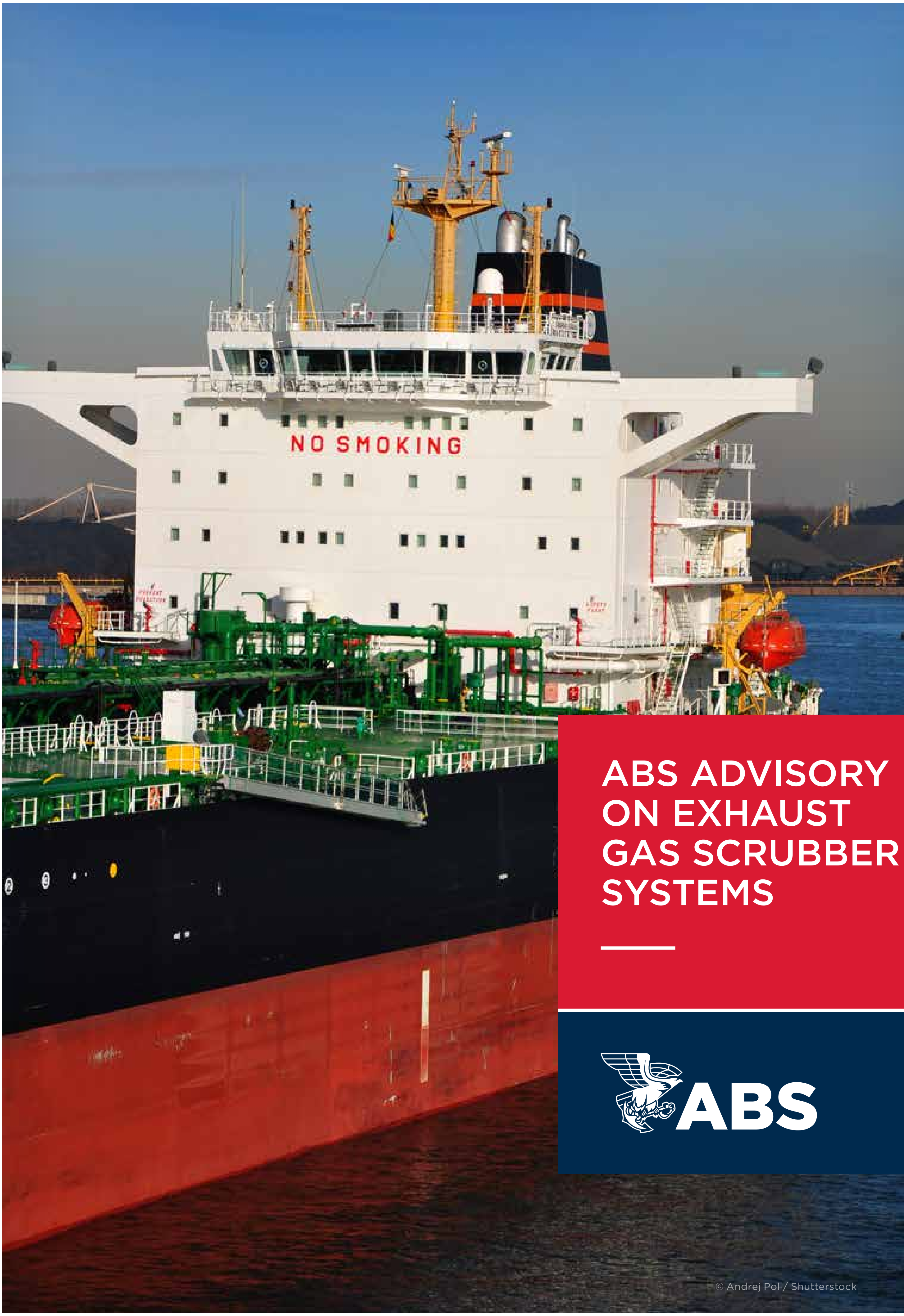


# ABS ADVISORY ON EXHAUST GAS SCRUBBER SYSTEMS

ABS

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# INTRODUCTION

The marine industry is facing the challenge of adopting new technologies and/or operational practices to comply with stricter international, regional, national and local regulations introduced to reduce air emissions from ships. The adverse effects of exhaust emissions from internal combustion engines and boiler exhaust gases on human beings and sensitive ecosystems have been well documented by the scientific community. The objective of regulations introduced by the International Maritime Organization (IMO), the European Union (EU), the 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 to reduce the negative impact shipping makes 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 marine fuels. Ship designers, owners and operators have a number of different routes to achieve SOx regulatory compliance:

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

This Advisory was produced to summarize 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 vessel compliance with current and future exhaust gas emission regulations.

Marine air pollution regulations typically require the use of low-sulfur fuel in order to reduce SOx gaseous emissions and the sulfate portion of the particulate matter (PM) emissions. However, the use of EGCS technology is generally permitted as an alternative means of compliance. While EGCS have limited commercial marine references, they are proven technologies with numerous land-based installations and applications as part of the inert gas systems on tankers. Scrubbers can be effective in complying with regulations that require the use of 0.1 percent sulfur fuel.

With regard to meeting the regulatory requirements for emissions of nitrogen oxides (NOx), a typical EGCS provides only negligible reduction in NOx emissions and is not an effective method for obtaining compliance with NOx emission requirements. A number of primary (engine) and secondary (after treatment) techniques for reducing NOx emissions exist. One primary engine technique is the use of exhaust gas recirculation (EGR), which involves the recirculation of a portion of the exhaust gas, typically 20 to 40 percent, back into the combustion chamber. For marine applications, this technique may include an EGCS to prevent engine fouling, corrosion and wear issues because of the relatively high sulfur content in the fuel. In these circumstances the general concepts detailed in this Advisory would be applicable to the scrubber part of an EGR system. IMO is currently in the process of developing guidelines applicable to the bleed off water from EGR systems. Selective catalytic reduction (SCR) after treatment systems may be used as a means of reducing NOx emissions, which have the potential to reduce emissions by up to 95 percent. EGR and SCR systems are not specifically covered by this Advisory.

While scrubbers offer the potential for lower operating costs by permitting the use of less expensive high-sulfur fuels, capital, installation 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 burned where mandated, has its own complications and risks but should also be considered during an evaluation of fuel compliance options. The ABS Fuel Switching Advisory should be referenced for more information on 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. This Advisory contains three key sections:

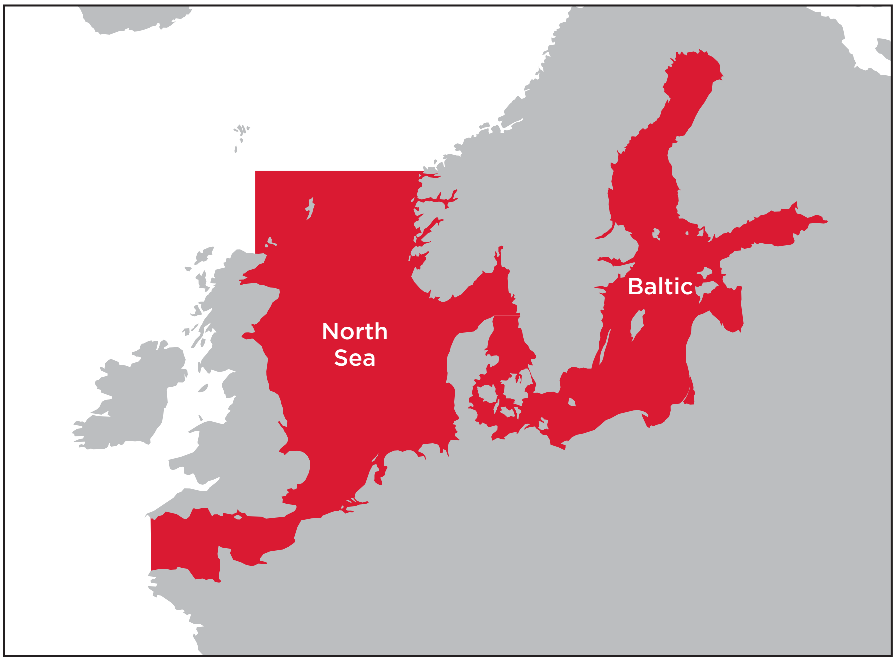
| | |
|---|---|
| Section 1 | Regulatory Background and Requirements |
| Section 2 | EGC System Concepts |
| Section 3 | Considerations for EGC System Selection |

# 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 marine fuels of 4.5 percent and a limit within designated SOx emission control areas (SECA) of 1.5 percent. 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*



The 58th IMO MEPC session, in October 2008, 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 MEPC 70 held in October 2016, member states agreed that a 0.5 percent global sulfur cap on marine fuel will be implemented from 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*

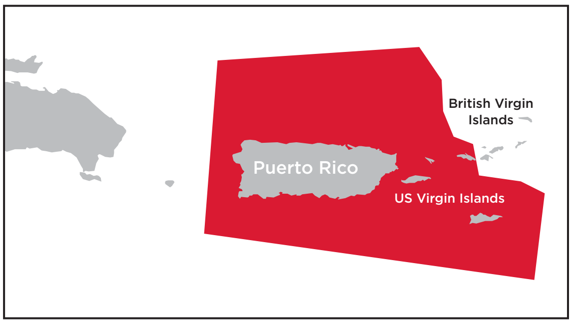
| IMO Global | | SECA/ECA | |
|---|---|---|---|
| **Date** | **Sulfur %** | **Date** | **Sulfur %** |
| Initial limits | 4.5 | Initial limits | 1.5 |
| Jan 1, 2012 | 3.5 | Jul 1, 2010 | 1.0 |
| Jan 1, 2020 | 0.5 | Jan 1, 2015 | 0.1 |

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. At present, IMO does not define PM limit criteria but PM is significantly reduced through the reduction of the sulfate portion of the PM, by the use of low-sulfur fuels or other technological means such as 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 all ships to 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 (i.e. outside SECAs) beginning January 1, 2020. The EU have now issued Directive (EU) 2016/802 which has codified the original 1999 Directive and subsequent amendments into a single codified 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 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 LNG and 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.

## 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. Canadian vessels operating only within the Great Lakes are exempt from the NOx requirements contained in Title 40 of the CFR, as Canada established an alternative NOx control measure that is in accordance with the Vessel Pollution and Dangerous Chemicals Regulations (SOR/2012-69) under the Canada Shipping Act.

Environmental regulatory policy in the U.S. is developed by the EPA and, for marine applications, policies were implemented through 40 CFR Part 94, Part 1042 and Part 1043. The EPA set emission standards for all new compression ignition engines intended for use on a commercial marine vessel. The regulations are set as a tiered approach to emission reductions across three categories of engines: Category 1: under 7 liters; Category 2: 7 to under 30 liters; and Category 3: 30 liters and above. Additional limits on hydrocarbons (HC), carbon monoxide (CO) and, for category 1 and 2 engines, PM apply. The U.S. EPA has a goal to reduce PM as part of the overall objective of reducing harmful emissions from engine exhaust. While no PM standards apply for Category 3 engines, PM emissions must be measured for certification testing and reporting.

EPA certification is required for all U.S. flagged vessels. The EPA requirements differ in a number of fundamental areas from the IMO requirements. For example, the EPA requires an engine to remain within the certified emissions limit throughout its service life and has identified a 'not to exceed' (NTE) limit requiring engine emissions to remain within defined limits from the individual emission test cycle mode points.

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.

Vessels must comply with all Federal and State regulations; individual U.S. States have set additional air emission limits. 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 CARB regulations do not specifically allow the use of any fuel other than low-sulfur distillate fuel for compliance. However, CARB has permitted the use of ECA compliant non-distillate, low-sulfur fuel or equivalent alternative emission control technologies under a 'Research Exemption', which is applicable during the sunset review period. This is the period during which CARB staff will evaluate the emission reductions achieved by the ECA Regulations and compare them to the emission reductions achieved by the California OGV Fuel Regulation. In all cases, the vessel owners/operators must notify the CARB authority to agree to the 'Research Exemption'. The notification is to be sent prior to the first entry into regulated California waters.

*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 0.5% sulfur |
| | August 1, 2012 | Marine gas oil (DMA) at or below 1.0% sulfur; or Marine diesel oil (DMB) at or below 0.5% sulfur |
| **Phase II** | January 1, 2014 | Marine gas oil (DMA) at or below 0.1% sulfur; or Marine diesel oil (DMB) at or below 0.1% 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 for more than two hours. From January 1, 2017, ships at berth must use fuel with ≤ 0.5 percent sulfur content; from January 1, 2019 this fuel limit is also applicable within the PRC Marine ECAs. The use of alternatives such as shore power connections or EGCS is permitted. Emission control requirements include:

1. As of January 1, 2016, ships shall implement existing international conventions and domestic laws and regulations for SOx, PM and NOx emission control. Ships at berth within an ECA may voluntarily use fuel with ≤0.5 percent sulfur content, or permit the implementation of equivalent measures that achieve emissions equivalent to the use of fuel with a sulfur content of ≤ 0.5 percent.
2. Starting from April 1, 2016, it became mandatory for ships at berth in the Yangtze River Delta core ports that include Shanghai, Ningbo-Zhoushan, Suzhou and Nantong to burn fuel with a sulfur content of ≤ 0.5 percent.
3. Notwithstanding the timeline identified in (6), (7) and (8) below, based on an assessment of the effectiveness of the measures enforced in the Yangtze River Delta ECA, a decision will be taken whether or not to enforce the following actions in the future, which may or may not precede those identified in (6), (7) and (8) below:
   a. Ships operating within the Yangtze River Delta ECA to use fuel with ≤0.5 percent sulfur content
   b. Ships operating within the Yangtze River Delta ECA to use fuel with ≤0.1 percent sulfur content whilst at berth.
   c. Ships operating within the Yangtze River Delta ECA to use fuel with ≤0.1 percent sulfur content
4. Beginning October 1, 2016, the core port of Shenzhen of the Pearl River Delta ECA requires the use of fuel with a sulfur content of ≤0.5 percent for vessels at berth.
5. Starting January 1, 2017, ships at berth one hour after arrival and up to one hour before departure in core ports within the Pearl River Delta and Bohai Rim Area ECA should use fuel with ≤0.5 percent sulfur content.
6. Beginning January 1, 2018, ships at berth in all ports within the ECA should use fuel with ≤0.5 percent sulfur content.
7. Starting January 1, 2019, ships operating within the ECA should use fuel with ≤0.5 percent sulfur content.
8. 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 conduct the actions below:
   a. Ships operating within the ECA to use fuel with ≤0.1 percent sulfur content
   b. Expand the ECA
   c. Other further action
9. 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 compliant fuel until one hour prior to departure
- Record dates and times of 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 capability of achieving 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.

## IMO EXHAUST GAS CLEANING SYSTEM (EGCS) GUIDELINES

The development of EGCS for use on-board 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 guidelines provide guidance for the monitoring of the $SO_2/CO_2$ content of the exhaust gases for varying sulfur contents of the fuel (see Table 3) to provide equivalency to the prescribed specific SOx emission limits as stipulated in Regulations 14.1 and 14.4.

The 2008 revision to 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 would need 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 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).

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

The two 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 on board 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 need to be pre-certified as meeting the emission limit value but must demonstrate compliance with the required equivalent emission values to the fuel sulfur content requirements 14.1 and 14.4 of 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 shipowners should be supplied with an EGCS Record Book in the same manner as Scheme A.

## REQUIRED EGC SYSTEM 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: EGC System Sulfur Content Emission Equivalence*

| Fuel Oil Sulfur Content (% m/m) | Ratio Emission $SO_2$ (ppm)/$CO_2$ (% v/v) |
|---|---|
| 4.5 | 195.0 |
| 3.5 | 151.7 |
| 1.5 | 65.0 |
| 1.0 | 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 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 II to the 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 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 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 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 sea water, 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)).

During commissioning of EGCS, 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, 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 are 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 EGC system is certified (Scheme A) or used with (Scheme B)
3. Where the washwater flow rate is varied in accordance with the EGC system 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

## POLYCYCLIC AROMATIC HYDROCARBONS

The washwater discharge is also to be monitored for polycyclic aromatic hydrocarbons (PAH), whereby the maximum continuous PAH concentration is not to be greater than 50μg/L PAHphe (phenanthrene equivalence) above the inlet water PAH concentration. The 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. MWh 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 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 Guideline. 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 are tested for nitrates in the discharge water and, if typical levels are above 80 percent of the upper limit, they should be recorded in the ETM-A or ETM-B.

## DATA MONITORING

The 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.

- When the system is in use, time against Universal Coordinated Time (UTC) and vessel position by Global Navigational Satellite System (GNSS) position
- Washwater pressure and flow rate at the inlet connection
- Exhaust gas pressure before and pressure drop across the scrubber
- Engine and/or boiler load(s)
- Exhaust temperature before and after the scrubber
- Exhaust gas $SO_2$ and $CO_2$ content
- Washwater pH, PAH and turbidity

The data recording device should be robust, tamper-proof, 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 on board and available as may be required. The device should be able to download a copy of the recorded data and reports in a readily usable format. The copy of the data and reports should be made available to the flag Administration or Port State Control (PSC) authorities upon request.

## U.S. ENVIRONMENTAL PROTECTION AGENCY (U.S. EPA)

The EPA's Vessel General Permit (VGP) 2013 regulations cover scrubber washwater discharge limits, which have some variations compared to the IMO guidelines. Differences include the pH of the washwater discharged from the scrubbing process to be no less than 6.0 measured at the ship's overboard discharge and no other methodology of pH determination would be acceptable. This requirement would be applicable within 3 nm of U.S. shores. 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 nm 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 Guidelines.

## WASHWATER RESIDUES

Residues from the EGCS washwater are to be collected on board 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 on board is not permitted. It is also mandated by the Guidelines that storage and disposal of such residues are to be recorded in the EGC Record Book, inclusive of the date, time and location of delivery. The EGC Record Book may form a part of an existing logbook or electronic recording system as approved by the Administration.

## EGCS SYSTEM APPROVAL

There are two basic parts to obtaining full approval of an EGC system: the statutory MARPOL approval process covering the environmental performance aspects, and classification society approval to the individual society's rules. Type approval from a classification society covers 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*

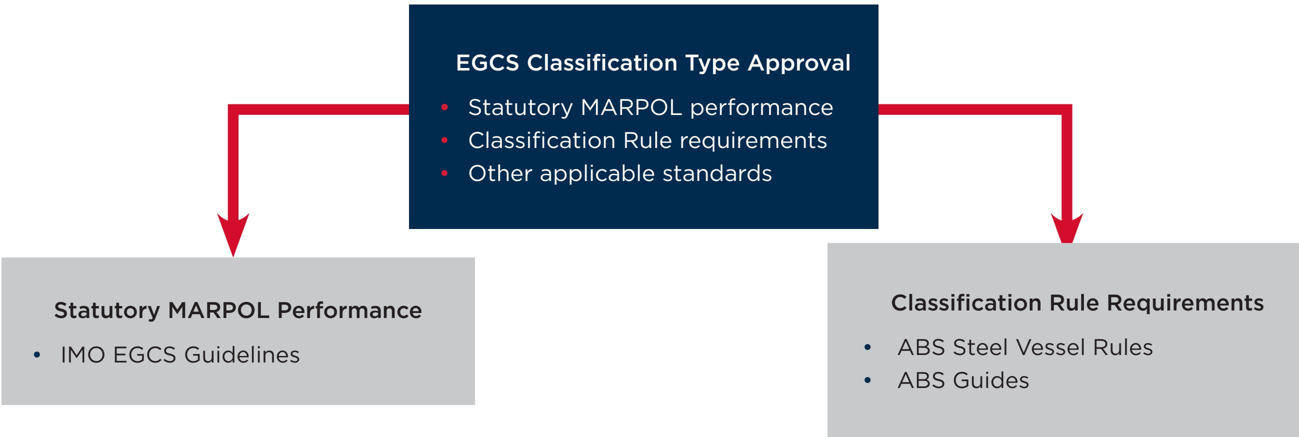
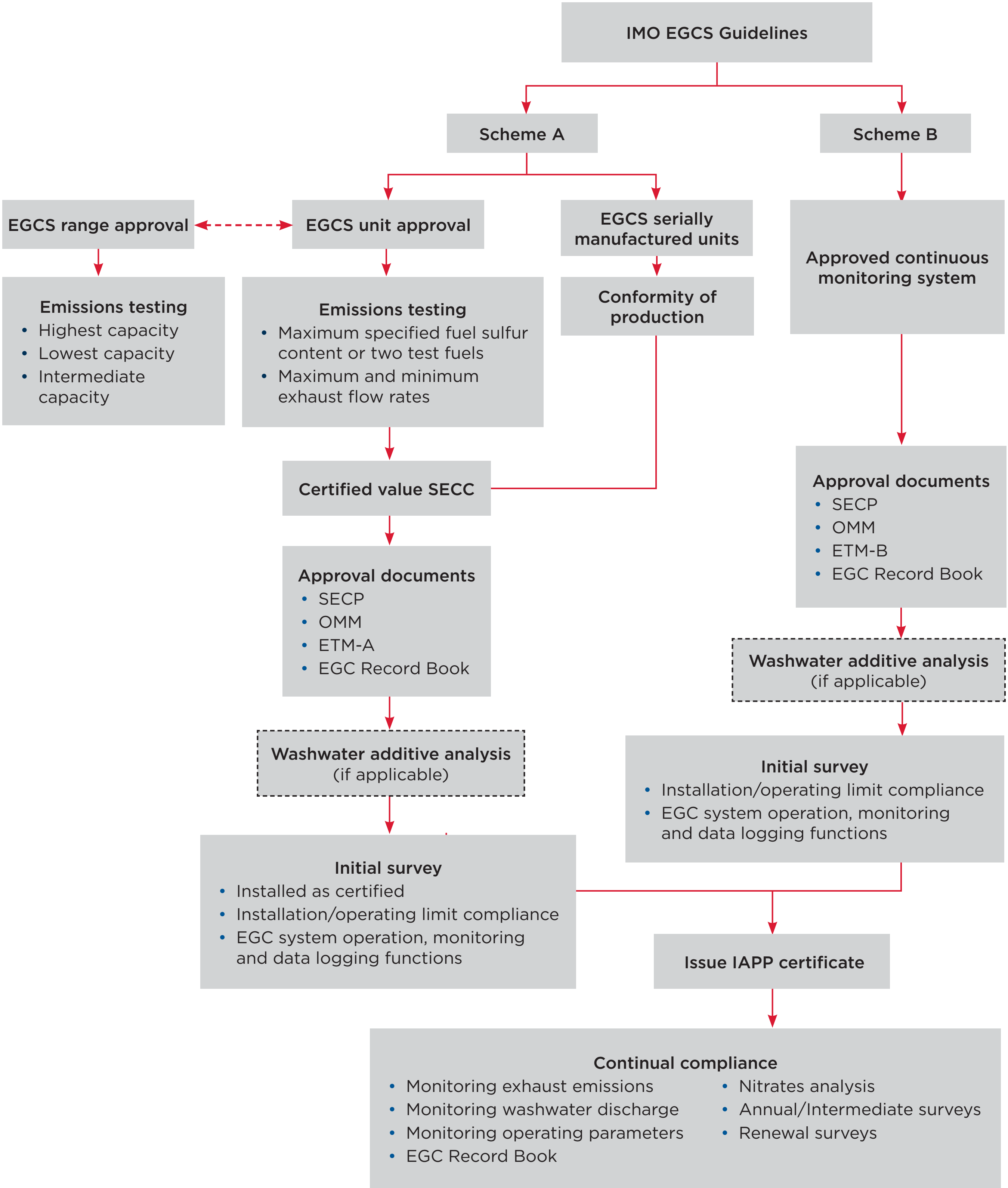



*Figure 6: EGCS Statutory Approval*


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 RO. 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 Guidelines requires a number of steps, as depicted in Figure 7. Application for approval is typically made by the equipment supplier, in association with the shipowner, since a number of the elements can be assessed during design and manufacturing, but full verification is vessel-specific and requires in-situ testing after installation.

*Figure 7: Statutory Performance Approval*



# EGCS SYSTEM 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 emitted 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.

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

Engine Exhaust Gas Chemistry:

$S + O_2 \rightarrow SO_2$ ~ 95%
$SO_2 + \frac{1}{2}O_2 \rightarrow SO_3$ ~ 5%

SOx Reactions in a Scrubber:

$SO_2 + H_2O \rightarrow H_2SO_3$
(Sulfurous Acid)
$SO_3 + H_2O \rightarrow H_2SO_4$
(Sulfuric Acid)

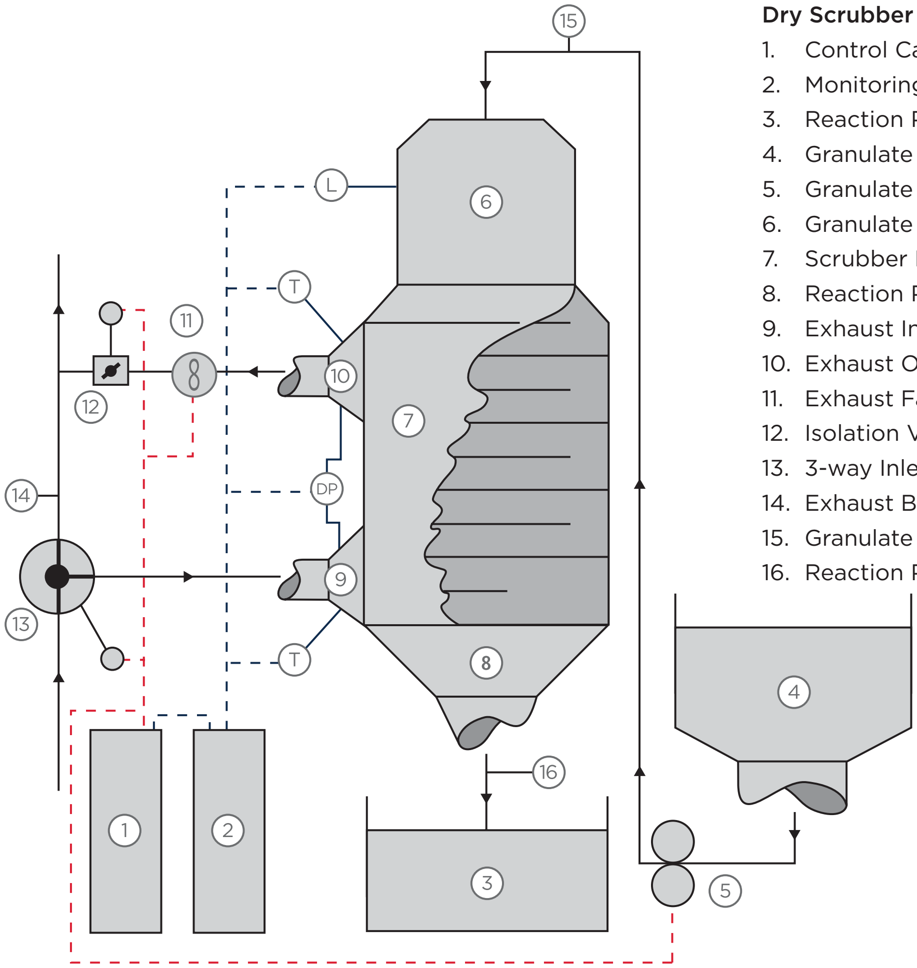
Sulfurous gases in water are in a state of rapid oxidation; sulfur dioxide ($SO_2$) oxidizes to sulfur trioxide ($SO_3$), which dissolves in water to form sulfuric acid ($H_2SO_4$). Also, upon dissolution in water, $SO_2$ forms the hydrate $SO_2 + H_2O$ or sulfurous acid $H_2SO_3$, which dissociates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

There are two basic concepts commonly proposed for shipboard application of EGCS: the dry scrubber-type and the wet scrubber-type. The basic principles for the dry and wet scrubbing concept are described further in this section.

## DRY SCRUBBERS

A dry scrubber does not use water or any liquid to carry out the scrubbing process, but instead exposes hydrated lime-treated granulates to the exhaust gas to create a chemical reaction that removes the SOx emission compounds. Since the exhaust does not pass through water it is not cooled, therefore, dry scrubbers can be placed before an exhaust gas economizer (EGE) or used in conjunction with SCR units, which typically require exhaust gas temperatures above 350° C to enable the catalysts to operate correctly, reducing both SOx and NOx emissions. They are commonly used on land-based EGC installations. A schematic of a dry scrubber system is shown in Figure 8.

*Figure 8 : Dry Scrubber System*




**Dry Scrubber System**

1. Control Cabinet
2. Monitoring Cabinet
3. Reaction Product
4. Granulate Storage
5. Granulate Pneumatic Conveyor
6. Granulate Silo
7. Scrubber Reactor
8. Reaction Product
9. Exhaust Inlet
10. Exhaust Outlet
11. Exhaust Fan
12. Isolation Valve
13. 3-way Inlet/Bypass Valve
14. Exhaust Bypass Manifold
15. Granulate Sorption Inlet
16. Reaction Product Outlet

Dry scrubbers use granulates with caustic lime (Ca(OH)2) that reacts with sulfur dioxide ($SO_2$) to form calcium sulfite:

$SO_2 + Ca(OH)_2 \rightarrow CaSO_3 + H_2O$

Calcium sulfite is then air-oxidized to form calcium sulfate dehydrate or gypsum:

$CaSO_3 + \frac{1}{2}O_2 \rightarrow CaSO_4$

Reaction with sulfur trioxide ($SO_3$) is:

$SO_3 + Ca(OH)_2 \rightarrow CaSO_4 + H_2O$

Which with water forms:

$CaSO_4 \cdot 2H_2O$ (Gypsum)

## WET SCRUBBERS

The exhaust gas passes through a liquid medium in order to remove the SOx compounds from gas by chemically reacting with parts of the wash liquid. Systems are identified by their operation 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 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 such as $SO_2 + H_2O + \frac{1}{2} O_2 \rightarrow H_2SO_4$ (sulfuric acid) can take place depending on the chemistry of the liquid. In all cases, alkaline liquid must be provided to neutralize the acidic SOx-based constituents.

In an open loop 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, freshwater/seawater 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

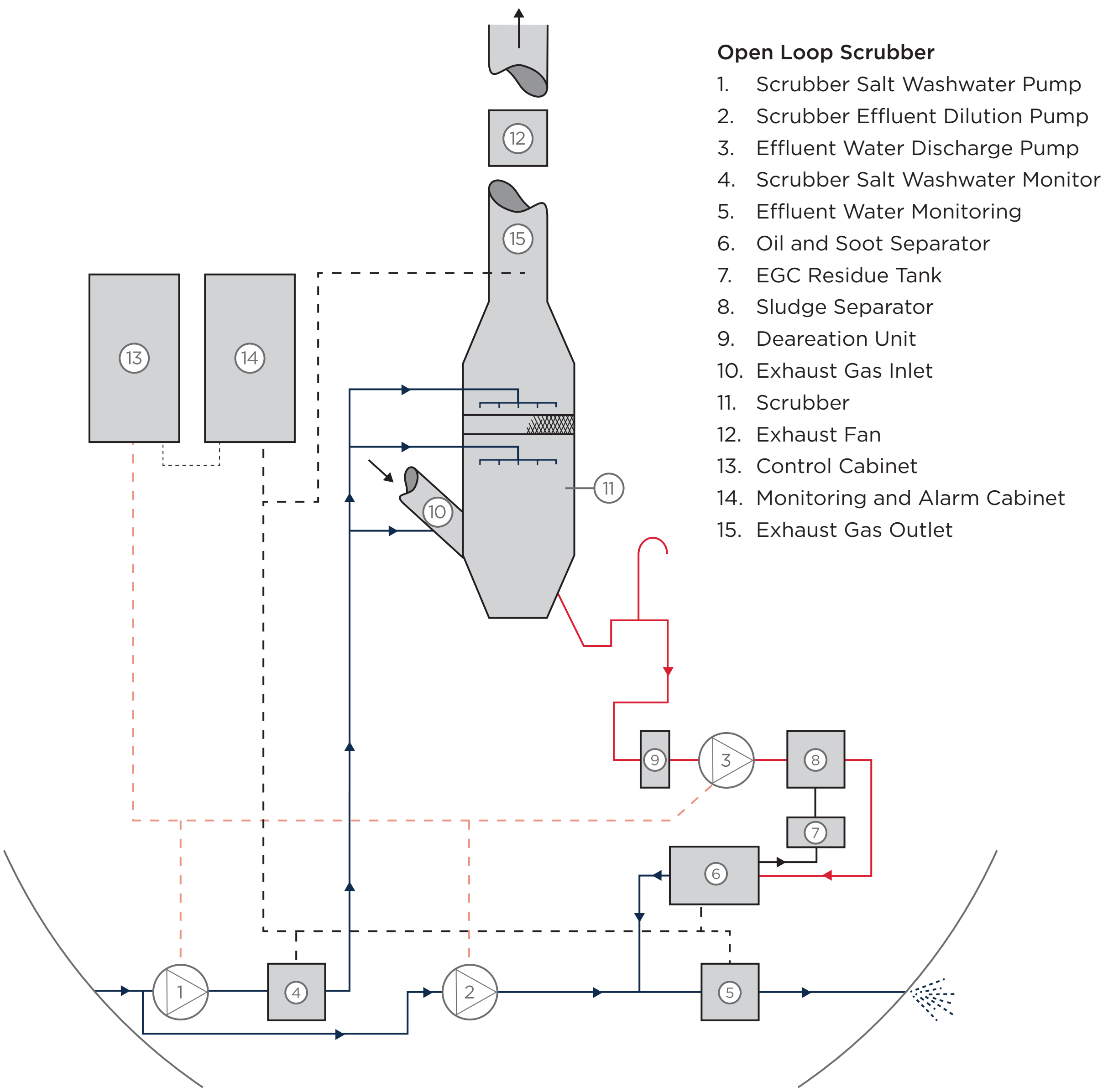
An open loop scrubber uses seawater as the medium for cleaning or scrubbing the exhaust, as shown in Figure 9. Seawater is normally supplied by a dedicated pump.

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

$Na_2CO_3 + H_2SO_3 \rightarrow Na_2SO_3 + H_2O + CO_2$ (Sodium Sulfite)
$Na_2SO_3 + \frac{1}{2}O_2 \rightarrow Na_2SO_4$ (Sodium Sulfate)
$Na_2CO_3 + H_2SO_4 \rightarrow Na_2SO_4 + H_2O + CO_2$ (Sodium Sulfate)

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

*Figure 9 : Open Loop Scrubber System*



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 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 EGC system unit.

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

The collected residue will contain PM, ash, heavy metals, etc. removed from the exhaust gas, as well as insoluble calcium sulfate and silt entrained in washwater drawn from estuaries, rivers or harbor waters. Where the source of the washwater has a large amount of silt, this silt can make up the dominant portion of the sludge volume. Sludge generated from substances like silt in the incoming water can cause issues only with open loop scrubbers.

Once the residuals are cleaned from the washwater, the washwater can be discharged overboard or retained on board if discharge of such water is restricted. In most cases, the discharge washwater pH can be adjusted by diluting the acidic substances in the washwater by increasing through-put when using open loop systems, or by diluting it with 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.

## CLOSED LOOP SCRUBBERS

In a closed loop-type scrubber, treated water is circulated through the scrubber to keep the scrubbing process independent of the chemistry of the waters the vessel is sailing in. There is little or no water discharged overboard from the scrubbing process, thus reducing the need for processing the washwater to make it suitable for discharge. Sodium hydroxide as a chemical additive is typically used in marine EGCS to control the water alkalinity, which can also be produced by electrolysis of seawater (see Figure 10).

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 caustic soda 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 caustic soda injection process.

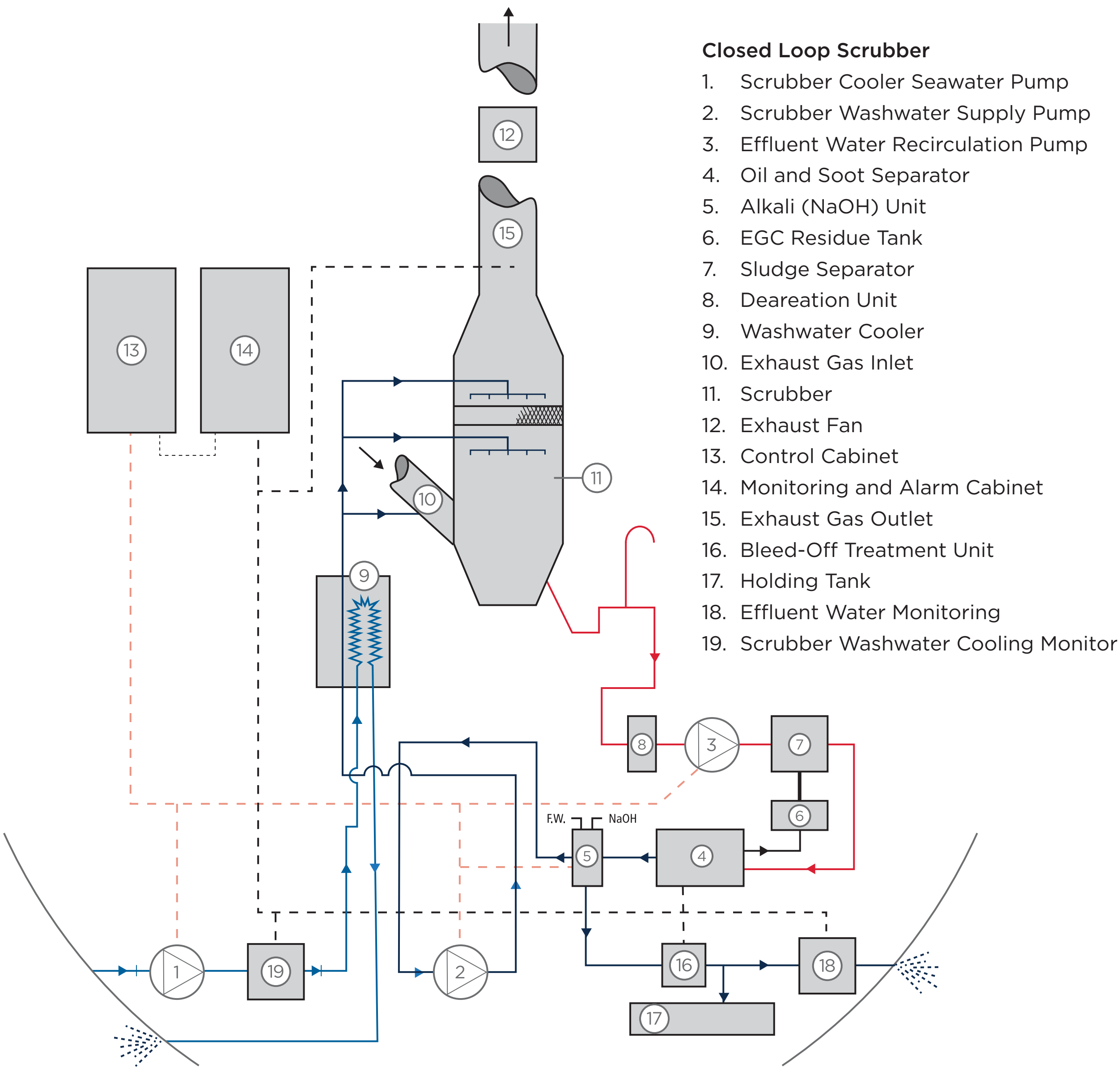
In fresh water scrubbers, $SO_2$ combines with a salt and consequently does not react with the natural bicarbonate of seawater. There is no release of $CO_2$.

$2NaOH + SO_2 \rightarrow Na_2SO_3 + H_2O$ (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. A limited quantity of washwater from the bottom of the process tank, where the residuals have collected, is extracted using low suction. It then goes to a hydro-cyclone or separator, similar to an open loop system, where the residuals are removed, or for some systems the extracted water passes through a bleed-off treatment unit (BOTU).

During any of the 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, 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.

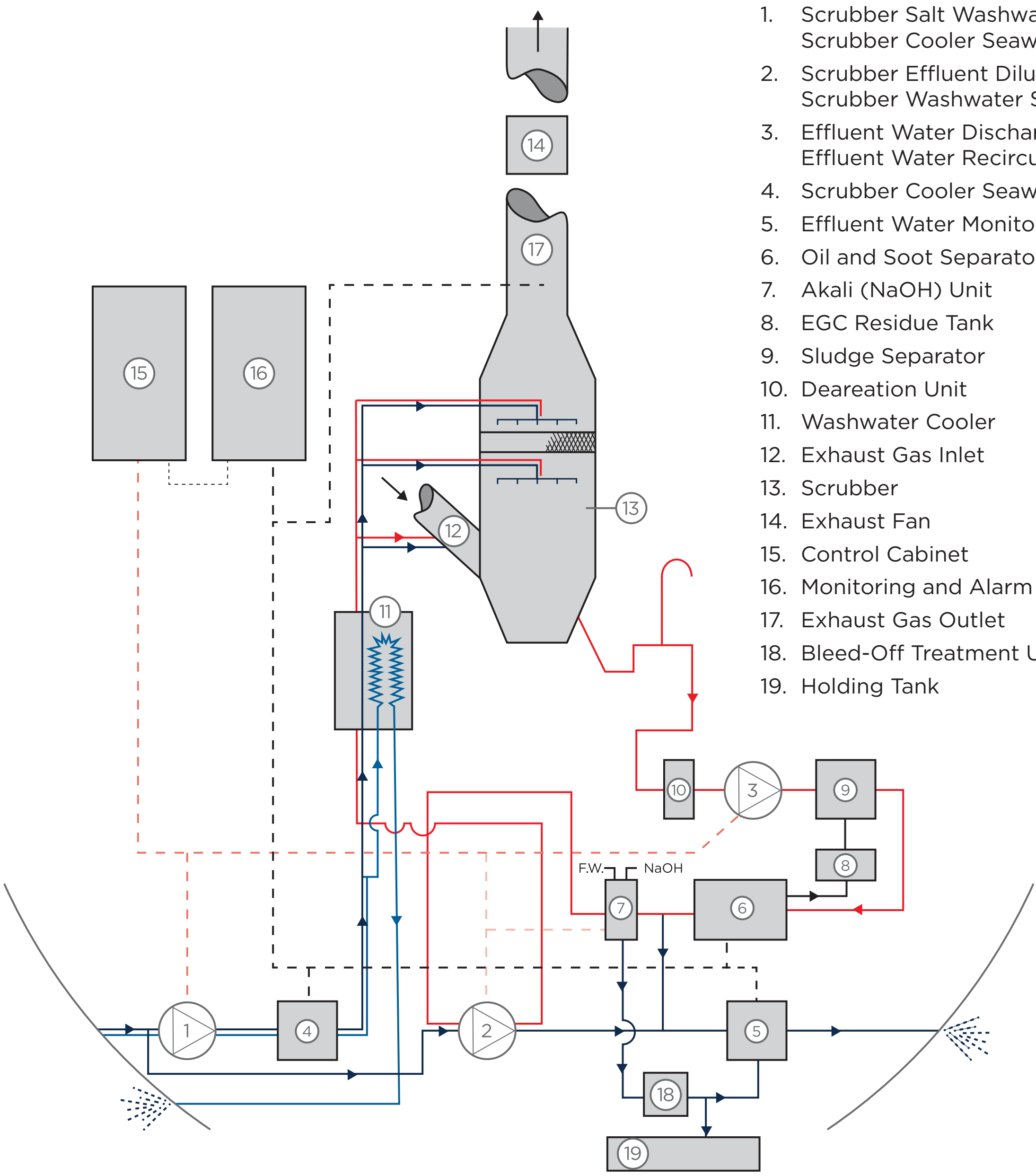
*Figure 10: Closed Loop Scrubber System*



## HYBRID SCRUBBERS

There are advantages to open loop-type systems, such as the avoidance of purchasing and handling 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 river area (see Figure 11). The changeover from open to closed loop is done by changing over the circulating pump suction from seawater to the freshwater circulating tank, and by changing the washwater discharge from the overboard discharge to the circulating tank.

*Figure 11: Hybrid Scrubber System*




**Hybrid Scrubber**

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

## EFFECTIVENESS OF WET SCRUBBERS

Since the primary goal of scrubbers is removal of SOx from the exhaust stream to achieve SOx emission levels equivalent to ships consuming low-sulfur fuel, the effectiveness of scrubbers in SOx removal is of great importance and the key measure of their performance. There are a limited number of wet scrubbers in service, so an exhaustive amount of data demonstrating the effectiveness of scrubbers on a long-term basis is currently in the development stage. 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. Alkalinity of water is expressed in units of pH, and 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 6 lists estimates of scrubber effectiveness in the removal of harmful substances from exhaust gases based on minimum levels of alkalinity being present in the washwater.

*Table 6: 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.

# EMERGING TECHNOLOGIES

## MEMBRANE SCRUBBER SYSTEM

Newly developed 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 contactor to 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. A schematic of the membrane scrubber system is shown in Figure 12.

The membrane scrubber consists of an array of ceramic tube membranes suspended in the exhaust stream as depicted in Figure 12. 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.

*Figure 12: Membrane Absorption Module*

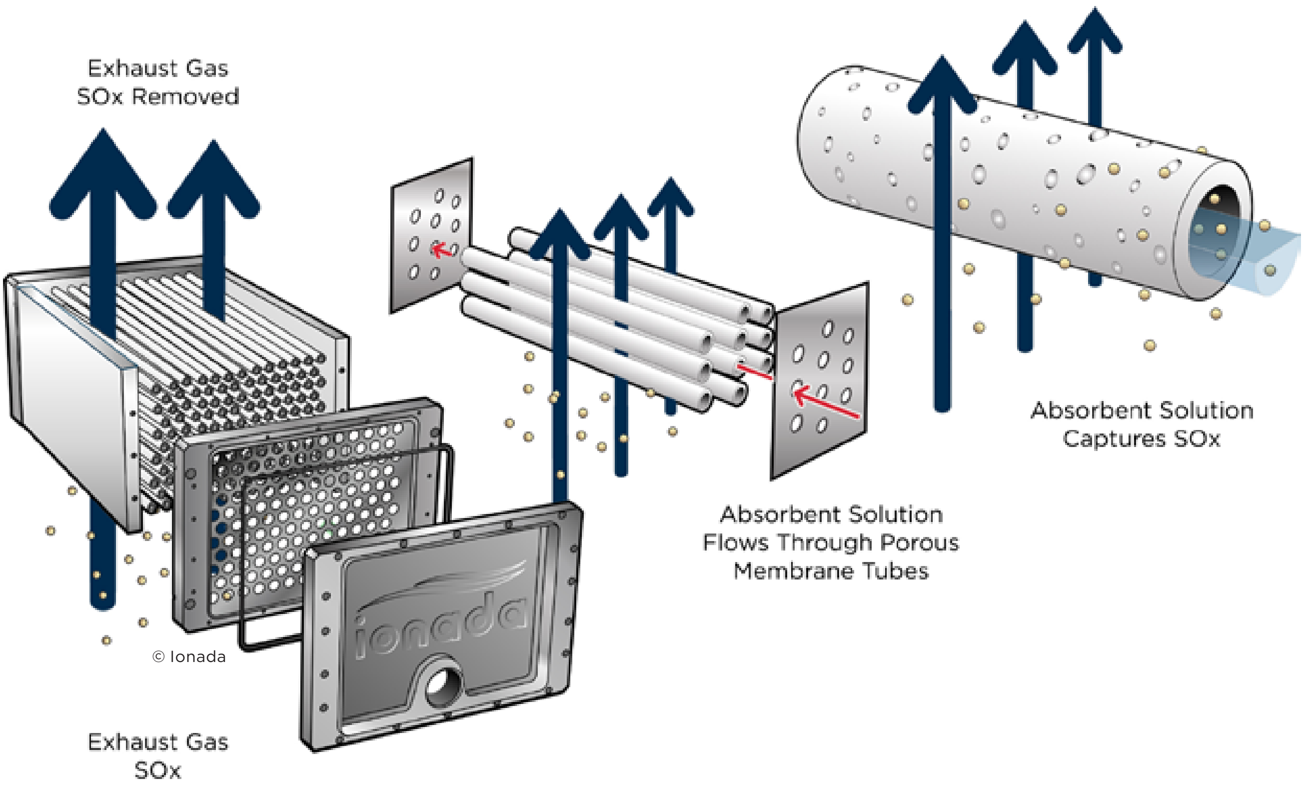


*Figure 13: Membrane Scrubber Schematic*

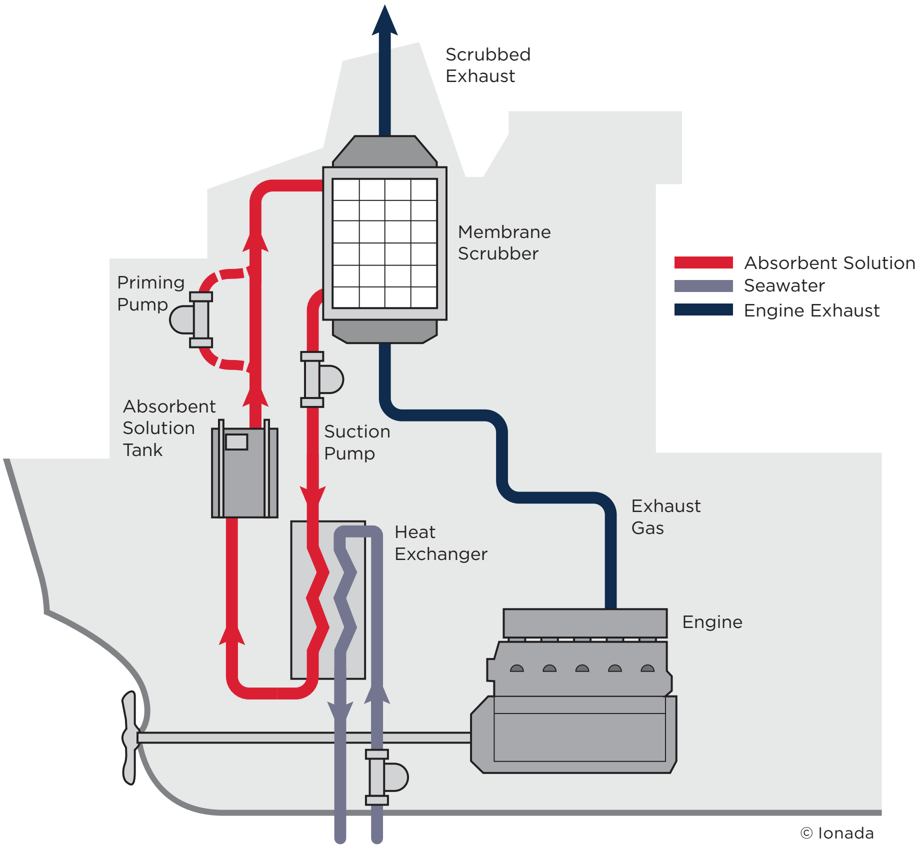





Figure 13 depicts a simplified system schematic. At startup, the priming pump draws caustic solution from the absorbent solution tank and primes the Membrane Scrubber with caustic solution. Once primed, the priming pump is turned off and the suction pump is turned on to draw the caustic solution through the membrane scrubber, maintaining a constant suction/negative pressure on the system. The discharge from the suction pump is passed through a plate and frame seawater heat exchanger to cool the caustic solution and discharged back into the absorbent solution tank.

The membrane scrubber modules can be turned off or on to adjust to the load on the engine and fuel sulfur concentrations, improving operating efficiencies and dynamic loading response.

There is no wastewater generated during the regular operation of the membrane scrubber and no water is consumed during the regular operation of the scrubber. This is in contrast to wet scrubbers that require feed water saturating the exhaust gas with moisture. Therefore the membrane scrubber exhaust does not have the steam plume cloud typical of wet scrubbers.

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.

The membranes require periodic cleaning to remove soot fouling on the membrane outer surfaces. The frequency of cleaning is dependent on operating conditions of the engines. The membranes are regenerated by turning on the priming pump and pressuring the membrane scrubber. The caustic solution under pressure will 'back wash' the membranes.

Some claim 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 no longer concerns. The key disadvantage of the membrane scrubbers over wet open loop scrubbers is the additional operating cost of the caustic soda.

# CONSIDERATIONS FOR EGC SYSTEM SELECTION

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

For retrofit installations, engine exhaust system casing modifications previously mentioned, together with space necessary for new pumps and piping systems, including possibly new sea chests and overboard discharges, plus space for the alkaline material storage (for closed loop scrubbers) and wastewater processing can mean significant conversion work. There may not be space available in existing engine rooms, and other spaces would need to be modified to fit new equipment; 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.

## DRY SCRUBBER USAGE RATES AND DIMENSIONS

For a typical dry scrubber system, 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 on board 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 7 and Figure 14 show the principal dimensions based on the engine power rating for scrubbers (see Appendix II for more detailed information). 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 may need to be considered based on the increased wind profile and additional weight of the scrubber.

*Figure 14: Scrubber Dimension Layout*




*Table 7: 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 would experience higher operating temperatures which, therefore, limits the materials selection to high temperature acid and chloride-resisting alloys; typically nickel alloys. Ferritic-austenitic stainless steels (duplex stainless steels) have also been shown to perform well in corrosive environments. Above the lower portions of the scrubber unit a less corrosion-resistant stainless steel is often used. However, the selection of the appropriate stainless steel grades should be considered in detail and should be based on conservative assumptions.

## EXHAUST GAS BYPASS

An exhaust gas bypass for a scrubber 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 be able 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 the ship is outside an ECA or low-sulfur fuel is being used, the exhaust bypass can be used and the scrubber shut down, saving on EGC system electric power consumption.

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

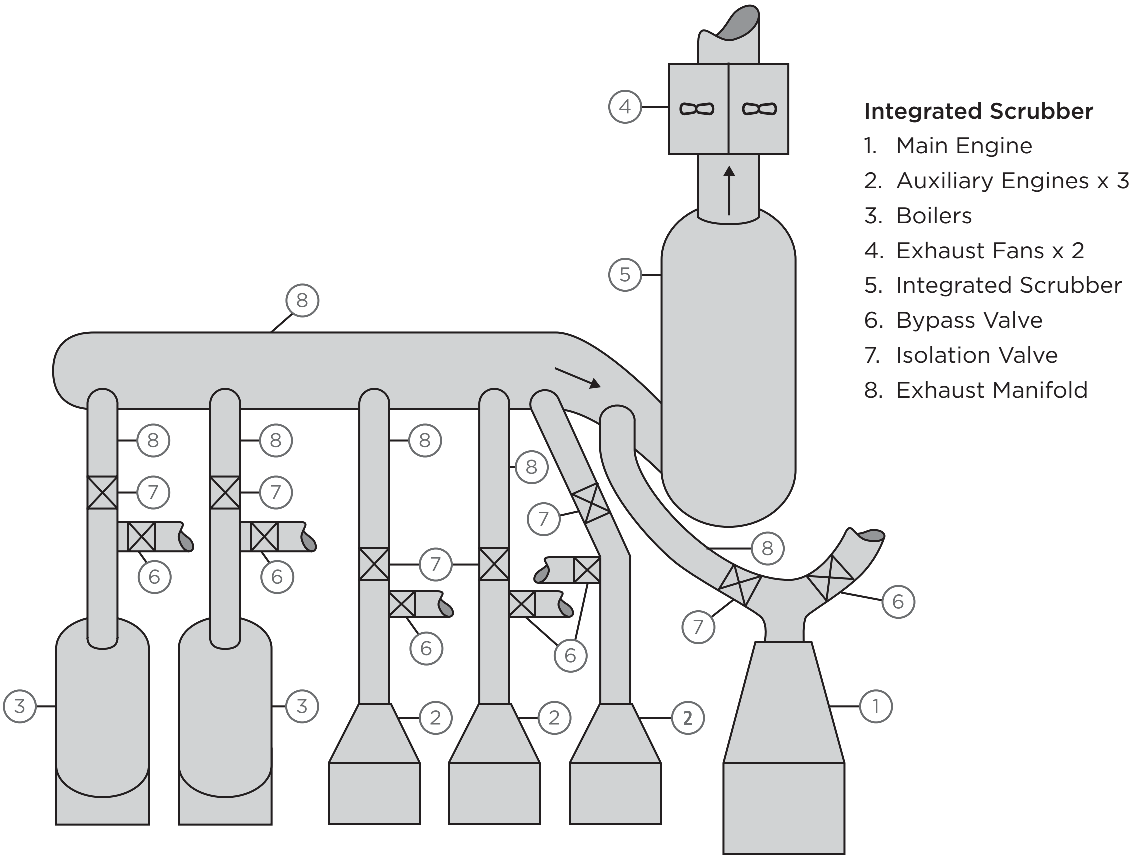
Where the valve is a two-damper design, an interlock would be required to prevent both dampers from being closed at the same time. Exhaust bypass valves may require frequent maintenance because of the hot gas environment and soot accumulation that occurs. For main engines, an EGE is also frequently provided before the scrubber. For operation with the scrubber bypassed, it is recommended to have a silencer fitted in 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 will need to be evaluated and approved based on its merits with regard to interconnections and safe vessel operations. Any arrangements proposing the interconnection of exhaust systems, along with the isolation and control system arrangements involved, would require specific ABS approval in accordance with the provisions of 4-6-5/11.5 and 4-6-6/13 of the ABS Steel Vessel Rules.

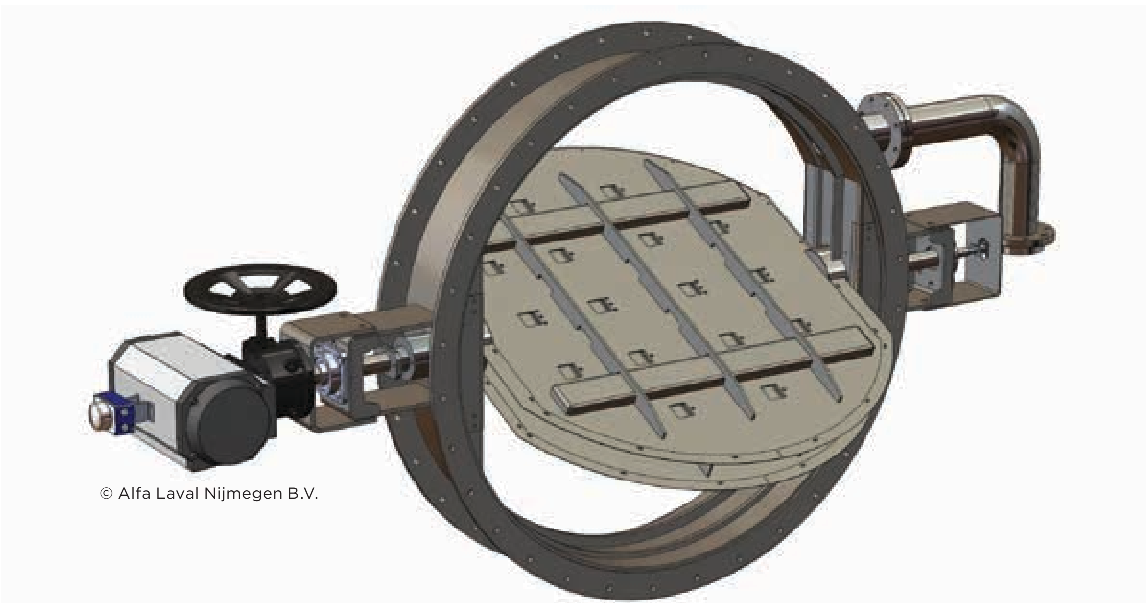
When using an integrated scrubber, bypasses for each exhaust are required (see Figure 15). For safety reasons, special measures are needed to make sure that the isolation valves are positioned and sealed properly when an engine or boiler is out of service so that exhaust will not backflow down the exhaust 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 15: 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 16).

*Figure 16: 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 is 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 the scrubber fan failure on safe operation of the fuel burning units should be carefully considered. The scrubber manufacturer should submit complete details related to the anticipated 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 and the same pipe material requirements would 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, driving the need for 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.

## EXHAUST PIPE

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

## SLUDGE PIPE

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

## AUXILIARY EQUIPMENT

In addition to the scrubber itself, there is a need to consider the space and power requirements of the associated scrubber auxiliary equipment, such as pumps, process tanks, particulate separators and coolers, which are similar in size to other engine room auxiliary equipment of the same type. The auxiliary equipment can be located lower down in the machinery space than the engine exhaust system casing since 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 engine load, otherwise excessive water supply will occur at low engine loads. There is significant difference in the types of auxiliary equipment in use and flow rates dependent on whether a scrubber is an open loop-type or closed loop-type and for hybrid scrubbers in which mode they are operating in.

*Table 8: Sample Wet Scrubber Auxiliary Equipment Sizing*

| Engine Size | 5 MW | | 20 MW | | 40 MW | |
|---|---|---|---|---|---|---|
| Equipment | Open loop | Closed loop | Open loop | Closed loop | Open loop | Closed loop |
| Scrubbing water flow ($m^3$/hr) | 225 | 120 | 900 | 480 | 1,800 | 960 |
| Pump electric load (kW) | 70 | 15 | 280 | 60 | 560 | 120 |
| Process tank ($m^3$) | N/A | 9.0 | N/A | 30 | N/A | 60 |
| Sludge generation (liter/hr) | 10 | 10 | 40 | 40 | 80 | 80 |
| Caustic soda usage – 50% solution (kg/hr) | N/A | 150 | N/A | 600 | N/A | 1,200 |

Notes:

1. Scrubbing water flow rate and power estimates are based on Wärtsila data.
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.
3. Open loop-type scrubber has higher water flow because seawater is less effective as a scrubbing medium than treated freshwater.
4. Sludge generation rate can be reduced if effective means are used to remove water, and depends on water overboard discharge quality requirements, which affect how much sludge has to be removed.
5. Caustic soda usage rates and storage requirements can vary significantly depending on the engine load and scrubber operation. Indicated values 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. For dry scrubbers, it is for the pneumatic systems that transport the pellets to and from the scrubber. 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 9. 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 9: 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 implementing regulations for sulfur emissions. However, if these systems fail while the ship is operating in an area where low-sulfur fuel is required, the ship will no longer be in compliance with the emission regulations. In addition, if there are failures, there could be 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.

## 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. Some EU member countries require closed loop operation. For example Germany has prohibited scrubber washwater discharges in inland water rivers and certain ports like the Kiel Canal, and Belgium has prohibited scrubber washwater discharge within three nautical miles off its coast.

In the U.S., the VGP 2013 Part 6 identifies additional requirements for specific states and tribes for their Clean Water Act (CWA) § 401 certifications for exhaust gas scrubber washwater discharge. An example of these additional requirements are those mandated by the states of Connecticut and Hawaii. Due to different possible requirements mandated by different states in the U.S. and other countries, due consideration is to be given to the installation of a hybrid scrubber system for vessels unless the owner/operator can be certain that the intended area of operation will not be subject to prohibition from washwater discharge at the present time or in the future.

## ABS OFFERS "SOx SCRUBBER READY" NOTATION

ABS has 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, the vessel would be assigned 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 Exhaust Emission Abatement (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 Scrubbers: 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 ECAs and with minimum time at sea, a hybrid or closed loop scrubber system could be considered. The global IMO fuel sulfur limits scheduled to be reduced to 0.5 percent sulfur in 2020 will influence this decision-making process.

The total cost of a scrubber system includes the initial cost of the scrubber, installation expenses, additional miscellaneous auxiliary equipment, off hire, ship modifications, etc., together with the cost of the additional fuel consumption to operate the scrubber system and the cost of consumables (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.

The Appendices to this Advisory provide more information on a number of scrubber systems that are on the market, and reference should be made to the accompanying checklists for owners. 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.

# REFERENCES


1. IMO Resolution MEPC.132(53) – Amendments to the Annex of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978 relating thereto (Amendments to MARPOL Annex VI and the NOx Technical Code); July 22, 2005
2. IMO Resolution MEPC.176(58) – Amendments to the Annex of the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (revised MARPOL Annex VI); October 10, 2008
3. IMO Resolution MEPC.82(43) – Guidelines for monitoring the worldwide average sulfur content of residual fuel oils supplied for use on board ships; July 1, 1999
4. IMO Resolution MEPC.183(59) – 2009 Guidelines for monitoring the worldwide average sulfur content of residual fuel oils supplied for use on board ships; July 17, 2009
5. IMO Resolution MEPC.192(61) – 2010 Guidelines for monitoring the worldwide average sulfur content of residual fuel oils supplied for use on board ships; October 1, 2010
6. IMO MEPC 62/4 – Sulfur monitoring for 2010; February 28, 2011
7. EMSA Technical Report – The 0.1 percent sulfur in fuel requirement as from January 1, 2015 in SECAs – An assessment of available impact studies and alternative means of compliance; December 13, 2010
8. UK Maritime and Coastguard Agency – Impact Assessment for the revised Annex VI of MARPOL, performed by ENTEC; July 2009
9. Ministry of Transport and Communications Finland Report 31/2009 – Sulfur content in ships bunker fuel in 2015 – A study on the impacts of the new IMO regulations on transportation costs; April 9, 2009
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11. IMO Resolution MEPC.190(60) – Amendments to the Annex of the protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978 relating thereto (North American Emission Control Area); March 26, 2010
12. LQM Petroleum Services Inc. Survey – Current and anticipated availability of LS IFO (maximum 1 percent); June 12, 2012
13. IMO Resolution MEPC.202(62) – Amendments to the annex of the protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the protocol of 1978 relating there to; (Designation of the United States Caribbean Sea Emission Control Area and exemption of certain ships operating in the North American Emission Control Area and the United States Caribbean Sea Emission Control Area under Regulations 13 and 14 and Appendix VII of MARPOL Annex VI); July 15, 2011
14. European Council Directive 1999/32/EC – Relating to a reduction in the sulfur content of certain liquid fuels and amending Directive 93/12/EEC; April 26, 1999
15. European Council Directive 2005/33/EC – Amending Directive 1999/32/EC; July 6, 2005
16. European Council Directive 2009/30/EC – Amending Directive 1999/32/EC; April 23, 2009
17. European Council Directive 2012/33/EC – Amending Directive 1999/32/EC; November 21, 2012
18. U.S. Code of Federal Regulations – Title 40: Protection of Environment, Part 1043, Control of NOx, SOx and PM emissions from marine engines and vessels subject to the MARPOL protocol
19. U.S. Code of Federal Regulations – Title 40: Protection of Environment, Part 94, Control of emissions from marine compression ignition engines
20. U.S. Code of Federal Regulations – Title 40: Protection of Environment, Part 1042, Control of emissions from new and in-use marine compression ignition engines and vessels
21. California Code of Regulations (CCR) 13 CCR 2299.2 – Fuel sulfur and other operational requirements for oceangoing vessels within California waters and 24 nautical miles of the California baseline
22. CARB Marine Notice 2012-1 – Advisory to owners and operators of oceangoing vessels or ships visiting California ports; July 2, 2012

23. IMO Resolution MEPC.130(53) – Guidelines for Onboard Exhaust Gas-SOx Cleaning Systems; July 22, 2005
24. IMO Resolution MEPC.170(57) – Guidelines for Exhaust Gas Cleaning Systems; April 4, 2008
25. IMO Resolution MEPC.184(59) – 2009 Guidelines for Exhaust Gas Cleaning Systems; July 17, 2009
26. IMO Protocol of 1997 to MARPOL 73/78 – Annex VI, Regulations for the Prevention of Air Pollution from Ships – Resolution 2, the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines (NOx Technical Code); September 1997
27. IMO Resolution MEPC.169(57) – Procedure for Approval of Ballast Water Management Systems that make use of Active Substances (G9); April 4, 2008
28. IMO Circular MSC.1/Circ.1221 – Validity of Type Approval Certification for Marine Products; December 11, 2006
29. IMO Resolution MEPC.259(68) – 2015 Guidelines for Exhaust Gas Cleaning Systems; May 15, 2015
30. Marine Emission Control Area Plan for Pearl River Delta, Yangtze River Delta, Bohai Rim Area, translated from the Chinese text source posted by Ministry of Transport of People's Republic of China, website: http://www.moc.gov.cn/ (not an official English version of the Plan)

## FREQUENTLY ASKED QUESTIONS

**When transiting an ECA, 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 in the realm of the concerned flag Administrations. For the exemption to be granted, the owner would need to exhibit that due diligence had been exercised in both design and operation, i.e. sufficient redundancy, has been incorporated 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?**
California Air Resources Board (CARB) does not currently accept SOx scrubbers as an alternative means for using low-sulfur distillate fuel, but it has temporarily authorized, through CARB Marine Notice 2014-1, August 2014, the use of the EGCS as a 'Research Exemption' for the duration of the sunset review process for the vessels that are in compliance with the ECA. The sunset review is a study that is being conducted by CARB staff in order to evaluate the emissions reductions achieved by the ECA Regulation and compare them to the emissions reductions achieved by the California Ocean Going Vessel (OGV) Fuel Regulation.

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 PSC associated with MARPOL Annex VI are described in IMO Res. MEPC.181 (59), where it is stated that the PSC officer should examine the "approved documentation relating to any installed exhaust gas cleaning systems, or equivalent means, to reduce SOx emissions (Reg. VI/4)." Furthermore, as per 4.2.3.2 and 5.3.2 of the Annex to Res. MEPC.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 in respect of sample overboard discharge drawn from each EGC system within the previous three months prior to the survey." However, the Administration may require an additional sample to be drawn and analyzed at their discretion. The nitrate discharge data and analysis certificate is to be retained on board the ship as part of the EGC Record Book and is to be made available for inspection as required by Port State Control or other parties.

**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 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. 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.

During its 68th session, the MEPC approved the definition of Black Carbon, which was agreed and proposed by the PPR 2. The committee was aware of the need for Black Carbon measurement studies, to gain knowledge with the application of the definition and the methods of measurement. The Committee agreed to the need for a protocol for any voluntary measurement studies to collect data, focusing on using the agreed definition of Black Carbon to support data collection; to identify the most appropriate measurement method(s) of Black Carbon emissions from international shipping, and inviting interested Member Governments and international organizations to submit additional relevant proposals/information to PPR 3.

**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 equivalents; shipowners/operators must submit all monitoring data to the U.S. EPA's e-reporting system unless specifically exempted from electronic reporting. Monitoring data must be submitted at least once per calendar year, no later than 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 be adding other conditions related to vessels in general.

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

As per 2.2.26.2.2 of the proposed 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.

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

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

**Will the scrubber function as designed at all loads?**

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

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

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

# CHECKLIST FOR OWNERS

## BASELINE FOR COMPLIANCE WITH ECA LOWSULFUR REQUIREMENTS

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

## SCRUBBER INSTALLATION FEASIBILITY – NEW VESSELS

1. Determine the operating ports and coastal areas that the ship will be calling at over its expected life. Do any of these areas have low alkaline fresh or brackish water? If so, determine how often the ship would be in these waters, as this will limit the effectiveness of open loop 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 has minimum port stays or minimum transit time in ECAs, the open loop may be considered. However, if the vessel has long port stays with an appreciable time spent in transiting in ECAs with minimum time at sea, a hybrid or closed loop could be considered.
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, details are available on 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 re-use and details of required equipment. For discharged washwater, the proposal should specify the method to adjust pH and other characteristics to meet permitted limits.
        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 on board 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 when the scrubber does not, such as use of lowsulfur fuel. Determination should be made on whether the scrubber will be operated when outside ECAs or other areas where low emissions are required.

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 for the scrubber purchase and installation and annual operating costs, versus the costs for alternative means of compliance (see Baseline for Compliance)

## SCRUBBER INSTALLATION FEASIBILITY – EXISTING SHIPS

1. Is there adequate space on the existing ship to add one or more 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)

# APPENDIX I

## EXHAUST GAS CLEANING SYSTEM ASSOCIATION MEMBERS

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

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

- AEC Maritime
- Alfa Laval Nijmegen
- Clean Marine
- CR Ocean Engineering
- DuPont BELCO Clean Air Technologies
- Eco Spray Technologies
- Fuji Electric
- Ionada
- Langh Tech
- MAN Diesel*
- PureteQ Marine Turbo Scrubber
- Saacke Marine System
- Wärtsila Hamworthy
- YARA Marine Technologies

Most of the members of the EGCSA produce wet scrubbers, using processes similar to those described in this Advisory. The EGCSA periodically offers instruction courses and workshops and can be a good source of information on the latest types of scrubbers being marketed and developed, technical details, performance and how an EGCS impacts the environment. EGCSA members have agreed to follow a Code of Conduct that promotes ethical and responsible actions by member companies. Of course EGCSA members are not the only companies offering EGCS solutions to the marine community.

* MAN does not offer scrubbers independently. They have developed a scrubber as an integrated part of their Tier III EGRsystem for NOx control.

# APPENDIX II

## LOW-SULFUR FUEL AVAILABILITY

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

*Low-Sulfur Phase-In Dates*

| Low-Sulfur Fuel | | Operating Areas | | | |
|---|---|---|---|---|---|
| Requirements | Outside ECAs | Inside ECAs | EU Ports | California Coastal | US EPA Category 1 and 2 Vessels |
| Starting Year 1 January | % Sulfur In Fuel | % Sulfur In Fuel | % Sulfur In Fuel | % Sulfur In Fuel | % Sulfur In Fuel |
| 2010 | 4.5 | 1.0 | 0.1 | 1.5 (0.5)* | 0.0500 (500 ppm) |
| 2012 | 3.5 | 1.0† | 0.1 | 1.0 (0.5)** | 0.015 (15 ppm) |
| 2014 | 3.5 | 1.0 | 0.1 | 0.1 | 0.015 (15 ppm) |
| 2015 | 3.5 | 0.1 | 0.1 | 0.1 | 0.015 (15 ppm) |
| 2020 | 0.5 | 0.1 | 0.1 | 0.1 | 0.015 (15 ppm) |

Notes:

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

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

† North American ECA took effect on August 1, 2012

## FUEL OIL AVAILABILITY AS MANDATED IN REGULATION 18 OF ANNEX VI MARPOL 73/78 IS AS FOLLOWS:

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

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

**2.1.1** Present a record of the actions taken to attempt to achieve compliance; and

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

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

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

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

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

## U.S. EPA REQUIREMENTS ON FUEL OIL NON-AVAILABILITY

When any vessel owner/operator is making a claim regarding the non-availability of ECA-compliant fuel oil, they should submit the Fuel Oil Non-Availability Report (FONAR) to the United States government prior to entering the North American ECA. The report should be submitted as soon as the party determines that they will be unable to procure and use compliant fuel oil upon entry into the North American ECA, but no later than 96 hours prior to entering the North American ECA.

The FONAR is to be submitted electronically to the U.S. EPA using the electronic Fuel Oil Non-Availability Disclosure portal (FOND). In order to use the FOND, a user must first sign up to use the EPA's Central Data Exchange (CDX) system through URL: http://cdx.epa.gov/

*Marine Distillate Fuels: ISO 8217:2010 Marine Fuel Specifications*

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

*Specifications of ECA Compliance New Low-Sulfur Hybrid Fuel Oils*

| | Shell ULSFO | ExxonMobil HDME 50 | LUKOIL | CEP SA | BP | Phillips 66 |
|---|---|---|---|---|---|---|
| Density | 790-910 | 908.8 | 886 | 86.8 | 845.4 | 855.2 |
| Viscosity | 10-60 | 53.9 | 16 | 8.8 | 8.8 | 8.6 |
| Micro Carbon (MCR) | NA | 0.28 | 0.1 | 0.1 | 0.1 | 0.04 |
| Sulfur | <0.1 | 0.08 | 0.07 | 0.05 | 0.03 | 0.06 |
| Pour Point | 18 | 6 | 18 | -12 | 21 | -12 |
| Flash Point | >60 | 175 | 165 | 72 | >70 | 79 |
| Water | 0.05 | 0.05 | 0.05 | 0.004 | 0.01 | 0 |
| Acid Number | <0.5 | 0.1 | 0.5 | 0.27 | 0.04 | NA |
| Vanadium | 2 | 3 | 1 | NA | <1 | <0.10 |
| Al+Si | 12-20 | 2 | 2 | NA | <1 | 2 |
| Lubricity | NA | 264 | 270 | 410 | 326 | NA |
| CCAI | 794 | 794 | 793 | NA | 765 | NA |
| ECN | 60 | 60 | NA | NA | 80.4 | 58.5 |

## FUTURE DESIGNATION OF EMISSION CONTROL AREAS

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

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

## ECONOMIC EFFECTS OF BUNKERING LOW-SULFUR FUEL OIL

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

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

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

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

## CONCLUSION

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

# LIST OF ACRONYMS

| | |
|---|---|
| **BC** | Black Carbon |
| **BLG** | IMO Bulk Liquids and Gases Sub-committee |
| **BOTU** | Bleed Off Treatment Unit |
| **CARB** | California Air Resources Board |
| **$Ca(OH)_2$** | Calcium Hydroxide (Hydrated Lime) |
| **$CaSO_4$** | Calcium Sulfate (Gypsum) |
| **CFR** | Code of Federal Regulations |
| **CO** | Carbon Monoxide |
| **$CO_2$** | Carbon Dioxide |
| **DWT** | Deadweight Tonnage |
| **ECA** | Emission Control Area |
| **EEDI** | Energy Efficiency Design Index |
| **EEZ** | Exclusive Economic Zone |
| **EGCS** | Exhaust Gas Cleaning System |
| **EGCSA** | Exhaust Gas Cleaning Systems Association |
| **EGE** | Exhaust Gas Economizer |
| **EGR** | Exhaust Gas Recirculation |
| **EPA** | Environmental Protection Agency |
| **ETM-A** | EGC Technical Manual Scheme A |
| **ETM-B** | EGC Technical Manual Scheme B |
| **EU** | European Union |
| **FNU** | Formazin Nephlometric Units |
| **FW** | Fresh Water |
| **GESAMP** | Group of Experts on the Scientific Aspect of Marine Environmental Protection |
| **GNSS** | Global Navigational Satellite System |
| **GRE** | Glass Reinforced Epoxy |
| **HC** | Hydrocarbons |
| **HFO** | Heavy Fuel Oil |
| **IGS** | Inert Gas System |
| **IAPP** | International Air Pollution Prevention |
| **IMO** | International Maritime Organization |
| **ISO** | International Organization for Standardization |
| **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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