OCIMF

Guide for Implementation of Sulphur Oxide Exhaust Gas Cleaning Systems

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The Oil Companies International Marine Forum (OCIMF)
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Abbreviations

CO_2	Carbon Dioxide
EGCS	Exhaust Gas Cleaning System/s
ECA	Emission Control Area
ETM-A	EGCS Technical Manual – Scheme A
ETM-B	EGCS Technical Manual – Scheme B
GRE	Glass Reinforced Epoxy
GRP	Glass Reinforced Plastic
IMO	International Maritime Organization
MEPC	Marine Environment Protection Committee
NO_x	Nitrogen Oxides
OMM	On-board Monitoring Manual
PAH	Polycyclic Aromatic Hydrocarbon
PPE	Personal Protective Equipment
SDS	Safety Data Sheet
SECC	SO_x Emissions Compliance Certificate
SECP	SO_x Emissions Compliance Plan
SO_x	Sulphur Oxide
SO_2	Sulphur Dioxide

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Hield, P. (2011). *The Effect of Back Pressures on the Operation of a Diesel Engine.* Australian Government Department of Defence.

Additional recommended reading on local legislation considerations

Impacts of Scrubbers on the Environmental Situation in Ports and Coastal Waters, TEXTE 65/2015, Umwelt Bundesamt.
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1 Introduction

Sulphur oxide (SO_x) Exhaust Gas Cleaning Systems (EGCS) are principally used to remove sulphur dioxide (SO_2) from air emissions associated with exhaust gases that are inherent with the relatively high sulphur content of marine fuels. EGCS can also remove particulate matter (such as ash and heavy metals) and unburnt hydrocarbon liquids from exhaust gas. EGCS can be categorised as wet or dry systems. Dry systems are configured in a dry arrangement (no water), while wet systems may be configured in three ways: open loop, closed loop and hybrid loop, as explained in section 4. All EGCS, however they are configured, are available to suit different vessel types, trading patterns and local conditions.

The use of EGCS in the maritime industry is relatively new and there is a general lack of technical understanding and operational experience. MARPOL Annex VI SO_x compliance can only be achieved through the use of either low sulphur fuels or an EGCS. Due to the high cost of low sulphur fuels, there is an interest in continuing to use high sulphur fuels which would require the use of an ECGS. This information paper provides practical guidance for the selection, installation and use of SO_x EGCS.

2 Mandatory International Maritime Organization guidelines

The International Maritime Organization (IMO) has published mandatory guidelines in MEPC.184(59), *2009 Guidelines for Exhaust Gas Cleaning Systems* for the validation of scrubber systems, the allowable sulphur content in emissions and limits on the content of waste water discharged. In January 2015, the IMO amended the 2009 guidelines to make it easier for ship owners and equipment manufacturers to document the functionality of an EGCS. This amendment was adopted on 15 May 2015 as MEPC.259(68), *2015 Guidelines for Exhaust Gas Cleaning Systems*. Despite being called 'guidelines', these are given mandatory effect under MARPOL Annex VI, Regulation 4. The 2015 guidelines specify requirements for the testing, survey and certification of an EGCS. They also establish limits for pH, Polycyclic Aromatic Hydrocarbon (PAH), turbidity along with nitrites+nitrates in wash water discharge and the sulphur content in the exhaust gas.

The 2015 guidelines establish an SO_2/CO_2 % v/v (emission ratio) as an equivalent for the sulphur content in emissions in comparison with the specified sulphur content in fuel (see table 2.1). The emission ratio is used to verify emissions in accordance with the regulation, including during transient operation. SO_2 concentration in exhaust gases will vary with the combustion process fuel-to-air ratio which makes it a poor indicator of the amount of sulphur actually in the fuel. Since marine fuels have a fairly consistent carbon-to-sulphur ratio, measuring this ratio in the emissions provides more consistent results. SO_x and CO_2 levels should be monitored after the exhaust gas treatment, except when the treatment process absorbs the CO_2, in which case the CO_2 has to be monitored before the treatment. For low alkali systems, CO_2 is not absorbed during the treatment and therefore monitoring of both gases is done after the cleaning process.

Fuel oil sulphur content (% m/m)	Emission ratio SO_2/CO_2 (% v/v)
3.50	151.7
1.50	65.0
1.00	43.3
0.50	21.7
0.10	4.3

Table 2.1: *Sulphur content equivalents (©IMO)*

The 2015 guidelines establish two schemes for the testing, certification, survey, and verification of an EGCS. Scheme A certifies the unit itself, with continuous automatic recording of the installation parameters, but recommends daily spot checks only of the exhaust gas quality. Scheme B does not certify the unit, but requires continuous emissions and parameter monitoring to demonstrate compliance. The items required by each scheme are described in table 2.2.

Document	Scheme A	Scheme B
SECP: SO_x emissions compliance plan	X	X
SECC: SO_x emissions compliance certificate	X	
ETM-A: EGCS technical manual for Scheme A	X	
ETM-B: EGCS technical manual for Scheme B		X
OMM: On-board monitoring manual	X	X
EGCS record book	X	X
Electronic monitoring system and data collection		X

Table 2.2: *Scheme A and Scheme B compliance (©IMO)*

The SO_x Emissions Compliance Plan (SECP) should list all combustion units fitted with an EGCS. For Scheme A, the plan should demonstrate compliance without continuous monitoring of the exhaust gas emissions. For Scheme B, the plan should outline how continuous exhaust gas monitoring meets compliance.

The On-board Monitoring Manual (OMM) should detail service, maintenance and calibration requirements for all sensors and analysers. The manual should also indicate the positions from which emissions and wash water measurements are taken and other information relevant to the functionality of the monitoring system.

Each EGCS must be accompanied by an EGCS Technical Manual (ETM) appropriate to the scheme it is certified for (ETM-A/ETM-B). Except where noted, the following outlines the required information to be included in the ETM-A and ETM-B:

1. Maximum and minimum exhaust gas flow rates.
2. Parameters of the combustion unit(s) the EGCS is designed to.
3. Maximum and minimum wash water flow rate, inlet pressures and alkalinity.
4. Exhaust gas inlet temperature ranges and maximum/minimum outlet temperature.
5. Required salinity level necessary to provide adequate neutralisation.
6. Requirements and restriction applicable to EGCS.
7. Maintenance, service and adjustment requirements (ETM-A only).
8. Corrective measures for exceeding maximum allowable emission ratio.
9. Verification procedure for surveys (ETM-A only).
10. Variation of wash water characteristics throughout the operating range.
11. Design requirements of wash water system.
12. SO_x Emissions Compliance Certificate (SECC) (ETM-A only).

Scheme A requires an EGCS to be certified by the manufacturer to meet the requirements of MARPOL Annex VI 14.1/14.4. Under Scheme A, the manufacturer is to test the unit with fuel containing the maximum sulphur content specified by the operating parameters. The manufacturer is also required to test maximum and minimum exhaust gas flow rates at all points in the system.

When the unit is verified by the manufacturer, a SO_x Emissions Compliance Certificate (SECC) can then be sought. The purpose of Scheme A is to forego continuous exhaust gas emission monitoring via electronic data collection of system operational parameters. However, a record book must be kept for the purpose of logging daily spot checks, maintenance and service.

Scheme B does not require initial approval of the EGCS from the manufacturer and does not require an SECC. The purpose of this scheme is to demonstrate compliance through continuous electronic monitoring. Daily spot checks are also required to verify performance.

Approval, survey and certification of the EGCS are to be carried out in accordance with the provision of the applicable IMO Resolution. Schemes A and B both require classification society approval which encompasses a full design assessment, validation or type testing, and a manufacturing assessment. Emissions testing for SO_x should meet the requirements of chapter 5 of the 2008 NO_x Technical Code.

The 2015 guidelines also specify the following for water sampling:

- Discharge measurements are to be taken after wash water is dosed, but before any dilution to determine pH, PAH, turbidity and nitrites+nitrates.
- Inlet water is to be measured at the sea chest where seawater is at ambient temperature.
- Discharge water should have a pH of no less than 6.5, measured at the ship's overboard discharge. When the ship is manoeuvring or in transit, a maximum difference between the inlet and outlet of 2 pH units is allowed, measured at the ship's inlet and overboard discharge.
- The allowable concentration of PAH (a by-product of incomplete combustion).
- Wash water turbidity increase limits above the inlet water turbidity (turbidity is a measure of how much material suspended in water decreases the passage of light through the water).
- The discharge levels of nitrites+nitrates (a measure of how much NO_x has been removed from the exhaust gas).

There are several international standards available for the use and calibration of monitoring equipment (e.g. BS2586:1979; BS EN 60746-2:2003; ISO 7027:1999). However, these standards are not statutory under IMO regulations. There is also no formal certification of monitoring and data collection equipment; however, the data collection and recording device should be tamper-proof and robust, with read-only capability. It should be capable of retaining data for 18 months, suitable for preparing reports and have means to download recorded data and reports.

3 Local legislation considerations

At the time of publication some countries, specifically those within the European Union (EU), are reviewing the composition and impact of effluent discharges from exhaust gas cleaning systems within local waters. The pollutant composition and concentrations, along with the environmental impacts on ports and coastal waters are being researched.

Prior to consideration of an EGCS it is suggested that the ship owner/operator check with local authorities and perform their own analysis to consider the type of EGCS to install, bearing in mind the trading pattern of the ship and other technical considerations such as compatibility, as discussed in section 5.3.

Further reading can be found in Bibliography and additional recommended reading.

4 SO_x exhaust gas cleaning systems

EGCS can be categorised as wet or dry systems, in four different configurations:

Wet	Open loop Closed loop Hybrid (open loop when at sea, closed loop when in port or as required)
Dry	Dry system

For open, closed or hybrid systems the seawater, or treated seawater/freshwater, is sprayed into the exhaust gas scrubber unit of the EGCS, which is a component of the system that acts to remove SO_x. To increase the absorption of SO_x, the exhaust gas scrubber unit typically uses the counter flow of exhaust gas and water, water pressure and baffles to induce turbulence. As the water flashes to steam, energy is removed from the exhaust gas. This lowers the temperature and allows unburnt hydrocarbons to condense out of the exhaust gas. The wash water is then filtered and/or treated, and either discharged overboard or recirculated.

It is important to note that system configuration, effectiveness and operation varies between manufacturers and depends heavily on the gap between the design parameters and the actual operating parameters (sulphur content in the fuel, seawater alkalinity, etc.). The choice of appropriate design parameters is a key point for the efficiency and effectiveness of the chosen system.

4.1 Exhaust gas scrubber units

Most exhaust gas scrubber units are custom sized to suit the application aboard a vessel based on the following criteria:

- Expected exhaust gas flow rate and temperature.
- Operational conditions of the vessel.
- Machinery or operational constraints.

Many manufacturers create exhaust gas scrubber units with little or no moving parts to reduce maintenance and prolong operational life. Most manufacturers design their units to reduce the sulphur content from 3.5% to the Emission Control Area (ECA)'s required 0.1% with a seawater alkalinity of about 2,300 μmol/l. This covers the North Sea area, excluding the Baltic Sea where the seawater's low alkalinity may reduce efficiency.

When selecting an exhaust gas scrubber unit, the following items should be considered:

- Location and trade of vessel.
- Sulphur content of the fuel to be used.
- The alkalinity of the water that the vessel will be operating in.

Some exhaust gas scrubber units are in-line units that may replace the engine silencer(s). These units are similar to the silencer in weight and size. Some scrubber units are capable of performing the job of the silencer whether or not the exhaust gas scrubber unit is in operation. Other exhaust gas scrubber units are not in-line units and require multiple passes or stages to effectively remove the SO_x from the exhaust gas. These systems typically do not replace the silencer and have greater space requirements compared to in-line units. Some exhaust gas scrubber units are also available as multi-inlet solutions capable of handling exhaust gas from several pieces of combustion equipment at once. The capabilities of multi-inlet units vary by manufacturer and are ultimately limited by back pressure. There are also safety and other regulatory code issues to consider for dual-fuel (methane gas) combustion systems.

4.2 Types of exhaust gas cleaning systems

There are four different types of exhaust gas cleaning system available:

1. Open loop (seawater scrubber units) use untreated seawater (i.e. the natural alkalinity of the seawater) to neutralise the sulphur from exhaust gases.
2. Closed loop (freshwater scrubber units) are not dependent on the type of water the vessel is operating in, because when the exhaust gases are added to freshwater in a closed loop system they are neutralised with caustic soda or magnesium oxide.
3. Hybrid scrubber units - allows the use of either open loop or closed loop.
4. Dry scrubber units do not use any liquids in the process as exhaust gases are cleaned with calcium hydroxide, commonly known as caustic lime.

5 Considerations

5.1 Materials and corrosion

Most wet exhaust gas scrubber units involve caustic reactions at high temperatures (typically where the exhaust gas temperature is in excess of 250°C) which accelerate the corrosion process. The lower portion of exhaust gas scrubber units are often made of a high-grade nickel alloy or duplex stainless steel, chosen for their resistance to high temperatures and corrosion. The upper portion of the exhaust gas scrubber unit is typically made from a lower grade of stainless steel, because the increased condensation in the exhaust gas means it does not get as hot.

Hastelloy or AL6XN are examples of materials used in exhaust gas scrubber unit construction because of their increased oxidation, corrosion and high temperature resistance. However, such materials tend to cost more than lower grade materials of similar composition.

For ambient seawater supply systems, rubber-lined, galvanised, nickel-copper or Glass Reinforced Epoxy/Glass Reinforced Plastic (GRE/GRP) piping can be used. Any piping, pumps and separators that will come in contact with wash water should use materials appropriate to the pH, temperature and content of the wash water. Tanks containing wash water, sludge or caustic dosing chemical can be constructed from approved plastics, GRP or stainless steel. Pumps should be equipped with seals of the proper material to withstand the corrosive environment of the wash water.

5.2 Bypasses and back pressure

One issue associated with exhaust gas scrubber units, especially the wet type, is the exhaust back pressure. As back pressure increases, the engine must create more power to overcome it. As a result, back pressure can cause an increase in NO_x production, an increase in exhaust gas temperature and an increase in fuel consumption (Hield, 2011). Back pressure can be reduced by careful design of the exhaust gas scrubber unit with regard to nozzle design, baffle design, multiple stages, and flow rates of exhaust gas and water. Exhaust fans may also be used to mitigate back pressure, although careful consideration must be given to the effects of an exhaust fan failure. The engine manufacturer should be consulted for this data. Furthermore, the presence of an exhaust gas economiser may create additional back pressure on the system, though a majority of EGCS manufacturers claim that their systems can operate in line with an economiser.

An exhaust gas bypass will typically not be required for scrubber units that are capable of running dry (no wash water flowing).

5.3 Compatibility

Before the installation of a SO_x EGCS, consideration should be made in the evaluation of NO_x technology and its compatibility with the selected SO_x EGCS. NO_x systems will have to be suitable for operating with high levels of SO_x and other substances produced by burning high sulphur fuels at high operating temperatures. Operating NO_x technology satisfactorily with a SO_x EGCS will depend on the manufacturer's operating parameters of both systems. Manufacturers and Class Societies should be consulted for further assistance in the proper selection of a suitable and compatible EGCS.

5.4 Electrical loads

In a wet EGCS, the biggest electrical load is the feed pump and/or circulation pump. The capacity required for these pumps can be similar to the ship's seawater cooling pumps. Other loads to consider include:

- Exhaust fans.
- Separators.
- Dosing units.
- Control processes.
- Sensors and monitoring equipment.

An open loop system in some circumstances could require marginally more power than a closed loop system. A closed loop system is capable of removing the required amount of sulphur with a lesser flow rate of water through the scrubber unit, because it is dosed with reactants that are more effective than seawater per unit mass.

5.5 Installation

Installation time for an EGCS depends on the manufacturer and type of system being installed. The main considerations are size, complexity of the system and the components involved.

Depending on manufacturer, the EGCS may or may not be in-line. An in-line unit should be installed directly in-line with the silencer and exhaust gas economiser. Units that are not in-line require multiple passes and often have separate bypass ducts which tend to take up more space than an in-line unit.

Open loop systems have fewer components and require less tank space than a closed loop or hybrid system and installation can be expected to be less complicated and time consuming. Closed loop, hybrid systems and dry systems take up more space, require several tanks for storage, dosing units, separators, multiple pumps and more complex control units.

Depending on the complexity of the system and amount of preparatory work done beforehand, scrubber installation at wet berth can take several weeks.

5.6 Safety and crew training

IMO has identified the following as potential safety hazards associated with EGCS:

- Handling and proximity of exhaust gases.
- Storage and use of pressurised containers of pure and calibration gases.
- Position of permanent access platforms and sampling locations.
- Hazards associated with the handling of caustic materials.

Crews should be adequately trained to handle hazardous reactants or chemicals used (or chemicals that are created as a result of the process) and be trained to deal with possible medical emergencies. The required Personal Protective Equipment (PPE) is dictated in the associated Safety Data Sheet (SDS) of the hazardous chemicals that will be handled. Health, safety and environmental risk assessments associated with EGCS should be performed to identify hazards and to facilitate the reduction of uncertainties associated with costs, liabilities, or losses.

5.7 Cost

The biggest operating cost associated with an EGCS is the additional power requirements of the system, which is highly dependent on the cost of fuel. Other operating costs to consider include the EGCS and associated equipment maintenance; increased fuel costs due to increased back pressure and power consumption; manning (additional to or additional percent of an operating engineer); bulk reactant procurement, storage and consumption; waste management and disposal; and crew training.

The capital expenditure element of purchasing an EGCS is dependent on the size of the system, type of system, whether the system is single-inlet or multi-inlet, and the type of reactant used. Open loop systems are typically less costly than closed loop systems, which are similar in price to hybrid systems.

A voice for safety

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