ENVI-Marine™
Emission Control Systems
TECHNICAL BOOK
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In 2009 Pacific Green Group acquired the worldwide marketing rights for the EnviroTechnologies Inc. (ENVI) innovative emission control system.

ENVI has designed and has filed international patent applications for wet scrubbing systems whose unique approach makes them 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 special 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.

With its patented technology Pacific Green Marine is able to offer a wide range of emission control systems for ships of all classes anywhere in the World.

Our technologies represent the state of the art for marine exhaust gas scrubbing devices.

Our business is focused on a cleaner future and our goal is to mitigate hazardous emissions from the most significant sources of pollution on the planet.
The Technology

The ENVI-Marine™ process is a simple concept. The flue gases are first quenched then cleaned by specialized frothing through pure seawater using our patented TurboHead™ process before being discharged as harmless salts.

ENVI-Marine™ systems are fully flexible and can be supplied as open loop, open loop hybrid-ready 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™ foaming bed creates an intense turbulent zone to give superior gas-to-reagent contact in than competitive approaches. This efficiency advantage allows for a more compact and cost effective solution.

Functions by:

- Using the natural alkalinity of seawater to absorb SO2 emissions produced by marine engines
- Post treatment discharge of neutralized sulphur into sea
- Uses caustic soda (NaOH) as a 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

The ENVI-Marine™ system has four areas of interaction – the quench zone, and 3 special TurboHeads.
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 gas/liquid absorption.

The high energy liquid/gas interaction assures both the residence time and complete interaction required to achieve high efficiency removal of sulphur 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 scrubbing system is typically not large (e.g. 6 - 8" w.c.) and marine engines are capable of operating at this back pressure with ease.
Internal Window

Gas Conditioning Chamber (GCC)

This chamber uses water spray to quench the exhaust gas to approximately 55°C.

Bypass Dampers, Quench and Gas Conditioning Inlet

Each exhaust gas source will be fitted with a diverter damper so that the exhaust can be diverted from the stack into the scrubber. All diverter dampers will include expansion joints. Prior to flowing into the scrubber, the main engine exhaust will be quenched with seawater or wash water spray in a gas conditioning (GC) duct, and the exhausts from the auxiliary engines and boiler will be quenched in a second GC duct. The quenched exhaust gas streams will be further conditioned with seawater or wash water spray at the scrubber inlet. This will reduce the actual gas flow rate (due to the lower temperature) and moisten the gas and particulate matter prior to it entering the scrubbing heads. The wash water 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.

Scrubber Vessel

The scrubber vessel will have a rectangular cross section. After quenching, the exhaust gas will be distributed uniformly across the lower scrubbing head due to the back pressure created by the turbulent zone. The patented Turbo-Head™ 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 water. There will be three turbulent scrubbing heads in the scrubber vessel, approximately 2m above each other, each with a set of spray nozzles to provide them with fresh seawater or recirculated wash water for scrubbing. The scrubber water

The ENVI-Marine™ scrubbing system is comprised of the following components:

COMPONENTS
from the higher-level heads will drain down to the lower heads, so each head has a unique design to accommodate different volumes of scrubber water. After passing through the three heads, the exhaust gas will enter the mist eliminator section and then exit out to the atmosphere. The demister section will be equipped with water spray nozzles to periodically wash away accumulated solids and prevent scaling.

The scrubber vessel will be equipped with numerous ports for access, inspection, instrumentation, and water inflows and will be constructed of AL6XN and duplex 2205 stainless steel for corrosion protection. The heads and support beams will also be constructed of 2205 SS.

**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, as measured by flow meters. In closed mode for the hybrid system, a third seawater pump is used to provide cooling water to the heat exchanger. This pump will also provide reaction water for open mode operation if access to engine cooling water is not available.

**Scrubber Water Recirculation Tank**

The scrubber water recirculation tank is divided into two compartments for closed mode operation – a "raw" side and a "clean" side. During closed mode operation, the scrubber water drains into the raw side and is recirculated by the seawater pumps instead of being discharged. A side stream from the raw side is sent to the wash water treatment system, which consists of an ash and heavy solids hydrocyclone system and an oil and light solids hydrocyclone system, operated in series. The clean water from the treatment system is returned to the clean side of the recirculation tank and transfers to the raw side to keep it clean for recirculation. To control acid build-up, NaOH solution is added to the recirculation line at rates controlled by the NaOH metering pumps based on pH readings of the scrubber wash water. A minimal bleed from the water treatment system drains into the effluent holding tank (e.g. aft peak tanks) for storage until the next period of open mode operation.

When operating in open mode, the two sides of the recirculation tank simply act as a single residence tank. The scrubber water collects in the tank before overflowing past analysers for turbidity, PAH and pH. After mixing with engine cooling seawater, the combined stream is analysed for pH and then discharged to the sea.

**Caustic Dosing System**

The proposed caustic dosing system is designed to work with caustic soda (NaOH) as a 20-50% solution in water, although alternative neutralizing agents such as magnesium oxide (MgO) could be used instead. NaOH is an odorless and colorless liquid that is highly corrosive, reactive, and toxic if ingested, therefore proper storage 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.

Pacific Green Marine Technologies (PGMT) has specified one 20 m³ tank for 20%-50% NaOH, with two injection pumps, various valves, fittings and instrumentation assembled as a module. The pumps would be mounted on the 3 m³ overflow tank, which will also serve as a spill tray for the pumps. The caustic tank and overflow tank will be constructed of 316L stainless steel for corrosion protection.

### Hydrocyclone Wash Water Treatment System

The hydrocyclone systems operate in closed mode to remove oil, soot and ash from the wash water. A side stream of the wash water from the recirculation tank is pumped through the ash hydrocyclone system first to remove heavier solids, and then to a hydrocyclone cluster to remove light solids and oil. The treated water is returned to the clean side of the recirculation tank. The heavier solids (primarily fuel ash) are concentrated by a second stage to produce a sludge with 50-70% solids content. Approximately 0.5 L of ash solids are produced per tonne of HFO combusted. The sludge is stored in 1 m³ IBC totes for later transfer to shore. The extracted oily water is further concentrated by second-stage hydrocyclones into an oily sludge that is stored for disposal on-shore. About 2 L of oily sludge is generated for each tonne of HFO fuel combusted.

### Effluent Holding Tank

In closed mode operation, the bleed water containing high total dissolved solids (primarily sulfates, sulfites and chlorides) is discharged to the ship’s existing effluent holding tank (e.g. aft peak tanks). Once open mode operation resumes, the water is sent back to the recirculation tank using a transfer pump. NaOH is added to the water sent to the effluent holding tank to ensure that it is slightly alkaline. The location and size of the effluent holding tank will be decided in consultation with the owner and shipyard.

### Sludge Tank and Pump

In closed mode the oily sludge generated by the wash water treatment system is stored in designated sludge tanks, generally IBC totes. The amount of oily sludge generated will fill a 1 m³ IBC tote in about 6 days in closed mode at design engine operating capacity. Three such tanks are proposed to store the sludge during the voyage prior to disposal at a land-based facility while in port. Neither disposal at sea nor incineration of this sludge is allowed.

### Ash Storage Tank

The ash and other particulate captured in the ash hydrocyclone system is stored in separate 1 m³ IBC totes. The filling rate of a tote is estimated at 23 days to reach 75% capacity. When filled to 75% capacity the ash storage tanks will be removed from the vessel for disposal at a shore-based facility.

### 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 emission concentration 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 a condensation system to
In all cases the engine exhaust is ducted to the GCC for cooling by spray quench to a target of 55°C. The GCC is a downflow device leading to a plenum below the scrubber head. The cooled gas rises through the horizontal scrubbing head where it enters a turbulent zone above the head. The heads are sprayed with seawater from nozzles above to continuously replace the water that overflows through down-tubes into the scrubber sump below. This maintains the alkalinity of the scrubber water as the SO2 is absorbed and neutralized. After exiting the turbulent zone the gas rises and demisters remove any excess moisture prior to the gas exiting the scrubber.

**EXHAUST GAS FLOW**

In all cases the engine exhaust is ducted to the GCC for cooling by spray quench to a target of 55°C. The GCC is a downflow device leading to a plenum below the scrubber head. The cooled gas rises through the horizontal scrubbing head where it enters a turbulent zone above the head. The heads are sprayed with seawater from nozzles above to continuously replace the water that overflows through down-tubes into the scrubber sump below. This maintains the alkalinity of the scrubber water as the SO2 is absorbed and neutralized. After exiting the turbulent zone the gas rises and demisters remove any excess moisture prior to the gas exiting the scrubber.
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 through 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 exhaust gas flow, the scrubbing efficiency and the pH of the effluent.

The wash water 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, and the pH is also monitored at that point to ensure the discharge meets the effluent quality requirements.
Closed Mode Operation

In closed operating mode, seawater 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. To clean the wash water for recirculation, a side stream of wash water is pumped through two hydrocyclone systems, one to remove soot and oil contaminants and the other to remove heavier ash solids. 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 wash water is removed using a heat exchanger in the recirculation loop. A seawater pump provides the heat exchanger with cooling seawater that is then discharged with other engine cooling seawater. This pump may also be used in open mode to provide reaction seawater. Caustic is added to the recirculating wash water 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 wash water to an effluent holding tank per tonne of HFO combusted. Once the scrubber returns to open mode operation, the stored effluent is returned to the recirculation tank for discharge along with the open mode effluent.
With regard to corrosion in the scrubber, we have selected the materials of construction very carefully to ensure a long service life for the scrubber. Common stainless steels such as 304L and 316L will not stand up to the service conditions as they are susceptible to pitting corrosion from chlorides at elevated temperatures.

We have consulted with industry experts and specialty steel suppliers to evaluate the options for material selection, and considered a variety of specialty steels including duplex 2205, austenitics 904L and 317LXN, super-austenitic 6-moly AL-6XN and nickel-based C-276 alloys such as Hastelloy. These specialty steels are higher in chromium and molybdenum, or nickel, to increase their pitting and crevice corrosion resistance.

The chart on this page illustrates the pitting resistance equivalence number (PREN) of various types of specialty steels. The PREN is a predictive measurement of corrosion resistance that the industry uses for design and material selection. In general, the higher the PREN value, the more corrosion-resistant the material. Typically, materials with a PREN above 32 are considered corrosion resistant for seawater as long as the temperature is not too high.

The graphed lines in the chart show that higher temperatures require a higher PREN. Therefore, for the quench zone where the exhaust gas is initially contacted with seawater, we have selected AL-6XN (6% molybdenum super austenitic stainless steel) due to the higher temperature it will experience. For the main scrubber body, which will be subject to temperatures below 40°C, we have selected duplex 2205 for its great performance against corrosion.
ENVI-Marine™
Competitive Advantages

High Efficiency
The system utilizes ENVI’s patented TurboHead™ to generate a turbulent interaction zone for complete interaction between the sulphur dioxide and scrubbing fluid.

Simplicity
The ENVI-Marine™ scrubber has no internal moving parts. All internal components are fabricated from stainless steel or fiberglass 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 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 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 be 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 in a hybrid mode.

Fabrication and Installation Capacity
Through its partnership with POWERCHINA SPEM, Pacific Green Marine has the largest fabrication and installation capacity in the world.
For fleets around the world few retro-fit systems are available on such a large scale and none are more efficient than the ENVI-Marine™ system.

With 2020 IMO regulations rapidly increasing the demand for scrubbers to previously unseen volumes, 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 advantage that lends itself to funding packages to effectively allow the technology to pay for itself in a short period of time.
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