H2SO_4 \rightarrow Na_2SO_4 + H_2O + CO_2$ (Sodium Sulfate)

Each EGCS 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. Note that it is necessary to know the alkalinity of the water before this can be determined.

Figure 8 : Open Loop Scrubber System



Open Loop Scrubber

1. Scrubber Salt Washwater Pump
2. Scrubber Effluent Dilution Pump
3. Effluent Water Discharge Pump
4. Scrubber Salt Washwater Monitor
5. Effluent Water Monitoring
6. Oil and Soot Separator
7. EGC Residue Tank
8. Sludge Separator
9. Deareation Unit
10. Exhaust Gas Inlet
11. Scrubber
12. Exhaust Fan
13. Control Cabinet
14. Monitoring and Alarm Cabinet
15. Exhaust Gas Outlet

Therefore, the effectiveness of an open loop scrubber depends on the chemistry of the water that the vessel is operating in. A vessel's intended operational area should be considered at the design and selection stage and again prior to deploying a vessel to new operational areas. If the water is not alkaline (pH is too low), the scrubber will not meet the required performance level and the operator will have to use low-sulfur fuel to be in compliance with the applicable SOx emission regulations.

As required by the 2015 IMO Guidelines, scrubber manufacturers must state the operational limits in terms of maximum fuel sulfur content to be in compliance with MARPOL 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 may pass through a demister or water droplet separator to remove water particles from the gas, which reduces the potential for steam generation as the exhaust exits to the atmosphere. This is advantageous because, 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 EGCS unit.

The water mixture generated during the scrubbing process falls to a wet sump at the bottom of the scrubber. This washwater is removed from the scrubber sump by gravity or by a pump after passing through a deaerator in some systems, then treated as appropriate to meet the water discharge quality criteria, and then discharged overboard. 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 cooling seawater or other reactant dosing methods. It is important to note that additional local and national restrictions may limit washwater discharge from an open loop scrubber.

For areas where more stringent washwater discharge requirements are applicable, the washwater may be treated by the installation of additional equipment such as hydrocyclones or separators to remove residues from the washwater. The removed residues will contain PM, ash, and heavy metals removed from the exhaust gas, as well as insoluble calcium sulfate and silt from turbid waters, and must be retained on board and held in a dedicated tank. MARPOL Annex VI Regulation 16 Paragraph 2.6 prohibits incineration of such residues. It must be disposed of at suitable reception facilities ashore.

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 through which the vessel is sailing. An alkaline chemical, usually sodium hydroxide (NaOH) or rarely magnesium oxide (MgO) is used in marine EGCS to control the water alkalinity, which can also be produced by electrolysis of seawater (see Figure 9).

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 tower 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 washwater, and the water is dosed with alkaline chemical to restore its alkalinity prior to returning to the scrubber tower.

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 pH level using the alkaline chemical injection process.

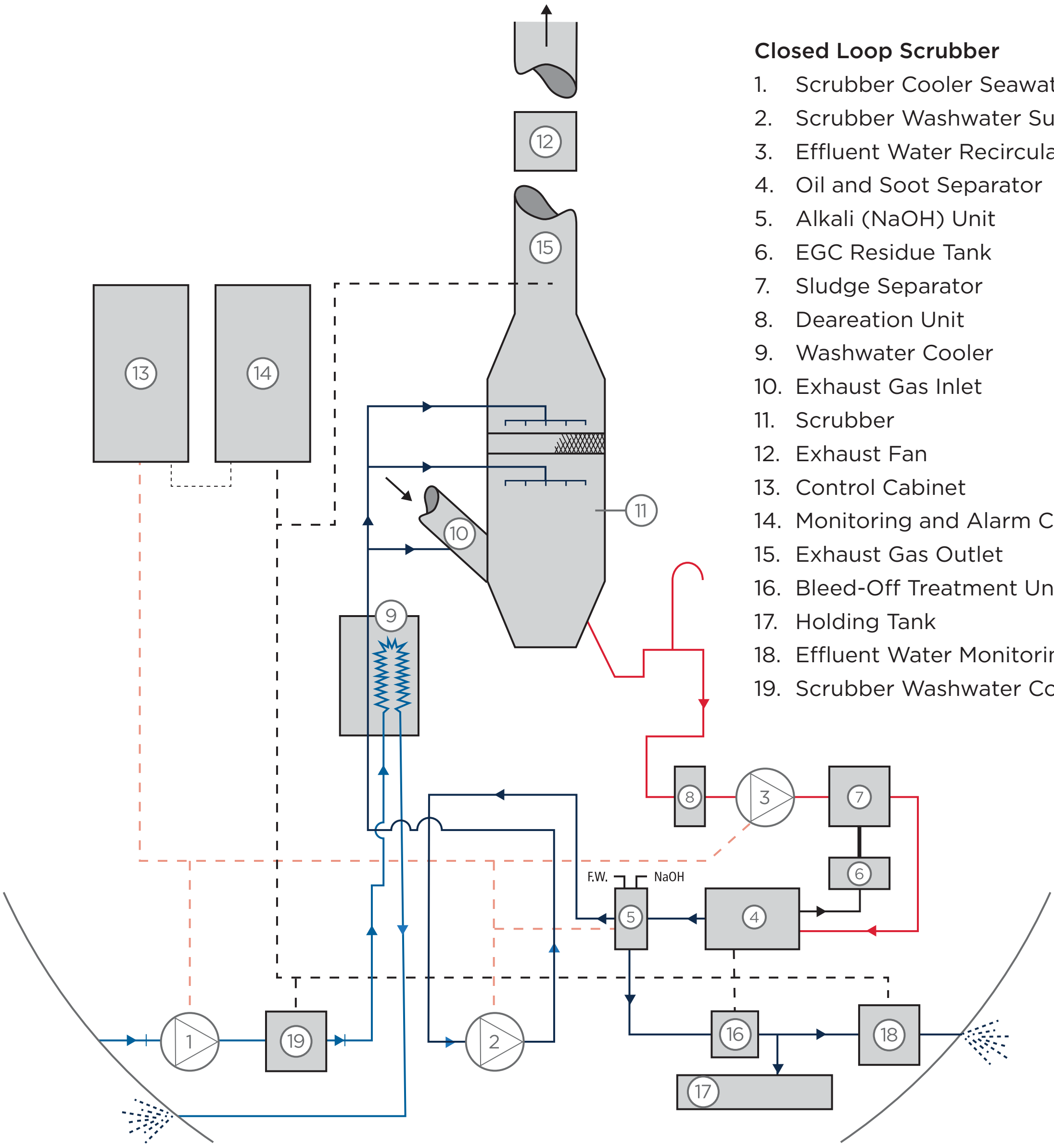
In fresh water scrubbers, SO_2 combines with a salt and consequently does not react with the natural bicarbonate of seawater. There is no release of CO_2.

$2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O$ (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 system, the dirty washwater exiting the scrubber goes to a process or circulating tank providing the required water quantity and any losses in water level and alkalinity is replenished. A limited quantity of washwater from the bottom of the process tank, where the residues have collected, is extracted using low suction. It then goes to a hydro-cyclone or separator, where the residues are removed, or for some systems the extracted water passes through a bleed-off treatment unit (BOTU).

During these processes, the cleaned bleed-off water is discharged either overboard or to a holding tank, depending on the ship's location and local regulations. Residual sludge removed from the washwater goes to a residue/sludge tank for disposal ashore. Make-up water is added to the process tank to replace the washwater lost in the particulate treatment process and 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 seawater cooler before re-injection into 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.

Figure 9: Closed Loop Scrubber System



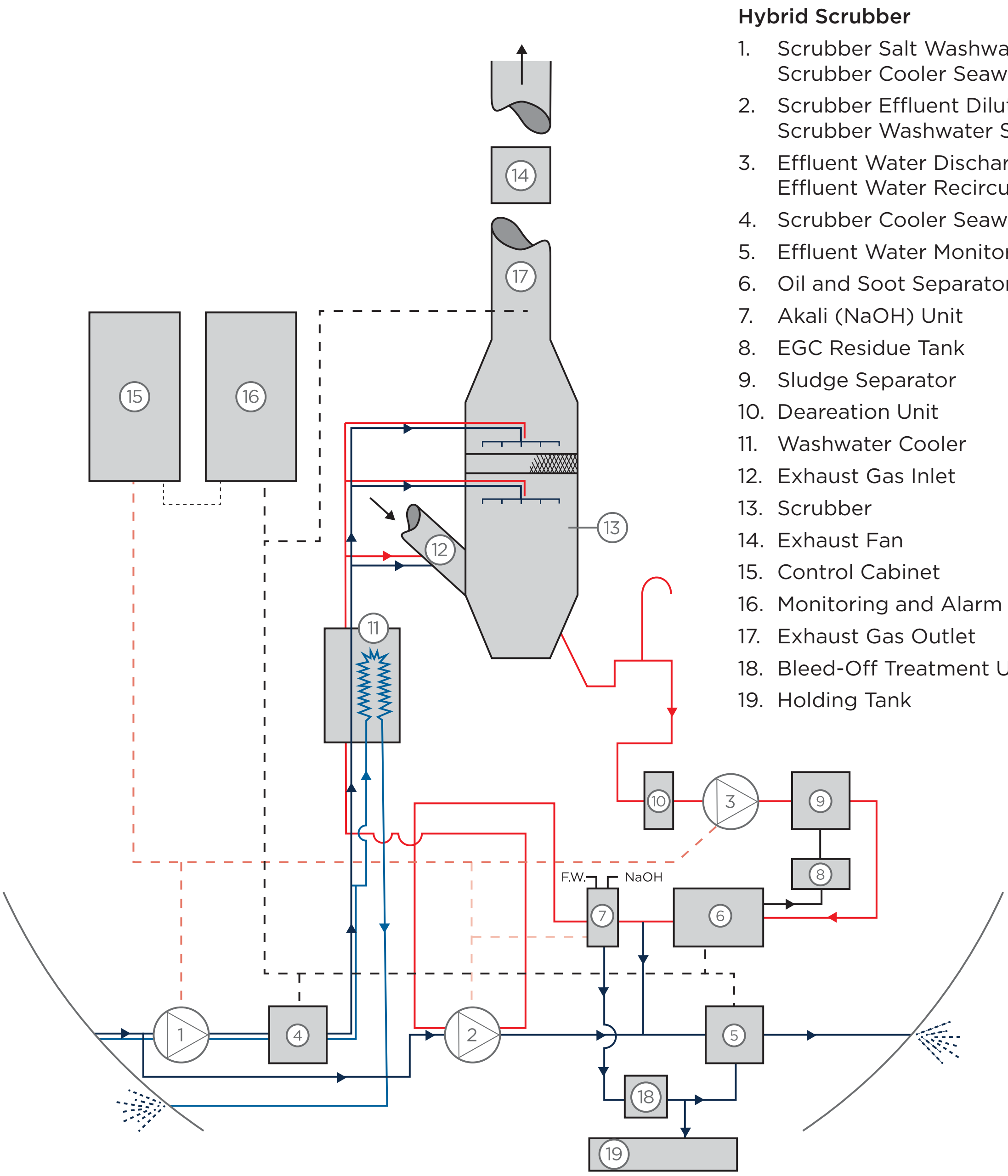
Closed Loop Scrubber

1. Scrubber Cooler Seawater Pump
2. Scrubber Washwater Supply Pump
3. Effluent Water Recirculation Pump
4. Oil and Soot Separator
5. Alkali (NaOH) Unit
6. EGC Residue Tank
7. Sludge Separator
8. Deareation Unit
9. Washwater Cooler
10. Exhaust Gas Inlet
11. Scrubber
12. Exhaust Fan
13. Control Cabinet
14. Monitoring and Alarm Cabinet
15. Exhaust Gas Outlet
16. Bleed-Off Treatment Unit
17. Holding Tank
18. Effluent Water Monitoring
19. Scrubber Washwater Cooling Monitor

HYBRID SCRUBBERS

There are advantages to open loop-type systems, such as not requiring caustic soda, and the avoidance of processing washwater. Closed loop system advantages include the scrubber working with the same efficiency independently of where the vessel is operating, and there is little or no water discharge making it best suited for coastal, port and inland waters. In order to utilize the advantages of both systems, some manufacturers have proposed hybrid scrubbing systems. These can be operated as an open loop system when in the open ocean and as a closed loop system when in a sensitive sea or in a low alkalinity water area (see Figure 10). The changeover from open to closed loop is done by changing over the circulating pump suction from seawater to the circulating tank, and by changing the washwater discharge from the overboard discharge to the circulating tank.

Figure 10: Hybrid Scrubber System



EFFECTIVENESS OF WET SCRUBBERS

Since the primary goal of scrubbers is the 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. An exhaustive amount of data demonstrating the effectiveness of scrubbers on a long-term basis is in the development stage as of the date of publication. A few individual systems have been deployed that have accumulated significant operational hours.

One key element of wet scrubber performance, particularly in an open loop operation, is the need for alkaline substances in the water. Closed loop alkalinity is directly controlled by the dosing process that injects an alkaline material into the washwater, so the performance of the scrubber can generally be controlled. For open loop scrubbers, the alkalinity of the washwater depends on the characteristics of the source water that the ship is traveling through. Therefore, the effectiveness of an open loop scrubber is significantly reduced if the vessel operates in brackish or soft freshwater with a 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 seawater. A 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 a sufficient volume of washwater is used.

Table 7 lists estimates of scrubber effectiveness in the removal of harmful substances from exhaust gases.

Table 7: Wet Scrubber Effectiveness Rates

Scrubber Performance Factor	Rate %	Remark
SOx Removal Required	97.10	Makes 3.5% S fuel equivalent to 0.1% S fuel
Expected SOx Removal Rate	>96	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.

OTHER TECHNOLOGIES

DRY SCRUBBERS

A dry scrubber does not use water or any liquid to carry out the scrubbing process, but instead exposes hydrated lime-treated granulates to the exhaust gas to create a chemical reaction that removes the SOx emission compounds. They are commonly used on land-based EGC installations.

Dry scrubbers use granules of caustic lime ($Ca(OH)_2$) that react 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:
$CaSO_3 + \frac{1}{2}O_2 \rightarrow CaSO_4$

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

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

MEMBRANE SCRUBBER SYSTEM

Membrane Scrubber Systems are wet scrubber types that do not directly mix the liquid scrubbing solution with the exhaust gases, but instead rely upon a membrane to contact, capture and remove SOx. Membrane gas separation technologies are commonly used on land-based applications, as well as limited marine applications such as inert gas nitrogen generators.

The membrane scrubber consists of an array of ceramic tube membranes suspended in the exhaust stream. A manifold system circulates the absorbent solution through the membrane tubes. Exhaust gases pass over the porous membranes, and SOx is absorbed by the absorbent solution.
The spent caustic solution containing sulfates in the absorbent solution tank must be periodically replaced with fresh caustic solution. The spent caustic solution can be discharged at shore when fresh caustic soda is taken on, or regenerated onboard via an electrolyzer.

It has been reported that the key advantage of membrane scrubbers over wet scrubbers for shipowners is the elimination of washwater generated by wet scrubbers. Overboard discharge PAH, turbidity and pH issues that require attention in wet scrubber installations are not concerns with membrane scrubbers. The key disadvantage of the membrane scrubbers over wet open loop scrubbers is the additional operating cost of the caustic soda.

CONSIDERATIONS FOR EGCS SELECTION

TYPE OF EGCS

The initial consideration for the selection of an EGCS is its suitability for the intended route of the vessel and its SOx emission compliance strategy.

There are three type of wet scrubber systems: open loop, closed loop and hybrid. Detailed description of the scrubbing process for each type are included under the section Wet Scrubbing Process in this Advisory. The Pros and Cons are summarized in the following table as reference for the determination whether an open loop, closed loop or hybrid should be installed.

Table 8

EGCS	Pros	Cons	Application
Open Loop	• Uses seawater for scrubbing; does not usually involve storage or handling of hazardous chemical (caustic soda) • Comparatively simple system; less equipment/system compared to closed loop • CAPEX and OPEX relatively low	• Not suitable for low alkalinity water • Restriction of washwater discharge in certain coastal/port areas • Large washwater demand	• Vessels operating most of the time in the ocean/open sea • Vessels not entering areas with washwater discharge restriction
Closed Loop	• Independent of operation location – in low alkalinity water; in discharge restricted coastal/ port areas • Effluent is stored onboard for the duration that the tank volumes will permit	• Complex washwater system • Additional equipment/system for water treatment • More space required • Special care for handling and storage of NaOH solution, a hazardous substance. • Operation duration limited by effluent tank size • Relatively higher CAPEX • Relatively higher OPEX due to use of NaOH and residue handling	• Vessels trading constantly in areas with discharge restriction or low alkalinity water
Hybrid	• Significant flexibility for operating in all regions regardless of seawater alkalinity or temperature • Effluent may be stored onboard for the duration that the tank volumes will permit	• Complicated system with more components • More space required • Handling and storage of NaOH, and residue disposal for closed mode operation • Highest CAPEX • Higher OPEX due to use of NaOH and residue handling	• Both in ocean/ open sea and discharge/ operation restricted areas

WASHWATER DISCHARGE PROVISION

The selection of an open loop, closed loop or hybrid scrubber system will depend on the area in which a vessel operates.

For open loop systems, one of the key factors to be considered is the restriction on washwater discharge imposed by national or local regulations.

For closed loop systems, supply of the caustic soda solution and onboard storage of the bleed off water and sludge generated from washwater are the key factors that determine the continuous operation duration of the system.

Table 10: Sample Wet Scrubber Auxiliary Equipment Sizing of this Advisory lists typical sludge generation rates and caustic soda usage for reference. For a specific scrubber system installation, the data should be provided by the respective vendor.

If a ship primarily operates in high sea and will enter washwater discharge restricted waters for limited periods of time, a hybrid system may be considered. Alternatively, the ship may be installed with an open loop system for operating in areas where discharge of wash water is not restricted and then switch to sulfur-compliant fuel for operating in washwater discharge restricted areas.

Refer to Regional and Local Regulations of this Advisory for details on the discharge restriction requirements.

SCRUBBER INSTALLATION

On most ships, the exhaust gas economizer (EGE) is normally installed in the lower engine exhaust system casing, above the main engines or boilers. Placing the scrubber above the economizer would necessitate that the scrubber be installed in the upper part of the exhaust system casing, where the casing is normally reduced in size. This installation location may require substantive changes to the engine exhaust system casing design to accommodate both the increased horizontal and vertical space requirements.

The funnel is also impacted by the addition of a scrubber and by the possible need for a second set of exhaust pipes for bypass if a wet scrubber is not designed for dry operation. 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 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 oftentimes 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 for 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 have less impact on other systems as for retrofits.
For retrofit installations, engine exhaust system casing modifications as previously mentioned, together with the below items, can require significant conversion work:

- space necessary for new pumps and piping systems, including possibly new sea chests or enlargement of the existing ones and overboard discharges
- space for the alkaline material storage (for closed loop scrubbers)
- space for wastewater processing

There may not be space available in existing engine rooms, and other spaces would require modification to fit new equipment; an enlargement of the engine room may also 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. For more information about retrofitting, refer to Appendix I.

DRY SCRUBBER USAGE RATES AND DIMENSIONS

For a typical dry scrubber system, a relatively large storage capacity for both lime and gypsum may be 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 onboard and for discharging the gypsum to shore.

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 EGE, since the scrubber cools the exhaust. Table 9 and Figure 11 show the principal dimensions based on the engine power rating for scrubbers. In general, it is anticipated that a scrubber will typically be about two to three times the size of a typical EGE or composite boiler.

It is estimated that the expanded engine exhaust system casing structure to support a wet scrubber 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 review of the stability need to be considered due to any increase of the wind profile and additional weight of the scrubber.

Figure 11: Scrubber Dimension Layout

Table 9: Wet Scrubber Principal Dimensions by Engine Power (courtesy of Alfa Laval Nijmegen)

Engine	Diameter	Length	Height	Dry Weight	Operational Weight
MW	**m**	**m**	**m**	**tonnes**	**tonnes**
4	1.7	3.4	7.1	3.3	4.0
8	2.4	4.4	8.1	5.9	7.4
12	2.9	5.2	8.7	8.1	10.4
16	3.4	5.9	9.0	10.6	14.1
20	3.8	6.4	9.5	12.8	17.2
24	4.2	7.0	10.1	16.5	21.7
32	4.8	7.9	11.0	21.2	28.2
55	6.2	10.0	13.0	41.4	53.7

SCRUBBER MATERIAL SELECTION

The lower portions of a wet-type 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 will experience higher operating temperatures which, therefore, limits the materials selection to high temperature acid- and chloride-resistant alloys; typically nickel alloys. Ferritic-austenitic stainless steels (duplex stainless steels) perform well in corrosive environments. Above the lower portions of the scrubber unit, a less corrosion-resistant stainless steel may be used. However, the selection of the appropriate stainless steel grades should be considered in detail and should be based on conservative assumptions.

EXHAUST GAS BYPASS

An exhaust gas bypass allows the exhaust gas to bypass the scrubber and go directly to the atmosphere. Unless made with suitable materials able to withstand 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 may not be required. For most scrubbers, fitting a bypass is a requirement if there is a need to operate the equipment connected to the scrubber when the scrubber is non-operational. This would apply to engines and boilers considered as essential services for a vessel. When the scrubber is not needed, such as when sulfur limit-compliant fuel is used, the exhaust bypass can be used and the scrubber shut down, reducing EGCS 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.

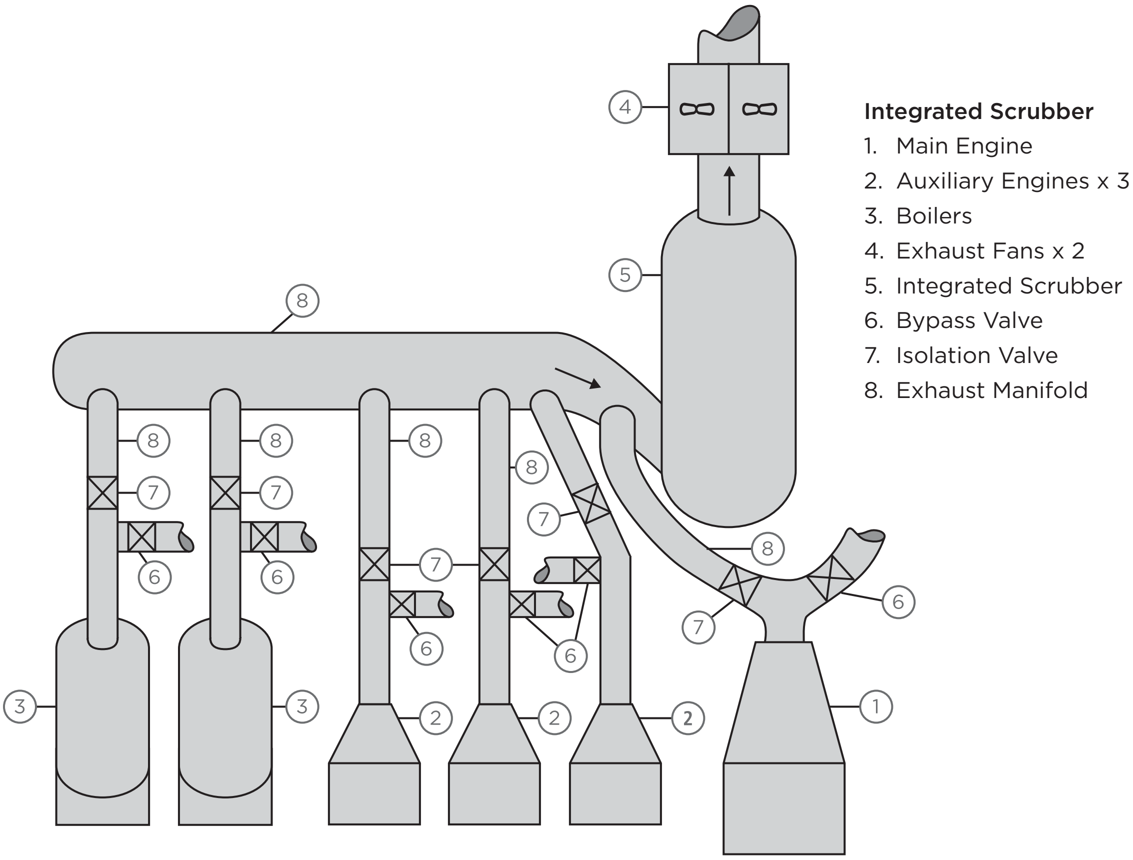
Where the valve is a two-damper design, an interlock would be required to prevent both dampers from being closed at the same time. Exhaust bypass valves may require frequent maintenance because of the hot gas environment and soot accumulation that occurs. For main engines, an EGE is also frequently provided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

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 needs 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.

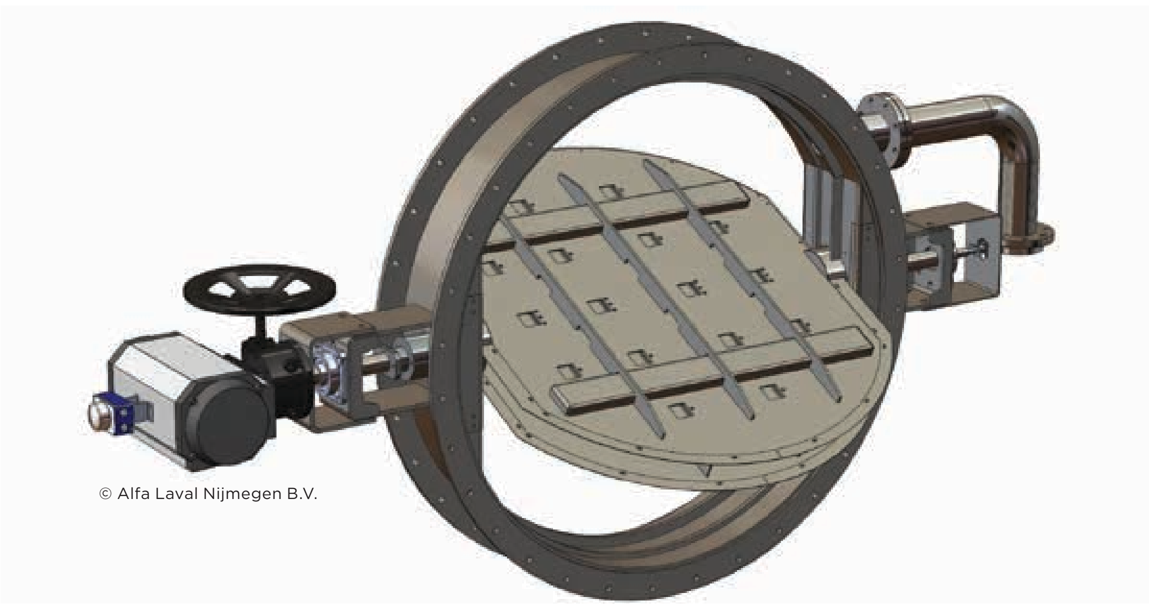
When using an integrated scrubber, bypasses for each exhaust are required (see Figure 12). For safety reasons, special measures are needed to make sure that the isolation valves are positioned and sealed properly when an engine or boiler is out of service so that exhaust will not backflow down the exhaust pipe to the idle engine or boiler. An exhaust fan is also typically needed to keep the exhaust system backpressure 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 12: Integrated Scrubber System with Multi-Engine Inlets



Exhaust isolation valves need to be designed to avoid leakage; 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 providing lower pressure between the discs to remove any leakage past the discs (see Figure 13).

Figure 13: Exhaust Gas Isolation Valve



BACKPRESSURE

Scrubbers may have an impact on the operation of any engine/boiler to which they are added if they cause excessive exhaust system backpressure. Continual compliance with IMO MARPOL Annex VI Regulation 13 requirements on NOx emissions may be affected if the engine is operated at an exhaust backpressure outside of 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 backpressure in the system. A fan may not normally be required for a scrubber attached to a single engine, but it more common on scrubbers connected to multiple engines and boilers to prevent higher backpressure from one engine or boiler affecting the other interconnected fuel burning units, either stationary or in operation.

Due to the potential impacts on engine operation through excessive backpressure and safety concerns of exhaust backflow to idle units, the impact of a scrubber fan failure on the safe operation of the fuel burning units should be carefully considered. The scrubber manufacturer should submit complete details related to the anticipated backpressure 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 backpressure will not create problems for the safe and continued operation of the equipment.

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:

SEAWATER SUPPLY

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

FRESHWATER/SEAWATER SUPPLY FOR CLOSED LOOP

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

SCRUBBER DRAINAGE PIPE

The water draining out of the scrubber is acidic and corrosive, and thus requires special piping materials. 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.

Where distance piece is fitted between the overboard discharge valve and the ship shell plate, piping with an increased wall thickness as specified under 4-6-4/3.3.5(a) of ABS *Steel Vessels Rules* should be considered.

EXHAUST PIPE

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

SLUDGE PIPE

The sludge generated by the scrubbing process may be acidic; therefore, the associated piping should be of acid corrosion-resistant 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 operations is scrubber flooding, which occurs if the washwater drainage from the sump, either by pump or gravity drain, stops or is blocked. This will quickly flood the scrubber and overflow of water down the exhaust pipe, and subsequent damage to the attached engine/boiler, may occur. The scrubber automation system should prevent such critical situation; this may be achieved with a high water level alarm, an automatic cut off of the water supply to the scrubber and opening of the exhaust bypass (if fitted), and 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 it does not have to be directly adjacent to the scrubber.

The main auxiliary equipment and typical sizes for three different scrubbers are listed below in Table 8 for both open loop and closed loop scrubbers. For the higher power engines, large pumping systems that use substantial amounts of electric power are required because of the high discharge head, particularly for open loop scrubbers (estimated to be about 70 m in the sample analysis). There are three main reasons that more power is needed:

- 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 to supply water at the required pressure to the spray nozzles (about 2 bar)
- Higher scrubbing water flow

Multiple water supply, circulating pumps or variable speed pumps are needed so that the water supply to the scrubber can be varied with fuel oil combustion equipment load, otherwise excessive water supply will occur at low 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.

Table 10: Sample Wet Scrubber Auxiliary Equipment Sizing (1)

Engine Size	5 MW		20 MW		40 MW	
Equipment	Open loop	Closed loop	Open loop	Closed loop (2)	Open loop	Closed loop (3)
Scrubbing water flow (m^3/hr)	225	225	900	675	1,800	1350
Cooling water flow	NA	150	NA	240	NA	450
Electric load (kW) (4)	65	85	205	190	395	350
Electrical load Open Loop Water Treatment System (kW)(5)	15	NA	65	NA	125	NA
Bleed-off water (m^3/hr)	NA	0.875	NA	3.5	NA	7
Sludge generation (liter/hr)(6)	0.5	15	2	25	4	45
NaOH usage (50% solution) (liter/hr)(7)	NA	95	NA	155	NA	290

Notes

1. The Table is based on Wärtsila's data for scrubbing emission from 3.5% S to 0.1% S fuel equivalency
2. The closed loop is sized for 8 MW.
3. The closed loop is sized for 15 MW
4. Assuming scrubber installed 20 meters above least draft of ship during scrubber operation
5. This is optional, consist of a residue tank, wash water pump, hydrocyclone and settling tank
6. For open loop operation, sludge is only generated if the water treatment system is chosen
7. Caustic soda usage rates and storage requirements can vary significantly depending on the engine load and scrubber operation. Indicated values are of the expected requirements.

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. As shown in Table 8, the electrical load for pumping can be substantial; several hundred kW for open loop scrubbers for large engines. There are also other additional electric loads to consider such as sludge removal, alkaline dosing, seawater 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 pump's 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 should be designed with generators able 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 must 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 must be 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.

WET SCRUBBER AUTOMATION AND MONITORING

EGCS 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 11. The monitoring and data logging system should be tamper-proof and in compliance with MARPOL and any additional national regulations that may be applicable.

Table 11: 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 seawater 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.

REDUNDANCY

Redundancy of the scrubber or active scrubber system components is not currently explicitly required by the regulations for sulfur emissions. However, if these systems fail, the ship will no longer be in compliance with the emission regulations. In addition, if there are failures, there could be resulting safety related issues that can be of concern to the operator and the classification society. Regulation 3 to MARPOL 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 avoid emission noncompliance.

The ABS EEA Guide details the redundancy requirements for ships assigned with optional EGC-SOx notation.

ABS "SOX SCRUBBER READY" NOTATION

ABS published the ABS *Guide for SOx Scrubber Ready Vessels* as an optional notation for ships under the ABS Rules for Building and Classing Steel Vessels. It is applied to vessels having design features that may be considered suitable for the retrofit of a SOx scrubber system at a future date, based on existing class requirements. The objective of this Guide is to offer acceptance of a defined level based on a three (3) leveled "SOx Scrubber Ready" scheme. The guide provides details and preparations needed for each level, as well as the associated type of recognition that ABS would offer subject to compliance of the requirements at each level.

Level 3, the final Level for acceptance, is associated with the approval of detailed drawings of the scrubber installation and its related specified equipment onboard the vessel. Upon satisfactory completion of approval to Level 3 and completion of the installation to the Surveyor's satisfaction, the vessel will be eligible for the "SOx Scrubber Ready" notation.

In the future, once the vessel has undergone a complete retrofit to install a SOx scrubber system that has been approved and verified to be in compliance with the EEA Guide, the above "SOx Scrubber Ready" notation would be replaced with an appropriate Class Notation offered accordingly by the EEA Guide as follows:

EGC-SOx: Where an exhaust gas cleaning system primarily designed for the reduction of SOx emissions using exhaust gas scrubbing is designed, constructed and tested in accordance with Section 2 of the EEA Guide.

EEMS: The notation for an exhaust emissions monitoring system may be assigned to a vessel fitted with, or without, an exhaust emission abatement system, where a permanently installed exhaust emission monitoring system is designed, constructed and tested in accordance with Section 5 of the EEA Guide.

SUMMARY

International, regional and local emissions regulations require reductions in exhaust emissions from oil- burning equipment. The reduction of SOx emissions is typically regulated by mandating reductions on the sulfur content of the fuel, but the availability and price of fuel compliant with impending regulations is unknown. Accordingly, there is growing interest in the application of exhaust gas cleaning systems that can provide alternative means of complying with the emissions regulations.

There are current international guidelines covering the testing, survey and certification of exhaust gas cleaning systems, which generally cover the performance and emissions compliance aspects, as well as additional classification society requirements that are in place to address 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 savings.

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 an operating profile with a minimum port stay or minimum transit time in ECAs, 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 areas with water discharge restrictions or low alkalinity waters, 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, and cargo loss, together with the cost of the additional fuel consumption required to operate the scrubber system and the cost of consumables (e.g. NaOH) 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.

This advisory provides information for adoption of EGCS as an equivalent method for meeting the sulfur limitation requirements in MARPOL Annex VI.

Appendix I to this Advisory addresses the consideration for retrofitting existing ships with EGCS. Information for EGCS manufacturers, frequently asked questions and answers, checklists for owners intending to adopt EGCS and other references are provided. It is advisable to communicate 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.

APPENDIX I, RETROFITTING SHIPS WITH EXHAUST GAS CLEANING SYSTEM

This Appendix is applicable for installation of an SOx scrubber on an existing vessel. The Appendix is based on a typical wet scrubber system under the approval scheme of IMO Guideline MEPC. 259(68).

Please refer to Scrubber Installation Feasibility – Existing Ships for the general questions related to installation of scrubbers.

The retrofit of an SOx scrubber system on an existing ship is challenging. A successful retrofit needs to consider different steps, such as planning, scrubber selection, hazard and safety evaluation, shipboard installation, and demonstration of compliance. Details for each of these items are provided below.

PLANNING

Effective planning should consider lead time for scrubber supply; scope of structure and system modification; engineering evaluation and class approval; fabrication, installation and integration; and testing, commissioning and demonstration of compliance.

The lead time for scrubber system equipment supply varies for different suppliers and different projects. For a specific retrofitting, this needs to be discussed and confirmed with the supplier.

For a ship that is not originally designed and constructed for the installation of an SOx scrubber, the retrofitting will involve structure modification and reinforcement, piping system modification, electrical system modification and respective engineering works and class and statutory approval. The scope of the modification will greatly impact the retrofitting duration.

The ship owner, scrubber supplier, engineering design company and shipyard are the major parties that will be involved in the retrofitting. It is important to define the roles of each party for a successful retrofitting.

SCRUBBER SYSTEM SELECTION

The EGCS selected is to suit the intended trading route of a ship and the SOx emission compliance strategy. The Pros and Cons for each type of the wet EGCS are summarized under Consideration for Type of EGCS.
In addition, the compatibility to the existing ships in term of space, layout, and integration with the existing equipment and system as outlined in the following sections are to be considered.

HAZARD AND SAFETY EVALUATION

The hazard and safety concern related to the installation of scrubber system may include the possible impact on the stability of the ship, flooding of the engines and boiler, operation and performance of the engines, chemical hazard and personnel safety.

For an existing ship installing a scrubber system as a retrofit conversion, the stability may need to be re-evaluated based on the additional weight of the EGCS and any increase of the wind profile. In general, if the change in lightship displacement exceeds 2% (excluding any certified weights, if any) of the lightship displacement and/or the change in lightship longitudinal center of gravity (LCG) exceeds 1% of the LBP, a stability test may be required, and the stability calculation would need to be revised. Vessel Stability of this Advisory and Section 2/7.15 of ABS EEA Guide may be referred to for more information.

One concern with the scrubber installation is the flooding of the engines and boilers connected to the scrubber. Refer to Flooding of this Advisory and Section 2/7.11 of ABS EEA Guide for information about the possible cause and means of prevention.

The installation of scrubber may exert additional backpressure to the engines. The total backpressure to the engine should be compatible with the backpressure limits specified by the engine manufacturer. Refer to Backpressure of this Advisory for more information.

For closed loop systems, and some open loop systems where chemical dosing is used to boost performance, caustic soda will be carried onboard. Caustic soda is highly corrosive and may cause a hazard to equipment and personnel during bunkering operations, storage and handling.

Please refer to Section 2/11.5 of ABS EEA Guide for information about the mitigation of such hazard.

SHIPBOARD INSTALLATION

Unlike new construction where the adoption of an SOx scrubber can be considered at the beginning of a project, for retrofitting, an evaluation of the existing ship will need to be carried out in order to accommodate the EGCSs and equipment, to support its operation and to avoid inadvertent impact on the safety and operability of the existing vessel particularly in the layout and space, structural modifications/scantling, integration with existing exhaust piping and electric power supply.

STRUCTURE MODIFICATION

It is unlikely that the existing engine room will have enough space for the additional equipment and systems. Survey of the engine room space is to be carried out to determine the additional space needed, the scope of structure modification and the layout changes. Such surveys may be carried out in conjunction with the scrubber selection process so that the selected system will fit the layout and space of the existing engine room as far as possible in order to minimize the structure modification and onboard equipment relocation.

For typical equipment and auxiliaries of the scrubber systems, refer to: Figure 8 : Open Loop Scrubber System, Figure 9: Closed Loop Scrubber System and Figure 10: Hybrid Scrubber System.

This Advisory provides typical Wet Scrubber Dimensions for reference. Project specific information should be obtained from the respective suppliers.

Enlargement of engine room casings/funnels could be the most significant structure changes for accommodating the scrubber tower(s) and additional section of exhaust pipes.

An additional sea chest or enlargement of an existing one would be needed to meet the scrubbing water demand, which could be a few hundred cubic meters per hour to more than thousand cubic meter per hour depending on the type and capacity of installed system. Table 10: Sample Wet Scrubber Auxiliary Equipment Sizing provided the reference information based on Wartsila data.

Some of the process tanks could be so large that structure modification could be necessary for creating the tanks, such as holding tanks for a closed loop system or a hybrid system operating in closed loop mode where overboard discharge is prohibited.

Structure reinforcement for the Installation of scrubber system would be also necessary.

The section for Scrubber Installation in this Advisory provides further information related to structure modification.

PIPING SYSTEMS:

Existing exhaust piping would need to be modified for the integration of scrubber system. Please refer to the following sections in this Advisory for the consideration of exhaust pipe modification.

Exhaust Gas Bypass

Integrated Scrubbers with Multiple Inlets

Backpressure

New piping systems associated with scrubber retrofitting include washwater system, and where applicable, chemical treatment and residue system. Relevant information is available under Scrubber Piping Systems of this Advisory.

Material of pipes and fittings in the EGCS that may be exposed to corrosive fluids is to be corrosion-resistant and suitable for the potential high temperature. Please refer to Scrubber Material Selection.

ELECTRICAL SYSTEM

Electrical load analysis is to be carried out to determine if the existing power supply system has the capacity to supply the additional power demand of the scrubber system.

The power demand of the scrubber system could be a few hundred kilowatts depending on the type and capacity of scrubber system. The typical electric power consumers include washwater pumps, forced fans, control panels, gas analyzers, water monitoring modules and additional equipment for closed loop systems. For electrical load analysis, these loads are considered continuous loads.

Table 10: Sample Wet Scrubber Auxiliary Equipment Sizing of this Advisory provides the power demand for EGCS (for a given engine rating and scrubber type) as reference values based on Wartsila data. For open loop systems, the electric load can reach as high as 395 kW for an engine rating of 40,000kW.

An additional generator set may be required to meet the power demand, and the generator engine will be subject to NOx and SOx emission requirements.

Even if the existing power supply system may meet the additional power demand, integration of the additional electrical loads into the power system may require re-evaluation of the power distribution for suitability, such as an electrical coordination study.

Scrubber Electrical Systems of this Advisory provide additional information for the consideration of electrical system for scrubber retrofitting.

DEMONSTRATION OF COMPLIANCE

For a scrubber installation, demonstration of compliance includes both the Class aspect and the statutory aspect.

The modification to the structure, piping and electrical systems as well as the evaluation for stability and electrical load analysis associated with the scrubber retrofitting are subject to class review and survey.

ABS offers the optional class notation EGC-SOx. For ships requesting such notation, additional class requirements specific to EGCS including certification of EGCS equipment as per the ABS EEA Guide will be applied in addition to statutory and general class requirements.

For ships not assigned the optional class notation the scrubber system is to comply with the minimum requirements prescribed under 1/9.11 of the ABS EEA Guide in addition to the statutory requirements.

EGC System Approval of this Advisory provides additional information regarding the approval process and demonstration of compliance.

For emission and discharge measurement, refer to Data Monitoring.

APPENDIX II, EXHAUST GAS CLEANING SYSTEM ASSOCIATION MEMBERS

While EGCS have been in widespread use on land and in inert gas systems on tankers, the widespread 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 Nijmegen BV
- ANDRITZ
- Bilfinger Enginering & Technologies GMBH)
- Bluesoul
- CEPT
- Clean Marine
- CR Ocean Engineering
- DuPont BELCO Clean Air Technologies
- Eco Spray Technologies
- Fuji Electric
- Ionada
- Lab
- Langh Tech
- MAN Diesel*
- Pacific Green Marine
- PureteQ Marine Turbo Scrubber
- Saacke Marine System
- Triton
- Valmet
- VDL AEC Maritime
- Wärtsila Hamworthy
- YARA Marine Technologies

Most of the members of the EGCSA manufacture wet scrubbers. The EGCSA periodically offers instruction courses and workshops and can be a good source of information on the latest types of scrubbers available and those being developed, technical details, performance and how an EGCS impacts the environment. EGCSA members have agreed to follow a Code of Conduct that promotes ethical and responsible actions by member companies.

* Although MAN does not offer scrubbers independently, they have developed a scrubber as an integrated part of their Tier III EGR system for NOx control.

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FREQUENTLY ASKED QUESTIONS

What would be required of a vessel if a failure occurs on its 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 under the purview 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 into the system.

ABS has determined that miscellaneous 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 achievable to maintain the vessel's propulsion and maneuvering capability, together with continual compliance with MARPOL Annex VI Regulation 14.

Are scrubber systems acceptable for use in the state of California in lieu of low-sulfur fuel?

EGCS alone is not an allowable compliance option under the California Ocean-Going Vessels (OGV) fuel sulfur requirements , except as noted below. Scrubbers can be used in ECA zones outside of Regulated California Waters per Code of Federal Regulations, but the low sulfur distillate fuel (e.g. MGO or MDO <0.1% S) must be used within Regulated California Waters (with or without the scrubber in operation).

There is an exemption provided for research projects as discussed in Marine Notice 2017-1: https://www.arb.ca.gov/ports/marinevess/documents/marinenote2017_1.pdf. However, this exemption is very limited. This exemption would only allow for the temporary use of noncomplying fuel (e.g. high sulfur heavy fuel oil) when necessary for a research project. For example, a research project could involve the emissions testing of a new scrubber design with high sulfur fuel. In this example, the use of the scrubber with high sulfur fuel would only be allowed for the duration needed to conduct the emissions testing. After that, the vessel would again need to use the low sulfur distillate fuel (even if the scrubber performed well). Also note that the research would need to use rigorous emissions testing protocols, and there would need to be a research report provided to ARB that is also available to the public.

The EPA has issued an "Interim Guidance on the Non-Availability of Compliant Fuel Oil for the North American Emission Control Area" dated June 26, 2012, which states that vessels may either use MARPOL 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).

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

Guidelines for Port State Control associated with MARPOL Annex VI are described in IMO Resolution 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 Resolution MEPC.259 (68), EGCS 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 for sample overboard discharge drawn from each EGCS 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 onboard 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.

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

The requirements for monitoring are described in MEPC.259(68) and there are installations that have substantial marine experience. In general, the monitoring devices required 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.259(68), and the details of these monitoring devices are required to be specified in the Onboard Monitoring Manual (OMM).

Scheme A – MEPC.259(68) recommends that, where a continuous exhaust monitoring system is not fitted, a daily spot check of exhaust emissions plus 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. In both cases 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 be 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 of monitoring 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. 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, U.S. 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 MARPOL Annex VI. The U.S. EPA defines PM limits for Category 1 and 2 marine engines (below 30 liters displacement/cylinder). The EPA emission measurement requirements for Category 3 engines (30 liters and over displacement/cylinder) require test bed monitoring of PM. EPA certification is required for all US flagged and US registered vessels. In response to a query put forth regarding the requirements for PM limits, the EPA advised that at this point in time that 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.

What are the IMO and regional regulations governing discharge water?

Washwater criteria limits for pH, PAH, turbidity/suspended PM and nitrates are defined in 10.1 of Resolution MEPC.259(68). The U.S. EPA washwater discharge limits are consistent with the IMO requirements in the VGP 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 the most common phenanthrene equivalent. Shipowners/operators must submit all monitoring data to the EPA's reporting system unless specifically exempted from electronic reporting. Monitoring data must be submitted at least once per calendar year, no later than February 28 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 add other conditions related to vessels in general.

In the CWA § 401 Certifications for exhaust gas scrubber washwater discharge, Connecticut prohibits the discharge of exhaust gas scrubber water and Hawaii requires the reporting of specific information regarding the onboard treatment system

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

As per 2.2.26.2.2 of the 2013 VGP, in addition to the continuous monitoring found in Part 2.2.26.2.1 of this permit, vessel owner/operators must collect and analyze two samples in the first year of permit coverage or system operation, whichever is first, for each of the constituents analyzed in Part 2.2.26.2.3 to demonstrate treatment equipment maintenance, probe accuracy and compliance with this permit. Samples must not be collected within 14 days of each other. Samples must be collected from inlet water (for background), water after the scrubber (but before any treatment system) and discharge water. For all vessels, one of those samples may be conducted as part of vessel's annual or other survey, and during the first year, one of those sampling events may be conducted as part of the installation of the system to ensure it is functioning properly.

After the first year, samples must be collected at least once per calendar year from inlet water (for background), water after the scrubber (but before any treatment system) and discharge water, and may be collected as part of the vessel's annual survey as appropriate. Records of the sampling and testing results must be retained onboard for a period of 3 years in the vessel's recordkeeping documentation, consistent with Part 4.2 of the 2013 VGP.

Are SOx scrubbers compatible with Selective Catalytic Reduction (SCR) or Exhaust Gas Recirculation (EGR) systems for NOx removal, considering Tier III requirements?

Vessels built after 1 January 2016, if operated within the North American and US Caribbean ECAs, or vessels built after 1 January 2021 and operated within North Sea and Baltic Sea ECAs, will need to meet NOx Tier III requirements. One option is to use NOx Tier III technology (e.g. EGR/SCR) to comply with Regulation 13 of MARPOL Annex VI in combination with compliant fuel oil (i.e. 0.10% sulfur content) to comply Regulation 14 of MARPOL Annex VI.

Other options are to use Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction (SCR) systems along with an EGCS (SOx scrubber) with the use of conventional high sulfur HFO.

When an EGR and SOx scrubber are used, the process takes out approximately 30%-40% of the exhaust gas which is washed with a scrubbing unit built in the EGR if high sulfur HFO is used. Sulfur and PM (Particulate Matter) are removed from the exhaust gas before it is recycled back into the engine cylinder as charged air. In general, a SOx scrubber in combination with EGR arrangements would not be in conflict. This combination may fully comply with both NOx and SOx requirements.

A SCR system requires high exhaust inlet temperatures to work. As a result, when a SOx Scrubber and SCR are used, the SCR system must be deployed upstream of the SOx scrubber. This means the SCR needs to deal with the fuel sulfur content, which may be a problem for some SCRs. Most manufacturers have catalyst technologies which allow SCR operation at a higher SOx content, however the catalyst service life expectancy may reduce at higher SOx exhaust levels. The simultaneous use of a SCR and SOx scrubber in the exhaust stream will increase back pressure, which may influence engine performance causing an increase of specific fuel oil consumption (SFOC) and a power reduction leading to increase of engine maintenance frequency. The shipowner is advised to inquire about catalyst service life expectancy at higher SOx exhaust levels, and identify the upper sulfur limit for the specific SCR.

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 sulfur limits 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.

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

The residues from the exhaust scrubbing processes cannot be incinerated onboard 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 capacity by 2015, the shipowner is 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.2, which contains an entry for exhaust gas cleaning residues) based on information sent by a ship having encountered difficulty in discharging waste to reception facilities – see MARPOL Regulation VI/17.2 and 17.3.

CHECKLIST FOR OWNERS

BASELINE FOR COMPLIANCE WITH LOW SULFUR REQUIREMENTS

1. The compliance with ECA sulfur cap requirements and 2020 global sulfur cap requirements may be through the following:
    a. Use of sulfur compliant fuel for inside and outside ECA respectively, or
    b. A combination of a scrubber/HFO operation outside ECA and use of 0.1% s compliant fuel inside ECA, or
    c. The installation and operation of a scrubber/HFO operation inside and outside ECA that achieve equivalent SOx emission level of 0.1% s and 0.5% compliant fuel

The above a) and b) approaches could involve the use of fuel with different characteristics. The ABS Marine Fuel Oil Advisory may be referred to for in-depth technical guidance covering a range of topics, from engine considerations to fuel properties to operational risks

SCRUBBER INSTALLATION FEASIBILITY – NEW VESSELS

1. Determine the operating ports and coastal areas in which the ship will be operating 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 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 designs.
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 will not operate in areas with water discharge restrictions or low alkalinity waters, 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.
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.
    a. For an integrated scrubber, the proposal should detail how exhaust gas will be prevented from entering offline engines. The scrubber proposal should include or indicate the following items:
        i. Weight and size of the scrubber
        ii. Need for bypass, bypass valve and silencer
        iii. Expected backpressure over a range of loads
        iv. Exhaust fan requirements and redundancy measures
        v. 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
    b. For closed loop systems, the proposal should include the amount of washwater bleed-off expected.
        i. Method of processing the water to make it acceptable for discharge or reuse and details of required equipment. For discharged washwater, the proposal should specify the method to adjust pH and other characteristics to meet permitted limits.
        ii. 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.

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

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

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

vi. 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

vii. 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.

viii. 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

ix. 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 are 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, 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 of 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 scrubber? 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 its impact will be 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, 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 dry docking 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).

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
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
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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