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REGULATORY REGIME GOVERNING MARITIME AIR POLLUTION
AND LEGAL COMPLIANCE ALTERNATIVES IN ERA OF SULPHUR
CAPPING 2020

Dr. (Capt.) Vivek Jain
Dr. Iris Jiyeon Kim

Abstract
In the last few decades, MARPOL has significantly contributed in preventing and minimising pollution from ships due to both operational and accidental issues. In the era of increasing sea-borne trade and worldwide awareness of global warming, the need for combating air emissions at sea has gathered pace. MARPOL Annex VI that entered into force on 19 May 2005 seeks to limit the air pollutants from the exhaust gases that are emitted from the merchant's vessels. MARPOL Annex VI has been amended over the years, in particular: a) pursuant to MEPC 63 adopted in March 2012, it mandates four sets mandatory regulations on Energy Efficiency for Ships in MARPOL Annex VI, and b) pursuant to MEPC 70 in October 2016; the fuel oil standard (0.50% sulphur limit) shall become effective on 1 January 2020. This complying fuel oil is available at a higher price in the market. At this stage, there is underlying uncertainty about the availability, as well, of such fuel notwithstanding at a higher price at most of the bunkering ports. This uncertainty has a potential to increase even further in light of increasing demand for such fuel due to regulatory constraints. However, MARPOL Annex VI, Chapter 1, Regulation 4 has provided ship owners and operators with an alternative path to the above-stated compliance by using exhaust gas cleaning systems also known as a SOx scrubber. There are equally important other alternatives to achieve compliance, for example, by changing the fuel composition through fuel blending, by improving and enhancing engines by replacing the fuel to LNG. At the same time, in many cases, such alternatives are not easy to implement due to various reasons.

In this interdisciplinary paper, an attempt is made to provide guidance to distinct stakeholders, including ship owners, ship management companies, and others on such alternatives, including associated feasibility study while complying with relevant regulatory regime.

Key words: MARPOL Annex VI, Scrubber, Open Loop, Closed Loop, High Sulphur and Low Sulphur Fuel, Emission Control Areas, LNG

1. INTRODUCTION AND REGULATORY REGIME:

It is very important to discuss the regulatory regime affecting the issue of maritime pollution to understand the compliance alternatives for combating air pollution regulations. The paper will first analyze the Regulatory regime and its evolution in context of regulations affecting merchant ships that operate on oceans and seas.

MARPOL:

The International Convention for the Prevention of Pollution from Ships (hereinafter “MARPOL”) is the main international convention pursuant to Public International Law applicable to the marine Industry. It encompasses a wide area that seeks to prevent and
minimise pollution of the marine environment by ships. The proximate cause of pollution from ships could stem from both the operational or accidental issues. A series of tanker accidents in mid-1970s led to adoption of the MARPOL Convention 1973 with added Protocol 1978. It took further five years before it entered into force on 2nd October 1983.

MARPOL comprise of six technical Annexes. All of these Annexes further embrace an idea of Special Areas with strict controls on operational discharges. The six Annexes are as follows:

- **MARPOL Annex II** comprises of regulations for the Control of Pollution by Noxious Liquid Substances in Bulk. It has entered into force on 2nd October 1983.
- **MARPOL Annex III** comprises of regulations for Prevention of Pollution by Harmful Substances (as identified by International Maritime Dangerous Goods Code popularly called as IMDG Code, as marine pollutants) Carried by Sea in Packaged Form. It has entered into force 1 July 1992.

**MARPOL ANNEX VI:**

In the era of increasing sea-borne trade and world-wide awareness of global warming, the need for combating air emissions at sea has gathered pace. MARPOL Annex VI entered into force on 19th May 2005, and accordingly seeks to limit the air pollutants from the exhaust gases that are emitted from the merchant vessels. MARPOL Annex VI has been amended over the years, in particular: a) pursuant to Marine Environment Protection Committee (MEPC 63) adopted in March 2012, it decrees the four sets of mandatory regulations on Energy Efficiency for Ships in MARPOL Annex VI, and b) pursuant to MEPC 70 in October 2016; the fuel oil standard (0.50% sulphur limit) shall become effective on 1st January 2020. This complying fuel oil is usually available at higher price; however, MARPOL Annex VI, Chapter 1, Regulation 4 has provided ship-owners and operators with an alternative path to the above stated compliance
and one such method will include exhaust gas cleaning systems also known as a scrubber. This will be discussed in later half of this paper.

As the issues of global warming seize the human imagination, the issues associated with risks of pollution at sea take the center stage in the maritime sector of the industry. Risks for pollution at sea include air pollution at oceans due to movement of merchant ships in oceans. For many years, _MARPOL_ has set the framework for relevant regulations governing the Pollution from Ships. _MARPOL_ has many Annexes and _Annex VI_, in particular, deals with the Regulations for Prevention of Air Pollution from Ships (hereinafter “_MARPOL Annex VI_”). This evolving framework is increasingly important in light of the fact that there has been increased in the size of the merchant fleet and volume of cargo that can be carried over the seas (please refer to Annex 1 to the Paper).

_MARPOL ANNEX VI_ in relation to air pollution from ships was considered as far back in 1973 but was not included in the regulations. In 1979, in Geneva, the first international legally binding Convention on Long-range Transboundary Air Pollution was agreed by 34 governments and the European Community. It was followed by Protocols - on reducing sulphur emissions in 1985, controlling emissions of nitrogen oxides in 1988, controlling emissions of volatile organic compounds in 1991 was agreed upon. In 1994, it was followed later by further mandating requirements to reduce sulphur emissions. In 1987, the _Montreal Protocol_ on substances that deplete the Ozone Layer was signed to cut consumption and production of ozone-depleting substances, including chlorofluorocarbons (CFCs) and halons in order to protect the ozone layer. This in itself was followed by two Protocols to _Montreal Convention_ banning ozone-depleting CFCs and HCFCs and methyl bromide. In 1980’s, IMO’s _Marine Environment Protection Committee_ (hereinafter “MEPC”) did consider air pollution in 1980s, but it was limited to the issue of fuel quality, and in respect to _MARPOL Annex 1_. In 1988, MEPC started discussing the issue of air pollution from ships more actively, and it led to the adoption in 1991, of an IMO Assembly Resolution A.719 (17) on _Prevention of Air Pollution from Ships_. It ultimately led to _Annex VI to MARPOL_. However, _Annex VI to MARPOL_ pertaining to air pollution from the ships was first adopted in 1997, and thereafter entered into force 19 May 2005.

_For the sake of completeness, MARPOL Annex VI_ was implemented in the United States through the Act to Prevent Pollution from Ships, _33 U.S.C. §§ 1901-1905 (“APPS”)._
requirements pursuant to this apply to vessels operating in U.S. waters as well as ships operating within 200 nautical miles of the coast of North America, also known as the North American Emission Control Area (ECA).

It is important to highlight the main purpose of the MARPOL Annex VI is to set the guidelines to limit the air pollutants from the exhaust gas emitted from the merchant vessels. The gases that are contained in exhaust gas are Sulphur oxides (SOx) and Nitrous oxides (NOx), and such guidelines also prohibit deliberate emissions of ozone-depleting substances. The MARPOL ANNEX VI includes, in particular, the following:

- A global cap of 4.5% m/m on the sulphur content of fuel oil; and
- Allowed for special SOx Emission Control Areas (hereinafter “SECAs”) to be established with more stringent controls on sulphur emissions, where the sulphur content of fuel oil used on board, the ships must not exceed 1.5% m/m; and
- New installations containing ozone-depleting substances are prohibited on all ships; and
- New installations containing hydro-chlorofluorocarbons (HCFCs) are permitted until 1 January 2020; and
- Annex VI also sets limits on emissions of nitrogen oxides (NOx) from diesel engines. A mandatory NOx Technical Code, was adopted by the Conference under the cover of Resolution 2; and
- The Annex also prohibits the incineration on board the ships of certain products, such as contaminated packaging materials and polychlorinated biphenyls (PCBs).

Revised MARPOL ANNEX VI:

Over the years, there has been technological improvement and more awareness of risks of air pollution has evolved from the time ANNEX VI to MARPOL was adopted in 1997. MEPC in July 2005 agreed to revise MARPOL Annex VI and three years later, MEPC 58 in October 2008 adopted the revised MARPOL Annex VI and the associated NOx Technical Code 2008, which entered into force on 1st July 2010. The key changes introduced by the Revised MARPOL Annex VI were:
➢ Introduction of Emission Control Areas (hereinafter “ECAs”) to reduce emissions of those air pollutants further in designated sea areas; and

➢ Progressive reduction of global emissions of SO\textsubscript{x}, NO\textsubscript{x}; and

➢ The global sulphur cap will be reduced from current 3.50% that is in place from 1\textsuperscript{st} January 2012 to 0.50%, effective from 1 January 2020; and

➢ The limits applicable in ECAs for SO\textsubscript{x} and particulate matter were reduced to 1.00%, beginning on 1 July 2010 (from the original 1.50%); being further reduced to 0.10 %, effective from 1 January 2015. For the sake of completeness, in many geographical areas, there are more stringent requirements, for example, in EU, where ships transiting EU ports y are subject to a 0.1% sulphur limit for a while.

➢ Progressive reductions in NO\textsubscript{x} emissions from marine diesel engines installed on ships are also included, with a “Tier II” emission limit for engines installed on or after 1 January 2011; then with a more stringent “Tier III” emission limit for engines installed on or after 1 January 2016 operating in ECAs. Marine diesel engines installed on or after 1 January 1990, but prior to 1 January 2000 are required to comply with “Tier I” emission limits, if an approved method for that engine has been certified by an Administration; and

➢ The revised NO\textsubscript{x} Technical Code 2008 includes a new chapter based on the agreed approach for regulation of existing (pre-2000) engines established in MARPOL Annex VI, provisions for a direct measurement and monitoring method, a certification procedure for existing engines, and test cycles to be applied to Tier II and Tier III engines.

SO\textsubscript{x} and Emission control areas:

MARPOL Annex VI, Chapter 3, Regulation 14 provides for General Requirements in relation to Sulphur Oxides (“SO\textsubscript{x}”) and is as follows:

1) The sulphur content of any fuel oil used on board ships shall not exceed 4.5% m/m [emphasis added]; and

2) The world-wide average sulphur content of residual fuel oil supplied for use on board ships shall be monitored taking into account guidelines to be developed by the Organization.
a. In addition, same regulation provides for SOx Emission Control Areas as follows:

3) For the purpose of this regulation, SOx emission control areas shall include: the Baltic Sea area as defined in regulation 10(1)(b) of Annex I, the North Sea area as defined in regulation 5(1)(f) of Annex V; and b) any other sea area, including port areas, designated by the Organization in accordance with criteria and procedures for designation of SOx emission control areas with respect to the prevention of air pollution from ships contained in appendix III to this MARPOL Annex VI. (Please refer to Annex II to this paper)

Further amendments to revised MARPOL ANNEX VI:

Over the years, amendments were made to MARPOL ANNEX VI that was adopted in 1997 and are in force from 19 May 2005. In addition, pursuant to the amendments to Revised MARPOL ANNEX VI provides:

- Resolution MEPC 62 adopted in July 2011 and entered into force from 1 January 2013, with the amendments to MARPOL Annex VI (resolution MEPC.203 (62), the Energy Efficiency Design Index (hereinafter “EEDI”) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (hereinafter “SEEMP”) for all ships. EEDI mandates the use of energy-efficient equipment and engines on board the vessel and is measured by energy efficiency level per capacity mile. IMO has used a non-prescriptive approach for the industry to decide the design provides there is a gram CO2 reduction per mile with reference line being the ships built between 2000 and 2010. The requirements related to the EEDI will progressively become onerous every five years. Another aspect of the resolution is SEEMP, which is an operative measure that establishes a mechanism to improve the energy efficiency of a ship in a cost-effective manner using a voluntary use of the Energy Efficiency Operational Indicator (hereinafter “EEOI”) pursuant to (MEPC.1/Circ.684).

- Pursuant to MEPC 63 adopted in March 2012, it mandates four sets of important guidelines to assist in the implementation of the mandatory regulations on Energy Efficiency for Ships pursuant to MARPOL Annex VI.

- Pursuant to resolution MEPC.212(63) in 2012 - Guidelines on the method of calculation of the attained Energy Efficiency Design Index (EEDI) for new ships.

Pursuant to resolution MEPC.214(63) in 2012 - *Guidelines on survey* and certification of the Energy Efficiency Design Index (EEDI).

Pursuant to resolution MEPC.215(63) - *Guidelines for calculation of reference* lines for use with the Energy Efficiency Design Index (EEDI).

Pursuant to MEPC 70 in October 2016 – It considered an assessment of fuel oil availability to inform the decision to be taken by the Parties to MARPOL Annex VI, and decided that the fuel oil standard (0.50% sulphur limit) shall become effective on 1st January 2020.

2. **COMPLIANCE WITH NEW REGULATORY REGIME** (**effective 1 January 2020**):

On merchant ships ordinarily having large marine diesel engines, it is observed that typical heavy fuel oil has an average sulphur content of 2.7%. During the combustion process, the sulphur is oxidized to sulphur dioxide (SO2).

We have discussed the new regulations and the requirements pursuant to MARPOL ANNEX VI in the regulatory regime applicable from 2020. Owners, in order to comply with the new regulations in relation to new fuel standard, will have to contemplate a switch to distillate fuel. These fuels complying with the regulations are available at higher prices, but also will raise additional concerns on board the ships, in particular, to the operating difficulties involving low viscosity, lubricity, lower flashpoints and catalytic fines. Fortunately, *IMO/MARPOL ANNEX VI*, Chapter 1, Regulation 4 has provided ship-owners and operators with an alternative path to MARPOL ANNEX VI compliance by using exhaust gas cleaning systems also known as scrubbing.

For the sake of completeness, *MARPOL Annex VI, Chapter 1, Regulation 4* provides:

*The Administration of a Party may allow any fitting, material, appliance or apparatus, such as SOx scrubbers [emphasis added], to be fitted in a ship or other procedures, alternative fuel oils, or compliance methods used as an alternative to that required by MARPOL Annex VI [emphasis added].*
The Administrations of Party that allow a fitting, material, appliance, apparatus or other procedures, alternative fuels, or compliance methods used as an alternative to that required by MARPOL Annex VI shall advise IMO on it. Notifications of use of equivalent provision from Parties are available through the Global Integrated Shipping Information System (GISIS). (Registration required for public users).

3. THE FOUR MAIN MODES TO OVERCOME 2020:

As discussed above, pursuant to the amendments to MARPOL Annex VI, IMO will enforce a new 0.5% global sulphur cap on fuel content from 1 January 2020. This measure will ensure to limit the global air pollution and also assisting populations living close to ports or the coasts that are not within Sulphur Emission Control Areas (“SECAs”). SECAs restricts the mass of Sulphur Oxide to just 0.1% m/m. SECs being the Baltic Sea, the North Sea, the North American ECA, including most of US and Canadian coast and the US Caribbean ECA.

This will compel the ship owners and operators to modify and improve their ships to comply with the regulatory regime as discussed above. Pursuant to MARPOL Annex VI, Chapter 1, Regulation 4, there are four main common variations that ship owners and operators are currently employing - (1) use of low sulphur oxide fuel, (2) installation of SOx scrubber (sulphur oxides scrubber), (3) use of alternative fuels such as LNG, and (4) less commonly called as oil blending or solution blending. In this paper, the authors will discuss the first more common options that are being employed, before moving to the option of scrubbers.

Option 1 – Low –Sulphur oil:
The use of low sulphur oxide fuels has the discernible and understandable advantage of the lowest investment cost, but the disadvantage is that the margins in operating the vessel can decrease considerably due to the rise in fuel price as a result of instability and/or unavailability of the fuel supply at various ports
Additionally, altering to low sulphur fuels will lead to significant increase in fuel cost. Refineries worldwide need to change its existing production system to low sulphur fuel, which is estimated currently to take more than five years. As a result, it is predicted that there may be instability and/or unavailability of fuel supply at various ports for time being.

Technically when switching from HFO to distillate oil, a slow changeover is necessary. The reason for the slow changeover is to allow adequate time for the temperature of the fuel pump to drop from 150°C to 45°C. It will accordingly prevent pumping seize; as a result of insufficient viscosity of the distillate oil might stop the pump from working efficiently.

When mixing HFO with the distillate in the booster system, to have a smooth changeover, a good compatibility between the HFO and the distillate is essential. If the fuels are not compatible, it will result in the build-up of deposit, and thereby clogging filters. It can be seen as above.

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1 Guidelines for Operation on Fuels with less than 0.1% Sulphur
**Option 2 – LNG (Liquefied Natural Gas):**
The use of alternative fuels such as LNG is basically an alternative that can lead to relatively low emission of nitrogen oxides and sulphur oxides. It has an added advantage of being available at relatively low fuel price. The complete removal of SOX and PM emissions and a reduction of NOX emissions of up to 85% can also reduce greenhouse gas (GHG) emissions by 10 to 20%, depending on engine technology.

However, the above advantages in this option come with their own disadvantages. The installation costs for employing LNG fuels are extremely high. Additionally, the process of induction on board, the merchant ships is very complicated to execute, and not all ports currently have stations that can refill the LNG tanks. The availability of LNG bunkers is gradually increasing. However, it is too early in time to eliminate the use of fuel oil or to ensure reasonable bunker infrastructure for LNG is available in ports. This may happen in a few years from now, but the date to comply with the new regulatory regime is fast approaching. This means that the owners’ options are practically limited at this time to comply with the new regulatory regime.

**Option 3 – Fuel Blending:**
Marine engineers and technologist are currently working on this option of solution blending or oil blending. Currently, it is unreliable and meanwhile, research has not reached the state where this option can comply with the regulatory regime. Engine manufacturers are also striving to meet the new regulatory regime as to the low sulphur requirements through new innovative approaches, but they are still very limited as far as technological breakthrough that is needed is concerned.

**Table-1: Comparative analysis of four options in Tabular form**

<table>
<thead>
<tr>
<th>MAIN ALTERNATIVES</th>
<th>PRO</th>
<th>CON</th>
<th>APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPLIANT SCRUBBER</td>
<td>It reduces exhaust emissions by 98% High returns on investment</td>
<td>Additional equipment installation required Complexity of engine and funnel area.</td>
<td>New shipbuilding and Retrofit for Container, Bulk carrier, etc.</td>
</tr>
</tbody>
</table>

2 ABS Advisory On Exhaust Gas Scrubber System July 2018
<table>
<thead>
<tr>
<th>MAIN ALTERNATIVES</th>
<th>PRO</th>
<th>CON</th>
<th>APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW- SULPHUR DISTILLED OIL (COMPLIANT FUEL)</td>
<td>Low investment cost</td>
<td>Oil prices fluctuate</td>
<td>Present ship operating available</td>
</tr>
<tr>
<td>LIQUEFIED NATURAL GAS</td>
<td>Low emission of NOx and SOx</td>
<td>High installation costs</td>
<td>Future new shipbuilding available</td>
</tr>
<tr>
<td>FUEL BLENDING</td>
<td>High price oil cost relatively</td>
<td>Effect to engine maintenances by density of oil Still research is undergoing, and compliance is doubtful.</td>
<td>Blending solution</td>
</tr>
</tbody>
</table>

*Note: NOx- Nitrogen Oxides, SOx- Sulphur Oxides, LNG- Liquefied Natural Gas*

**Option 4 – Scrubber:**

HSFO can still be used after installation of a regulatory regime compliant SOx scrubber that is also known as an *exhaust gas cleaning plant*. No changes will have to be made to the engines or fuel treatment plants by ship owners and operators. SOx scrubber installations have the advantages of reducing exhaust emissions from ships by up to 90% while still using heavy oil.

This alternative will, however, have a high initial cost, but due to use of low-cost HSFO, it will likely give a high return on investment over the years. It is estimated that the payback period of a scrubber is about one - two years based on oil price and amount of oil consumption on board the ships. The ECAs or SECAs including China, which have started to apply local limit of 0.5% local are increasing and therefore, the payback period is much shorter for ships with a higher chance of entry into the ECA zone. By a reasonable estimate, given that more than 50% of merchant's vessels are concentrated in ECAs or SECAs, a shorter payback period is expected in this option.

Due to excellent returns on the investment in short payback period, and with the applicability of new regulations in 2020, it is widely seen that increasingly the stakeholders are opting to install the scrubbers. However, procedures and debates around installation techniques to minimize the dry-dock are being discussed among engineers and naval architects. These debates in future will also contribute to reduce the installation costs of these scrubbers. Therefore, manufacturers are becoming increasingly focused on issues associated with installation of scrubbers.
4. PRINCIPLE AND TYPES OF SCRUBBER:

A scrubber (or an exhaust gas scrubbing apparatus) is a desulphurization apparatus, whereby it removes Sulphur Oxide (SO\textsubscript{x}) from exhaust gas discharged from ship’s engines and boiler. The system is made using the principle that sulphuric acid is discharged; after the sulphuric acid is removed by the water stream in the apparatus, while passing through the scrubber. This alternative is considered fully compliant of MARPOL Annex VI Regulation 4 with regards to compliance of Sulphur. Scrubbers have been in use in the marine industry since 2015, especially in the ECA zones in Europe and North America.

Dry type scrubbers are relatively used on land. However, wet type scrubbers are applicable to ships due to fact that the space is limited on board such ships. In wet type scrubbers, a relatively more periodic maintenance is required as compared to the dry types scrubbers. There are three main types of scrubbers for vessel: *Open, Closed and Hybrid*.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>Uses Seawater&lt;br&gt;The salt components in Seawater is effective in diluting acid components of sulphuric acid. Once that is done it is discharged into the sea.</td>
</tr>
<tr>
<td>Closed</td>
<td>Uses Purified water containing alkaline components&lt;br&gt;The alkaline component (Caustic Soda or Magnesium hydroxide) will neutralize the Sulphuric acid. After purifying the sulphuric acid, the water is reused and only an exceedingly small amount of water containing impurities is separated. These impurities are then removed before the water can be discharged into the sea.</td>
</tr>
<tr>
<td>Hybrid</td>
<td>Uses both seawater and alkine components&lt;br&gt;The Hybrid scrubber can switch between the two types (Open &amp; Closed) of scrubber functions depending on the condition of the ship.</td>
</tr>
</tbody>
</table>

Figure 3: Overview of types of scrubbers

If one has installed an open scrubber, the marine engineers can replace bunkers when entering the port such as in Singapore, where the open scrubbers are not permitted. If low sulphur fuel is used, it may cause performance deterioration due to low viscosity in the fuel pump, cylinder, etc., and accordingly the viscosity should be increased to at least 2 cst and lubricant needs to be replaced. When using MGO, one needs to apply oil cooler or chiller cooling system. There are separate guidelines that are available from different engine makers, but it is advised that the engine operators should operate with more stringent standards to avoid damage to machinery.
On the other hand, according to the analysis of advantages and disadvantages for the types of scrubbers, the open loop scrubber systems usually use a large amount of seawater, consume a relatively large amount of power, and are used mainly for ocean voyages. In addition, these have to be replaced with low sulphur oxide fuel in port. However, the closed loop mainly uses fresh water and dosing unit to add NaOH for maintaining the PH values. The process tank, the water-treatment system and the heat exchangers are additionally installed as compared with open loop scrubber systems. Accordingly, they occupy a lot of space, but the power consumption is relatively less.

Hybrid scrubber systems are used as an open loop scrubber during ocean navigation and closed loop scrubber in port. It has a complicated system and requires a lot of installation space. However, it can be used while navigating in oceans and within the ports both. The scrubber market is moving from an open loop to a hybrid loop due to low operating costs after installation and due to no limitations of the operating area. Hybrid type market is expected to increase in particular, the increasingly stronger marine standards are driving the hybrid market, but in the case of a retrofit, the cost is about 30% higher. Installation costs will increase in such hybrid systems, and the level of difficulty observed will also increase.
### Table-2: The Advantages and Disadvantages of different types of scrubbers in the tabular format

<table>
<thead>
<tr>
<th>Scrubber Type</th>
<th>Advantage</th>
<th>Disadvantage</th>
</tr>
</thead>
</table>
| **Open**      | • Simple structure  
                • Simple installation/operating with lower cost | • Increase of pump and pipe size  
                • Restriction on the Seawater condition (pH) and local discharge regulations |
| **Closed**    | • Reduction of drive pump and piping size  
                • No restriction on the Seawater condition (pH) / local discharge regulations | • Complex structure  
                • Complicated installation/operating  
                • Higher cost  
                • Supplement of neutralizing (NaOH) needed |
| **Hybrid**    | • Lower operating cost than closed type  
                • No restriction on the Seawater condition (pH) / local discharge regulations  
                • Need smaller amount of neutralizing (NaOH) than closed  
                • Flexible operation according to seawater condition | • Complex structure (Open/Closed scrubber)  
                • Complicated installation and operating  
                • Higher cost |

![Open loop type](image1) ![Closed loop type](image2) ![Hybrid Type](image3)

**Figure-5:** Exhaust gas cleaning systems

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3 Korean Register of Shipping, Exhaust Gas Cleaning Systems Technical Information November 2018

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5. THE FUTURE PROSPECT OF SCRUBBER:

Market Trends:

As discussed in Section 1 of the paper that at the 70th meeting of MEPC in London in October 2016, the International Maritime Organization (IMO) will limit emissions of ships from 3.5% m/m to 0.5% m/m by 2020 and accordingly concluded an agreement. According to the Clarkson and OECD surveys, currently, the most common options among ship owners are (1) use of low sulphur oxide fuel, (2) installation of SOx scrubber (sulphur oxides scrubber), (3) use of alternative fuels such as LNG.

The use of low sulphur oxide fuels has the advantage of the lowest investment cost, but the disadvantage is that the fuel price can rise due to instability and/or unavailability of the fuel supply. The scrubber installation has the advantages of reducing exhaust emissions from ships using heavy oil by up to 90% and the high return on investment. Due to the high initial investment costs or expectations for alternative technologies to replace them, the scrubber market has been underestimated. As the year approaches 2020, ship owners are quickly moving into the scrubber market due to the uncertainty of oil prices and the absence of economical alternative technologies.

A sharp rise in the price of a scrubber material and the delay in the material supply period prove this fact and have a great influence on the delivery period of the scrubber. In chartering contracts, it is known that the installation of the scrubber is the priority, and the main requirement of the ship owner's scrubber selection is frequently the delivery period.

The use of alternative fuels such as LNG can lead to relatively low emissions of nitrogen oxides and sulphur oxides. This is to be accompanied by a relatively low fuel price for the fuels that can be used in such systems. However, the installation cost of the LNG engine is remarkably high for installations, and the process is extremely complicated to execute on board the ships. As a result, an aggressive investment in the scrubbers is likely to be achieved by 2020. These scrubber installation agreements, market conditions and research results are particularly good opportunities for scrubber manufacturers. In addition, scrubbers are subject to an increased regulatory regime by the US Coast Guard and the EU, and accordingly they must be certified by Lions Clubs International), such as Lloyd's, DNV, and Bureau Veritas.
Table-3 Payback time of combined EGR/EGC scrubber system\textsuperscript{4}

<table>
<thead>
<tr>
<th>Engine size</th>
<th>Operating time</th>
<th>CAPEX EGC scrubber and EGR</th>
<th>OPEX per year Fuel, EGR and EGC scrubber (SW)</th>
<th>Payback time</th>
</tr>
</thead>
<tbody>
<tr>
<td>27MW</td>
<td>6000h/year</td>
<td>Ref. No EGC</td>
<td>OPEX (3%)</td>
<td>Saving per year</td>
</tr>
<tr>
<td>System</td>
<td>ECA share</td>
<td>Mio $</td>
<td>Mio $</td>
<td>Mio $</td>
</tr>
<tr>
<td>Combined</td>
<td>0% ECA</td>
<td>6.20</td>
<td>19.71</td>
<td>16.41</td>
</tr>
<tr>
<td></td>
<td>20% ECA</td>
<td>6.20</td>
<td>20.74</td>
<td>16.61</td>
</tr>
<tr>
<td></td>
<td>100% ECA</td>
<td>6.20</td>
<td>24.86</td>
<td>17.43</td>
</tr>
<tr>
<td>Reduced</td>
<td>0% ECA</td>
<td>5.30</td>
<td>19.71</td>
<td>16.63</td>
</tr>
<tr>
<td></td>
<td>20% ECA</td>
<td>5.30</td>
<td>20.74</td>
<td>16.79</td>
</tr>
<tr>
<td></td>
<td>100% ECA</td>
<td>5.30</td>
<td>24.86</td>
<td>17.43</td>
</tr>
</tbody>
</table>

**Payback period and other options:**

In the case of scrubbers, which are regarded as the most feasible solution amongst the four options, the focus is on the payback period, or ROI (Return on Investment) based on the current oil price and the oil consumption of the ship. Even the same vessel can be affected by the trading route and operating method. Table 3 shows an example of calculating the payback period. The calculation of the payback period depends on whether the view of the oil market is pessimistic or optimistic, and there are considerable differences depending on the opinion of any party, such as the manufacturer of the scrubber and the classification. It depends on the type of scrubber as well, but it is generally considered to be around two years. Even considering the unpredictable oil price, ship owners still can expect safe operation as well as economic operation if they were to operate the scrubbers from 2 years after installing the scrubber.

\textsuperscript{4} Reduction of SO2, NOx and Particulate Matters from Ships with Diesel Engines.
In order to do a thorough comparative analysis between the option of installing scrubber system and another option of using low sulphur oxide fuel, there are many variables that cannot be overlooked, in particular, there are unexpected factors that may originate in the four industries from 2020 – scrubber manufacturers, refinery company, blending solution company and engine manufacturer. It is therefore, very hard to predict how these industries will respond to uncertainty while complying with the regulatory regime as discussed in the first section of this paper.

Refinery companies need to change its existing production system to low sulphur oxide fuel, which is likely to take more than five years. In this scenario of an increase in the price of low sulphur fuel, then it is likely that payback period for the scrubber systems can even be reduced to just one year. Accordingly, the installation of the scrubber has additional advantages.

As discussed earlier, the option of Blending solution is unreliable and currently not good enough to be regulatory compliant. Considering the current situation with the refineries, using a low sulphur fuel is a significant risk as well. Since 2020, it is expected that the new scrubber system will be installed on the remaining 4,000 or more vessels to satisfy the IMO regulation until 2026. Clarkson estimates that approximately 6,000 vessels will be equipped with scrubbers until 2026. Based on Clarkson's announcement data, estimates retrofit markets will be around 600 ships per year based on new shipbuilding volume.

![Figure 6: Comparative analysis of different modes in graphical form](image-url)

Scrubber systems will increase the ship’s fuel consumption by approximately 2%. Downtime of the scrubber systems will introduce a cost for running these compliant fuels. Installation of scrubber system will be needed, and accordingly, it will increase the maintenance cost (more for closed loop scrubber systems). For closed loop systems, there will be an additional cost associated with alkali bunkering and sludge disposal system. It is expected that there will be an increase in demand for a Hybrid type scrubber system, which can not only avoid inconvenience due to the limitation of the operating area, but also can operate at a low cost.

**Figure-7:** Scrubber Product Value chain

**The Preparations and Procedures in context of Scrubber:**

To design a scrubber system, it needs to fulfil the strict regulatory environment, in particular, the various geographical areas of operation of the ships. Sufficient information must be
provided to installers of such as scrubber system such as fuel sulphur levels, the alkalinity of the seawater, any special conditions in which the ship would be operating in. The scrubber itself has its piping and cabling next to that, there is the heat exchanger, the separator, tanks, pumps, frequency converters, cabinets.

The size of the scrubber is determined by the amount of exhaust gas, and the shape of the scrubber could be different depending on the manufacturer of such scrubber systems. In general, competitiveness of the scrubber system is judged, when it has the optimum design with less installation space and low power consumption while satisfying the required performance expected on the ships. Most of all, it must be regulatory compliant. Ship owners and other stakeholders should request that these specific conditions, such as smaller scrubber size, washing water consumption, and power requirement be fully taken into account to achieve the goal of optimized scrubber equipment installation. U type and I type are typical, and the technique of processing the gas inside the scrubber is different. In the case of a retrofit, weight and footprint are important factors, which is an additional consideration of the ship's characteristics. A general scrubber configuration is as follows:

- After months of planning, the parts, pipes, and housings were prefabricated and delivered to the shipyard.
• Removal and repositioning of existing equipment began simultaneously at several places on board the ship.
• The various modifications that were required on board took almost three weeks.
• There were new walkways, handrails as well as maintenance platforms.
• Space was created for the new equipment.
• Then once it was installed, the testing was carried out as to whether the equipment was working, the installation was working, and importantly whether the results were within the IMO legislation.

6. CONSIDERATIONS FOR EGCS INSTALLATION:

*Positioning and Structure of Scrubbers in engine room:*

SOx scrubber equipment does not have any special hazards, so it can be installed inside or outside the engine room depending on space availability. In the case of retrofit, one can also create a separate compartment if one does not have proper space. In this case, prevention of freezing of equipment and requirements for pipelines and cables through engine compartment bulkheads/decks should be considered.

For all these cases, it should be ensured that sufficient space is available for operation and maintenance. As well as ensuring space, the gross tonnage of the ship will be increased. Stability is also taken into consideration because the center of gravity of the vessel changes depending on the location of the SOx scrubber installation. The lower part of the place where the scrubber is installed should be adequately reinforced; the issue of vibration and noise should as well be considered. *I* type installations have fewer footprints than the *U* type, although stability should be considered carefully as there is a simultaneous increase in vertical length.

If the position of the end of the exhaust pipe were to be changed, the exhaust gas should not be reintroduced into the accommodation area. In particular, the exhaust gas part of high temperature should be heat-sealed to avoid fire hazard for safety at sea.

Where the engine room boundary is extended adjacent to the container cargo area, the isolation requirements that are required for the loading of dangerous goods shall be considered as met.
From the viewpoint of installation of such systems, it is important to note that securing of space is often restricted depending on the condition of the vessel, and in the case of a retrofit, it is not easy to satisfy various demands of the owner or the operator.

**Power Load:**

The additional power required to operate the scrubber must be analyzed. The load ratio of the sea-going merchant ship should be considered and how it is affected by the sum of the power of the scrubber. Should such a system be selected, it is important that the total power should not exceed 90% of generator capacity. If it were to exceed 90%, an additional generator should be installed.

**Corrosion of Exhaust and Cleaning Water:**

The ship is equipped with main engines, auxiliary engines, boilers, and so forth. Gas is exhausted from the connected exhaust lines from each of these pieces of equipment. Accordingly, the exhaust pipe of various devices is connected with a single scrubber to exhaust the gas; that is, the multi-stream is installed. Therefore, the maximum emission of exhaust gases from all such equipment must be considered. The scrubber increases the back pressure of the exhaust gas of the engine and can additionally affect the performance of the engine, and that can in addition affect the NOx emission limit. When installing the scrubber with the multi-Stream method, there is a need for measures that are required to ease the flow by installing a separate exhaust fan to lower the back pressure.

This is one of the complex parts of the scrubber technology that should be considered. The choice of equipment with a reliable technology is, therefore, paramount in this respect as it can directly affect the operation of marine engines of the ships.

Sulphuric acid in this altered spray state, which has become strongly acidic by sprayed seawater, has the potential to cause severe corrosion on top of the scrubber. Additionally, the inside of the wash-water discharge pipeline is strongly acidic and is therefore installed under the water surface of the engine room to prevent the wash water from being reabsorbed through the other suction pipes of the engine room such as sea chest, etc. It is done to prevent excessive corrosion to pipelines and connections. Since the scrubber body and the connected pipeline are
large and long, the maintenance of the pipeline affects the performance of the scrubber device itself, and further affects the operation cost of the device after installation. Therefore, in the choice of the scrubber, the material from which the scrubber body and pipeline are manufactured is an important consideration because it affects the operations of the scrubber systems in long-term and in doing so provides required stability. The cost of materials and parts of any scrubber systems roughly accounts for around 40% of the total equipment price. It is to be appreciated that there is a considerable difference in the durability depending on the material or the composition of the material.

7. CONCLUSION:

Due to the difficulties in forecasting the market for oil that can comply with the new regulatory regime along with the fact that work is still in progress for other technologies, which may be in compliance with the regulatory regime in the near future, it is observed in the maritime sector that many ship owners’/ship managers are moving rapidly to the scrubber market. The feasibility studies carried out in this part along with the practical analysis of the scrubber system including the costs could assist the stakeholders in reaching the decision.

Depending on stakeholders, there are different viewpoints, for example, from manufacturers of engines, manufacturers of scrubber systems, shipbuilders, class societies, bunker companies, Port authorities, oil refineries and so forth. The authors agree that such views and opinions on the scrubber systems are rather varied and frankly, at times somewhat contradictory. However, considering the breakthrough in relevant technology at this point of time, the characteristics of the oil market and difficulties associated with changing the existing bunker lines on board the ships, it is the authors’ view that the ship owners cannot delay the selection of the scrubber system for their ships.

However, since a relatively higher initial investment that is required to install scrubber systems, it is necessary for these stakeholders to make a reasonable and effective choice while taking into account the size and age of the ships, its trading areas and so forth. Particularly, durable materials should be selected for stable and long-term operation, and high-level of engineering and yard techniques should be introduced to facilitate pipeline maintenance. In the authors’
view, no doubt the installation and operation of the correct scrubber systems will greatly contribute to and enhance the operations for ship owners and operators and other stakeholders.

The expertise of engineers and commercial stakeholders is only going to increase in the future in relation to scrubber systems. The expertise should also in the authors’ view keep pace with the rapidly changing expectations of societies and ensuing changes in the regulatory regimes. It seems only constant that stand out is the rapidly changing regulatory regime.

ANNEX I:

Figure 2.1. Annual growth of world fleet, 2000-2016 (Percentage annual change)


Figure 9: Annual Growth of Fleet rate (2000-2106)

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Table 4 - Overview of Emission Areas

<table>
<thead>
<tr>
<th>Emission Control Areas</th>
<th>Adopted By</th>
<th>Date of Entry in Force</th>
<th>In effect from</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Baltic Sea (SOx) (NOx)</td>
<td>26-Sep-1997 07-Jul-2017</td>
<td>19-May-2005 01-Jan-2019</td>
<td>19-May-2006 01-Jan-2021</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A ship constructed on or after 1 January 2021 and is operating in these emission control areas shall comply with NOx Tier III standards set forth in regulation 13.5 of MARPOL Annex VI.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A ship constructed on or after 1 January 2021 and is operating in these emission control areas shall comply with NOx Tier III standards set forth in regulation 13.5 of MARPOL Annex VI.</td>
</tr>
<tr>
<td>3 North American ECA (SOx and PM) (NOx)</td>
<td>26-Mar-2010</td>
<td>01-Aug-2011</td>
<td>01-Aug-2012 01-Jan-2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A ship constructed on or after 1 January 2016 and is operating in these emission control areas shall comply with NOx Tier III standards set forth in regulation 13.5 of MARPOL Annex VI.</td>
</tr>
<tr>
<td>4 United States Caribbean Sea ECA (SOx and PM) (NOx)</td>
<td>26-Jul-2011</td>
<td>01-Jan-2013</td>
<td>01-Jan-2014 01-Jan-2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>A ship constructed on or after 1 January 2016 and is operating in these emission control areas shall comply with NOx Tier III standards set forth in regulation 13.5 of MARPOL Annex VI.</td>
</tr>
</tbody>
</table>
ANNEX II - Emission Control Areas in a tabular form that were designated pursuant to MARPOL VI and subsequent amendments are as follows:

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