Pacific Green

ENVI-Marine™

Technical Book /

ENVI-Marine™ Exhaust Gas Cleaning System

Part of the Pacific Green Group of companies

ENVI-Marine™ Exhaust Gas Cleaning System

ENVI innovative emission control system

Pacific Green owns worldwide marketing rights for the internationally patented ENVI innovative emission control system.

ENVI's unique approach for wet EGC systems makes the system highly effective in the removal of particulate matter, acid gases and selected heavy metals from the combustion flue gases of coal, biomass, waste to energy and diesel processes.

The attributes that make the ENVI systems unique include multiple turbulent scrubbing heads working in series with the capacity to continuously process 100% of the flue gas, a high efficiency horizontal head design, small and flexible footprint, on-demand reagent addition and low capital and operating costs. Flue gases are first quenched then cleaned by our patented TurboHead™ process before being discharged as harmless salts.

Marine applications

ENVI-Marine™ systems are fully flexible and can be supplied as open loop and full hybrid systems capable of both open and closed mode operation.

For vessels running heavy fuel oil this system offers industry-leading ROI and will clean the exhaust to international emission standards and beyond into the future.

The ENVI-Marine™ system has definite advantages over conventional water spray exhaust gas cleaners. The patented TurboHead™ frothing bed creates an intense turbulent zone to give liquid-to-gas contact ratios that are lower than competitive approaches for more efficient SO2 absorption.

This efficiency advantage allows for a more compact and cost-effective solution.

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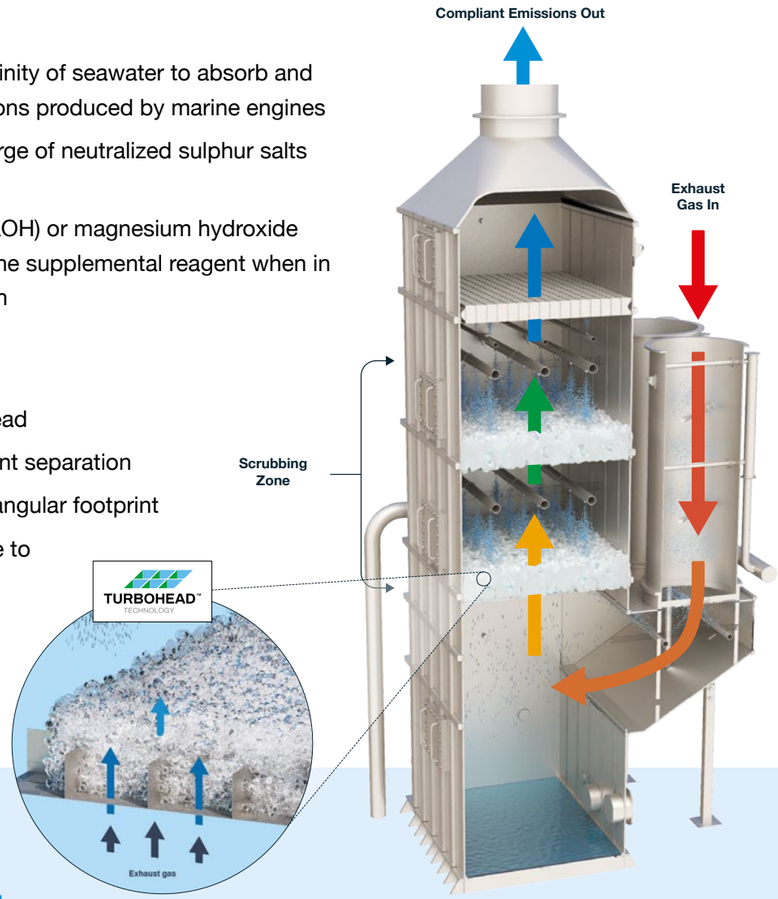
Technical Overview

Functions by:

- Using the natural alkalinity of seawater to absorb and neutralize SO2 emissions produced by marine engines
- Post treatment discharge of neutralized sulphur salts into sea
- Uses caustic soda (NaOH) or magnesium hydroxide (Mg(OH)2) as an alkaline supplemental reagent when in closed mode operation

Flexible layout due to:

- Patented horizontal head
- Potential for component separation
- Able to configure rectangular footprint
- Compact footprint due to efficiency



Seawater Scrubber

The ENVI-Marine™ seawater scrubber takes an alternative approach to seawater scrubbing by using ENVI's unique patented TurboHead™ to provide highly interactive contact between the seawater and the exhaust gas in a turbulent zone containing a high amount of surface area for SO2 absorption.

The high energy liquid/gas interaction assures both the residence time and complete interaction required to achieve high efficiency removal of SO2 from the exhaust gas. In addition, the highly turbulent interaction transfers particulate matter from the gas to the scrubber fluid. Marine fuel oil typically has a 0.1% to 0.15% ash content after complete combustion, and incomplete combustion adds carbon and hydrocarbon particulate and oils to that value. A high percentage of these pollutants are captured by the seawater scrubber resulting in a much cleaner exhaust plume.

The pressure required to push the exhaust gas through the EGC system is typically not large (e.g. 6 - 8" w.c.) and marine engines are capable of operating at this back pressure with ease.

System Operating Modes

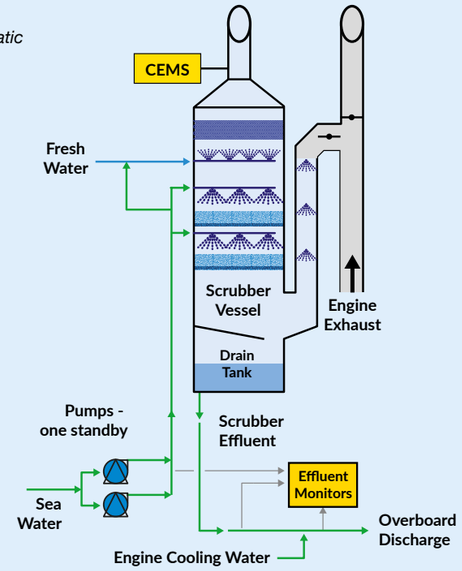
The ENVI-Marine™ system is designed to operate in two modes, open and closed depending on the effluent discharge regulations in the waters in which the vessel is located.

Open Mode Operation

In open operating mode, raw seawater is pumped to an array of nozzles situated above each of the TurboHeads™ which uniformly distribute seawater to the scrubber system counter-flow to the exhaust gas to absorb the SO2 and neutralize it with the seawater's natural alkalinity. The exhaust gas leaving the scrubber is analyzed for SO2 and CO2 by the continuous emission monitoring system (CEMS) to ensure that the scrubbing efficiency meets the regulatory requirements. The rate of seawater flow to the scrubber heads is controlled based on the scrubbing efficiency and the pH of the effluent.

The scrubber's washwater is analyzed for turbidity, pH and oil content (as PAH) on a continuous basis prior to being combined with reaction seawater and discharged. The reaction water may be sourced solely from engine cooling heat exchanger water with some modification to the overboard discharge piping. The reaction water increases the pH of the combined stream before discharge to the sea. The pH is monitored at the discharge point to ensure the discharge meets the effluent quality requirements.

Open mode schematic



Open Mode Components

The ENVI-Marine™ open mode EGC system is comprised of the following components:

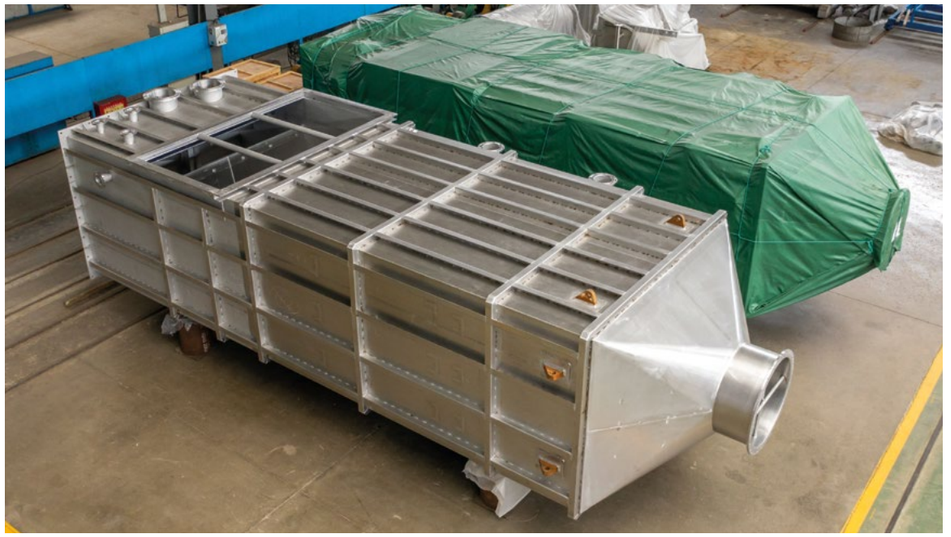
Bypass Dampers, Gas Quench and Conditioning Ducts, Seal Air Blowers

Each exhaust gas source is fitted with a double-vaned diverter damper so that the exhaust can be diverted from the stack into the scrubber. Seal air blowers (one standby) provide seal air between the double vanes of the damper when they are closed to ensure minimal leakage of exhaust gas. All diverter dampers will include expansion joints. Prior to flowing into the scrubber, the main engine exhaust is quenched with seawater spray (or washwater spray while operating in closed mode) in a gas quench and conditioning (GQC) duct to reduce the temperature to 55°C or less. The exhausts from the auxiliary engines are quenched in a second GQC duct. The GQC ducts and spray manifolds are made of Grade 2 titanium due to its excellent corrosion resistance during the temperature transition.

The quenched exhaust gas streams are further conditioned with seawater or washwater spray at the scrubber inlet. The reduced temperature reduces the actual gas flow rate and moistens the gas and particulate matter prior to it entering the scrubbing heads. The washwater draining from the quench area and lower head will flow down the sloping scrubber drain section to the recirculation tank located below the scrubber vessel. The scrubber inlet and recirculation tank is fabricated from duplex 2205 stainless steel.

Scrubber Vessel

The scrubber vessel will have a rectangular cross section. After quenching, the exhaust gas is distributed uniformly across the lower scrubbing head due to the back pressure created by the turbulent zone. The patented TurboHead™ provides a high-contact interaction zone between the exhaust gas and the scrubber water. In the turbulent zone, 100% of the exhaust gas is exposed to continuous contact with the scrubber



ENVI-Marine™ scrubber vessels ready for delivery

water. There are two turbulent scrubbing heads in the scrubber vessel, approximately 1.6m above each other, each with an array of spray nozzles to provide them with fresh seawater or recirculated washwater for scrubbing. The scrubber water from the upper head will drain onto the lower head, so each head has a unique design to accommodate different volumes of scrubber water. After passing through the heads, the exhaust gas will enter the mist eliminator section and then exit out the stack to the atmosphere. The demister section is equipped with water spray nozzles to periodically wash away accumulated solids and prevent scaling.

The scrubber vessel is equipped with numerous ports for access, inspection, instrumentation, and water inflows. The seawater piping is constructed of galvanized steel or polyethylene lined mild steel for corrosion protection. The scrubber body is made from duplex 2205 stainless steel and the heads are constructed of Grade 2 titanium.

Seawater Pumps

Two primary seawater pumps will be installed (one operating, one standby) to provide scrubbing water to the spray distribution manifolds above each of the turbulent scrubbing heads in open mode operation. These pumps are equipped with variable frequency drives to deliver the optimum volume of water to the scrubber.

Scrubber Water Drain Tank

In open mode, the washwater drains directly from the drain tank through GRE piping to the overboard discharge. En-route the washwater is analysed and data recorded by the system's process control system for turbidity, PAH and pH. After mixing with engine cooling seawater, the combined stream is analysed for pH and then discharged to the sea.

Continuous Emission Monitoring System

A Class-approved continuous emission monitoring system (CEMS) is required to demonstrate ongoing achievement of SO2 removal efficiency and adherence to SO2/CO2 emission ratio limits. SO2 and CO2 concentrations are both sampled using a gas conditioning system consisting of a heated particulate filter, a heat-traced Teflon line and (for dry basis systems) a moisture removal system to dry the gas. The gas is then analysed either cold and dry or hot and wet by the SO2 and CO2 analysers, depending on the system selected. The CEMS is a stand-alone system, with its output logged by the process control system for regulatory purposes. Calibration gas, if required, will be purchased locally.

ENVI-Marine™ assembly

Effluent Monitoring Systems

The Class-approved effluent monitoring system includes sensors for pH, turbidity and PAHs (as a surrogate for oil components). The water monitoring system is a stand-alone system, with its output logged by the process control system for regulatory purposes. A second pH meter monitors the combined discharge water after the washwater and reaction water are fully mixed.

Process Control System

The ENVI-Marine™ EGC system is operated using a process control system consisting of a programmable logic controller (PLC), multiple input/output modules and two touch-screen displays. The EGC process control system is linked to various ship systems including the power management system, the engine management system, the navigation system and the alarm management system. Ship engineers use a touch-screen interface to enable scrubber process components to operate automatically. The process control algorithms then optimize the system by adjusting pump speeds, opening, closing and adjusting dampers and valves, and for closed mode, turning on sub-systems such as the hydrocyclone systems and the NaOH/Mg(OH)2 delivery system. SO2/CO2 emission ratios are calculated from the CEMS data and used to adjust seawater pump flows to meet SO2 emission limits while minimizing CO2 emissions. For the most part, once the system is enabled and operational, very little operator intervention is required.

Process and emission data are recorded every minute and stored for a minimum of 18 months as per IMO regulations. Process and emission data may also have alarms configured for various settable levels. Exceedances of process and emission alarms triggers the alarm monitor, which then sends an alarm message to the ship's alarm management system as well as recording the alarm in the EGC alarm log. Events such as changes to settings, operating parameters, and SECA/Ocean zone are also recorded.

Programmable Logic Controller

The EGC system is controlled by a programmable logic controller (PLC) from two touch-screen displays, one at the main control cabinet housing the PLC and one in the engine control room. The system normally operates in automatic mode, but manual control, data logging and trend screens are also available. Data from the inaccessible PLC memory can be displayed and printed in 24-hour periods up to one month prior so that port authorities can audit system performance. A continuous record of performance can also be printed daily.

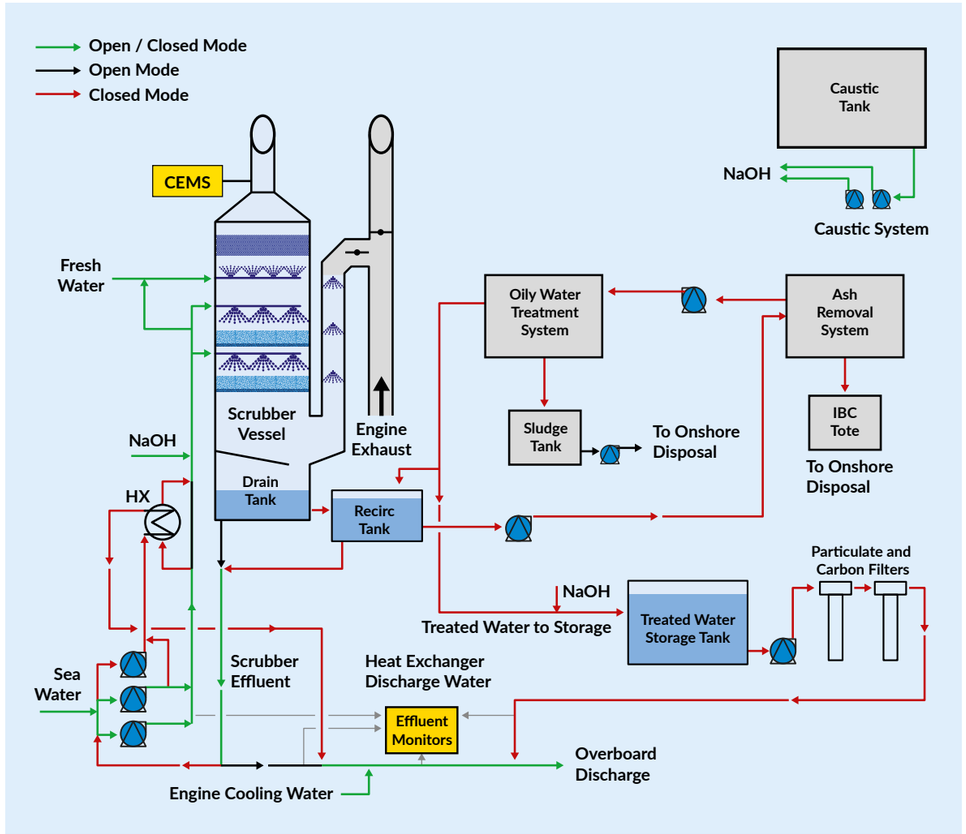
The EGC system data can also be downloaded to a USB drive so that it can be used to produce reports and statistical analyses for corporate purposes. A satellite phone link can allow secure remote access to the EGC system so that it can be monitored by Pacific Green and the owner/operator. This allows the ship operator and/or Pacific Green staff to troubleshoot problems from land-based offices.

Closed Mode Operation

In closed operating mode, conditioned washwater is recirculated through the scrubber with no discharge to the sea. Losses of water to stack humidity and effluent storage are made up with fresh water or sea water, depending on the planned duration of closed mode operation. In closed mode, washwater from the scrubber's drain tank is diverted to a recirculation tank. To maintain the washwater quality for recirculation, a side stream is taken from the recirculation tank and pumped to the primary hydrocyclone. The lighter overflow is piped to the oil thickening tank and the heavier underflow is piped to the ash thickening tank. Each of the ash and oil separation processes relies of the difference in density to separate the contaminants from the washwater. Both processes return the cleaned water to the recirculation tank.

Approximately 2 L of oily sludge and 0.5 L of ash sludge are generated for each tonne of HFO fuel combusted. These sludges are stored in 1 m3 IBC totes for later disposal onshore.

Heat that is transferred from the exhaust gas to the washwater is removed using a heat exchanger in the recirculation loop. A third seawater pump provides the heat exchanger with cooling seawater that is then discharged with the engine cooling seawater. This pump may also be used in open mode to provide reaction seawater. Caustic or magnesium hydroxide is added to the recirculating washwater as required to maintain the required alkalinity as measured by pH meters. Total dissolved solids are controlled by bleeding 1.0 - 1.5 m3 of washwater to an effluent holding tank per tonne of HFO combusted. Once the scrubber returns to open mode operation, the stored effluent is filtered and then discharged with the open mode effluent.



Closed mode schematic

Closed Mode Components

In addition to the open mode components, the following components are required for the system to operate in Closed Mode.

Scrubber Washwater Recirculation Tank

During closed mode operation, the scrubber washwater drains into a recirculation tank. The majority of the washwater is directed to the seawater pumps and recirculated back to the scrubber passing through a heat exchanger on its recirculation path, instead of being discharged overboard.

Hydrocyclone Washwater Treatment System

A side stream from the recirculation tank is sent to the washwater treatment system, which consists of a primary hydrocyclone to separate the heavy ash from the lighter oil and light solids. Both the ash and oil treatment systems return clean water from their respective treatment system to the recirculation tank.

ENVI-Marine™ naked installation

Ash Removal System

The heavier solids (primarily fuel ash) are concentrated in an ash thickening tank to produce a sludge with 50-70% solids content. This is accomplished by recirculating the higher concentrated sludge that is drawn from the bottom of the tank and processing it through a secondary set of hydrocyclones. The secondary ash hydrocyclone overflow is returned to the recirculation tank. The thickened underflow is returned to the ash thickening tank until the density is high enough to send it to an IBC tote where it is allowed to settle. Decant water is automatically drawn from above the settled solids in the IBC tote and pumped back to the recirculation tank, providing capacity for the next addition of dense solids slurry to be added to the IBC tote. When the IBC tote is 75% full of settled solids, it is decanted and replaced by another. The full tote is set aside for later transfer to shore for disposal.

Oily Water Treatment System

The oily water extracted from the overflow of the primary hydrocyclone is sent to the first of three thickening chambers in oil thickening tank. Oily water is drawn from the top of the first chamber and passed through hydrocyclones specifically designed to separate oil and water. The concentrated oily overflow water is sent to the second settling chamber of the oil thickening tank and the clean water is returned to the recirculation tank.

The residence time in the second chamber allows the oil to rise after which the oil-rich water at the top is pumped to a second set of oil-specific separation hydrocyclones. The concentrated oily overflow water is sent to the third chamber of the oil thickening tank and the clean water is returned to the recirculation tank. The top of the third chamber is periodically bled to an IBC tote or a small sludge tank for storage prior to pumping onshore for disposal. Neither disposal at sea nor incineration of this sludge is allowed.

Alkaline Dosing System

To control acid build-up in the recirculating washwater, neutralizing agents such as NaOH (caustic soda), MgO, or Mg(OH)2 (milk of magnesia) must be added to the scrubber washwater. The choice of reagent is at the discretion of the owner with the main considerations being the ease of handling and cost. The reagent is added using metering pumps controlled by the pH readings of the scrubber washwater.

An NaOH dosing system is normally designed to work with caustic soda as a 20-50% solution in water. NaOH is an odourless and colourless liquid that is highly corrosive, reactive, and toxic if ingested, therefore proper storage and handling of NaOH solution is essential. In addition, 50% NaOH solution freezes at approximately 11°C, so attention must be paid to maintaining pipe and tank temperatures above this level. As an alternative, 20% NaOH has a much lower freezing point (-27°C) so it is a better choice for cold weather. The size of the storage tank depends on what concentration is used for a given duration of usage. NaOH purchased as a 50% solution can also be diluted to 20% in a smaller storage tank as required.

MgO and Mg(OH)2 are much more benign in terms of handling, but are purchased as either powders or slurries so they require different designs for storage, mixing and delivery to the scrubber. Pacific Green is prepared to deliver either type of system depending on client preference.

Treated Water Storage Tank

A minimal bleed of the processed water containing high total dissolved solids (primarily sulfates, sulfites and chlorides) is taken from the clean side of first hydrocyclone in the oily water treatment system and sent into the treated water holding tank, typically an existing ship's tank (e.g. aft peak tanks) for storage and treatment.

Neutralizing agent is added to the water sent to the treated water holding tank to ensure that it is slightly alkaline. The location and size of the holding tank will be decided in consultation with the owner and shipyard. For long-term closed mode operation, the stored water can be filtered using particulate and carbon filters for overboard disposal at the minimal bleed rate after undergoing analysis to ensure it meets water quality standards.

If open mode operation is expected to resume prior to the storage tank being full, the stored water is not filtered until open mode operation resumes. It is then subjected to the same multi-stage filtration and analysis by the washwater monitoring system prior to mixing with the open mode scrubber washwater discharge.

ENVI-Marine™ enclosed scrubber fitting

Materials

Pacific Green consulted with industry experts and specialty steel suppliers to evaluate the options for material selection. A variety of specialty steels including duplex 2205, austenitics 904L and 317LXN, superaustenitic 6-moly AL-6XN, nickel-based C-276 alloys such as Hastelloy, super-duplex stainless steels such as 2507 and other alternatives such as titanium. Specialty steels are higher in chromium and molybdenum, or nickel, to increase their pitting and crevice corrosion resistance.

Figure 1 shows the pitting resistance equivalence number (PREN) of various types of specialty steels graphed against their critical pitting temperature. In general, the higher the PREN value, the more corrosion-resistant the material and the higher temperatures it can withstand.

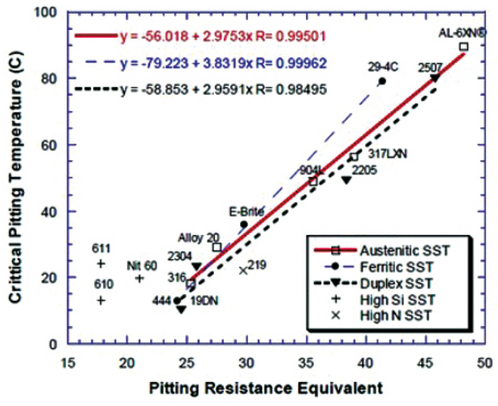
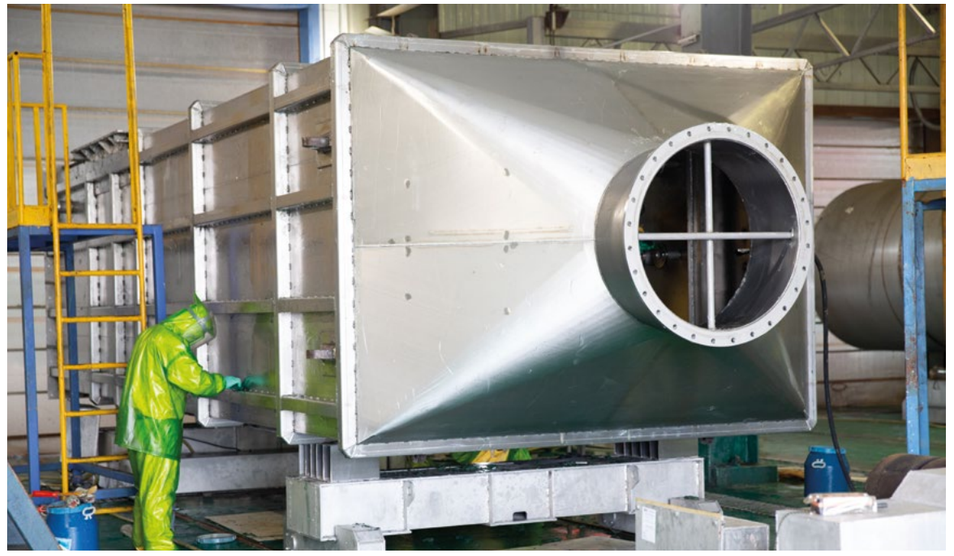


Figure 1 – Corrosion Performance of Specialty Steels

However, since the temperature scale only goes up to 100C, all of the selections listed, except for titanium, will have pitting issues to some extent in the transition area of the quench zone where the temperature drops from 300-450C to about 50C. There is also the tendency of chloride/carbonate scale to form on the hot surfaces that receive only a light mist of spray in the transition zone.

For this reason, in the quench zone where the exhaust gas is initially contacted with seawater, Pacific Green has selected Grade 2 titanium for the gas quenching transition zone. Titanium is not subject to chloride pitting at these transition temperatures and has never been seen to exhibit corrosion concerns in the 200+ gas quench ducts installed to date.

Below the gas quench ducts where the gas temperature is typically less than 50C, the specified material changes to 2205SS for the scrubber inlet box and drain tank. The gas temperature at this point is somewhat of a non-concern since the inlet box and drain tank walls are constantly wetted with seawater spray that is typically 5-35C, which is substantially below the critical pitting temperature for 2205SS, as well as the critical temperature for crevice corrosion. We also design the inlet box and drain tank to avoid crevices. In the 100+ installations we have completed to date, there has not been a single instance of pitting or crevice corrosion occurring in the inlet box or drain tank.



ENVI-Marine™ naked installation

The rest of the scrubber body is also constructed of 2205SS for the same general reasons: superior corrosion resistance and reasonable cost. The exception is the TurboHeads™ themselves, which are constructed out of Gr.2 titanium for protection against crevice corrosion. The heads are assembled in 300 mm wide formed panels that bolt together and naturally form crevices. The supporting rim at the perimeter of the rectangular scrubber is insulated using Teflon gasket to eliminate galvanic corrosion potential and the mated surfaces of titanium are not subject to crevice corrosion. With thousands of mated surfaces holding the head panels together on 100+ installations, there has never yet been a recorded instance of crevice corrosion occurring.

For the spray nozzles and internal piping, 2205SS is also used with good results. External piping for seawater is generally polyethylene-coated mild steel (4 mm thickness on the inside), while discharge piping for scrubber washwater is generally glass-reinforced epoxy (GRE) piping. For deck and bulkhead transitions, mild steel pipe coated internally with GRE is used.

The demister vanes are also constructed from 2205SS, and no instances of demister corrosion have occurred to date. The stack, which is attached by flanges to the scrubber body can be constructed of either 2205SS (for short stacks), or epoxy-coated mild steel, at the client's preference.

Pacific Green believes the combination of these materials offers the most practical and economical solution.

ENVI-Marine™ Competitive Advantages

High Efficiency

The system utilizes ENVI's patented TurboHead™ to generate a turbulent interaction zone for complete interaction between the exhaust gas and sea water.

Simplicity

The ENVI-Marine™ scrubber has no internal moving parts. All internal components are fabricated from Grade 2 titanium for long service life and are easily accessible.

Efficient Use of Space

The ENVI-Marine™ uses 100% of its cross section for scrubbing thus minimizing the footprint required. In addition, the ENVI-Marine™ system is fabricated from 2205 stainless steel in a rectangular configuration to make the greatest use of the space available. The scrubber system is equipped with inspection ports and access hatches for visual inspection of scrubber internal areas, and easy access for maintenance. This reduces the time spent diagnosing potential problems and fixing them.

Low Capital Cost

The simplicity and smaller size of the ENVI-Marine system results in lower capital costs for the equipment.

Multiple Operating Modes

The scrubber is capable of running in a once through open mode or closed mode.

Effective Particulate Removal

The turbulent interaction zone created by ENVI-Marine's patented TurboHead™ will effectively remove a significant portion of the total particulate matter and carried in the exhaust gas. This will reduce the visible plume and the associated health risks from particulate.

Computer Control and Optimization

The system is controlled by a programmable logic controller (PLC) with a graphic user interface in the operations station and control room. The system normally operates in automatic mode, but manual control, data logging and trend screens are also available. Depending on the ship's communication capabilities, the system can also be monitored and controlled remotely. This allows the operating company and/or Pacific Green staff to troubleshoot any problems from land-based offices.

The PLC has the capability of determining the most cost-effective operating conditions as established for individual ships and configure the scrubber to operate within those parameters.

Fabrication and Installation Capacity

Through its partnership with POWERCHINA SPEM, Pacific Green Marine has the largest fabrication and installation capacity in the world.

Conclusion

For fleets around the world few exhaust gas cleaning systems are available on such a large scale and none are more efficient than the ENVI-Marine™ system.

Pacific Green Marine has entered a joint venture agreement with PowerChina SPEM, a subsidiary of China state owned enterprise PowerChina to ensure Pacific Green Marine has unrivalled manufacturing and fabrication capabilities.

With numerous international manufacturing bases around the World, including Chinese ports Guangzhou, Longshan and Dalian Bay our available facilities rate amongst the World's largest and have many years experience in specialized marine fabrication.

The Pacific Green Marine system makes perfect financial sense by being able to utilize cheaper HFO, offering an obvious operating cost advantage that lends itself to funding packages to effectively allow the technology to pay for itself in a short period of time.

Pacific Green

World beating technology, one of the smallest and most flexible footprints on the market, high quality engineering and swift installation, these are just some of the reasons why Pacific Green's ENVI-Marine™ exhaust gas cleaning system has been installed on more than 120 ships.

As leaders in the field, Pacific Green has proven experience, outstanding performance and the aftercare service essential to both fit and maintain your vessel's EGCS ensuring the real benefits of reduced fuel costs and low emissions.

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