A WRSystems, Ltd. White Paper

2500 Almeda Avenue, Suite 214
Norfolk, Virginia 23513
757-858-6000
www.wrsystems.com

Maritime Emissions Monitoring - Are You Ready?

By W R Systems, Ltd.

Date: 02/16/09

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Introduction

Oceangoing ships including container ships, tankers, and cruise ships are major contributors to an increasing global air pollution problem. With about 90,000 [1] of these ships worldwide, the exhaust emitted from the large diesel engines that power these vessels poses a serious health threat to the world's population through the discharge of noxious gases and particulate matter into the atmosphere.

Under the upcoming amendment to MARPOL Annex VI maritime emissions regulations, directed by the International Maritime Organization (IMO), strict emissions monitoring is an imminent reality.

Problem Definition

Marine vessel engines are designed to burn the cheapest, lowest quality fuel available. This "bottom of the barrel" heavy fuel oil (HFO) is like thick tar and needs to be pre-heated to lower its viscosity to facilitate pumping to the engine and also for ignition. The exhaust emission constituents from this HFO include: Particulate Matter (PM), which results in respiratory problems and deaths every year; oxides of nitrogen (NOx), which contribute to smog and the formation of Ozone; sulfur oxides (SOx), which contribute to acid rain; carbon dioxide (CO_2), which as a greenhouse gas is suspected to contribute to global warming;

and a noxious brew of other toxic carcinogenic chemicals. [2]

Unlike land-based factories and power plants that are subject to monitoring, recordkeeping, and enforceable penalties for non-compliance, oceangoing vessels are currently allowed to operate with minimal emission controls. The maritime regulatory bodies have recognized this deficiency and are taking steps to put measures in place for stringent emissions monitoring worldwide.

MARPOL Annex VI Requirements

The IMO and its signatory nations are currently working on emissions regulations that will have a large effect within the maritime community. These new regulations will be presented as a modification to the current MARPOL Annex VI regulations and will reduce the allowable emissions of SOx, NOx, CO_2, and PM from maritime vessels.

The new standards will institute Emission Control Areas (ECA) defined in geographical locations throughout the world, based on proximity to a country's coast, and will regulate maritime vessel emissions. These ECAs will expand upon, as well as replace, the handful of existing Sulfur Emission Containment Areas (SECA). Within these emission governed zones, maritime vessels over 400 gross tons or with engines over 130kW will have to prove compliance to the required specifications. These regulations will be enforced by the IMO signatory nations' authorized emissions auditors (Port State Authorities) in ECA zones adjacent to their coasts and within their ports. Outside of these controlled areas in the open ocean, emissions will also need to be below the defined global emissions specifications. Infractions of non-compliance could result in fines in up to $500,000 per incident.[3]

Under the new MARPOL Annex VI regulations, current methods to verify emissions compliance, such as the costly and time consuming Engine Parameter Check method, may no longer be acceptable. Although IMO has yet to specify a specific method(s) of compliance verification, these upcoming regulations imply, at a very minimum, that the method must provide a traceable record of emissions. This could apply to the full duration of the vessel's voyage, or more specifically, when steaming within an ECA zone and "hotelling" in port. Additionally, emissions data would need to be available to auditors during the in-port time frame when pollutants are most visible to the public and when the vessel is most accessible for boarding.

Maritime Community Reaction

In the Maritime community, there is a lot of uncertainty with regards to what specific regulations will be implemented and the measure by which they will be enforced. Ship owners and operators might be asking themselves the following questions:

- What will I be required to do to conform to the new regulations?
- What will it cost to comply with these new regulations?
- What is the cost for non-compliance?
- What types of solutions/technologies are available to me?

These questions and many more are currently being compiled throughout the industry.

Possible Approaches

There are different approaches being evaluated by the maritime community on how to ensure compliance to the upcoming MARPOL regulations. These emissions reduction and emission compliance approaches are described below.

Emissions Reduction Methods

Voyage Management Systems

Many shipping lines currently employ a type of voyage management or route management system. This type of management tool provides fleet managers readily available data regarding routes, cargo, arrival, departures, and historical trend analysis just to name a few of the data sets collected. By using this data to plan and manage voyages across multiple vessels in a route, fleet owners can easily track fuel consumption and thereby plan and carry out a more cost effective and greener "slow boat to China" concept.

Essentially, cargo is loaded onto multiple ships versus just one ship and these vessels cruise at a slower speed, thereby reducing fuel consumption per ship and reducing emissions output. Although in practice this may help to reduce overall emissions output, actual emissions data during the route and when in-port cannot be quantified without sensor data

Distillate Fuel

Another approach is the use of low sulfur distillate fuel oil all of the time. This approach is widely accepted as a method to reduce harmful emissions and is currently mandated for vessels once they reach a certain proximity to land. Although the switch to distillate fuel may be reflected by a manual entry in a logbook, the true correlation for emissions reduction during this period for the specific engine and use case cannot be quantified without actual sensor data.

In addition, the use of distillate fuel is very costly. Currently, ships switch to distillate fuel approximately 48 nautical miles out from land so that when they have reached 24 miles out, all residual HFO has had a chance to burn off. Even if ships were to use distillate fuel continuously, there is some question as to whether or not these vessels would comply with the upcoming MARPOL Annex VI regulations on emissions. However, assuming that using purely distillate fuel could resolve the emissions problem, the cost associated with this could have a huge impact on the shipping industry and ultimately drive the cost of consumer products up "through the stack." Additionally, there are questions as to whether refineries have the capacity to produce distillate fuel in sufficient quantities to meet the worldwide fleet demand for full-time use.

Lastly, the high sulfur content in HFO acts as a lubricant for the cylinders on the vessel's diesel engines. When using purely distillate fuel, additional lube oil would have to be injected into the cylinders to protect the engine. While the newer engines might be able to automate this process via electronic controls, older engines in the fleet would need to have manual intervention to accomplish this type of periodic maintenance.

Seawater Scrubbers

A third approach would be to install seawater scrubbers in the stacks, similar to those found in land-based factories and power plants. This technique essentially uses seawater to filter out toxic gas and PM. Its application addresses only the reduction primarily of SOx. A major concern with this approach is the handling of the process byproduct, and careful consideration would be needed to determine the disposal of the contaminated seawater. With the most recent MARPOL regulations against discharging liquids overboard, the use of scrubbers may not be feasible, especially since ships are not currently equipped to store and handle this extra waste. Additionally, ports are not currently equipped to handle and dispose of this waste either, and to accommodate it would require upgrades to port infrastructures.

Table 1 - Emissions Reduction Techniques

Approach	Advantages	Disadvantages	Cost
Voyage Management	• Uses less fuel per ship • Less emissions per ship • Allows for adherence to delivery schedule	• Need a large number of ships • Uses more overall fuel for shipment • Uses more overall labor for shipment	Med
Seawater Scrubbers	• Seawater readily available • Proven technology in factories and power plants	• Cost of installation • No environmentally safe method for shipboard disposal or processing of contaminated seawater • No existing port infrastructure to handle or dispose of the waste	High
Distillate Fuel	• Accepted method for reducing emissions	• Very costly to ship owners and operators which would be passed on to consumers • Refinery capacity may not be able to meet worldwide demand • May not comply with upcoming MARPOL regulations	High

Emissions Compliance Methods

Theoretical Models

One proposed methodology is for the vessel operators to use a theoretical model based on a variety of current operating parameters such as engine RPM, fuel consumption, fuel temperature, fuel specific gravity, etc.

These parameters are then calculated against historical voyage data acquired from a similar engine type and a correlation is made to calculate emissions. There are multiple theoretical models being suggested by ship owners and operators to verify compliance, all based on different algorithms and equations. While these models may seem promising, they still need to be validated by comparison with the accuracy, consistency, and repeatability of real sensor data.

It is theorized that similar engines within a ship's class should produce identical results for the amount and type of emissions when correlated to similar engine performance. Questions regarding these theoretical models include whether variables such as rough sea state (harsh "deck" conditions) and excessive drag on a vessel's hull (i.e., due to buildup or unsmooth paint finish) add additional load to an engine for a given RPM and alter the emissions output. Also of interest, given the variance in the quality and sulfur levels of the HFO being used worldwide, is if similar engines have the same emissions characteristics based on their current individual operating conditions. Lastly, although theoretical models can calculate gas emissions (SOx, NOx, etc.), they do not calculate particulate matter emissions which will be regulated under the MARPOL Annex VI amendment.

Annual Certification

A second approach would be for all of the ship's engines (main and auxiliary) to undergo annual certification by an independent body, such as Lloyd's register, to verify compliance to the upcoming MARPOL Annex VI regulations. Currently, ships need to be certified annually to receive their Engine International Air Pollution Prevention (EIAPP) certificate to ensure compliance with NOx emissions under the current NOx Technical Code (Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines). This certificate gets added to the vessel's "technical file" for proof of compliance under the current regulations.

There are three listed NOx Technical Code verification procedures which are currently used by ship owners and operators to demonstrate NOx compliance. They are:

1.) Engine Parameter Check method to verify that an engine's component, setting, and operating values have not deviated from the specifications in the engine's Technical file. This method involves a detailed review of documentation with recorded engine parameters as well as an actual inspection of engine components and adjustable features. Those adjustable features are also checked to see if they are operating within the allowable range specified.

2.) Simplified Measurement Method which requires various engine parameters (such as Engine speed, Turbocharger speed, Total barometric pressure, Brake power, Fuel oil flow, Intake air temperature at air inlet, Fuel oil temperature before the engine) to be measured and recorded under a test condition. Those parameters are then calculated and compared against current regulations to determine whether or not the vessel is in compliance.
3.) Direct Measurement and Monitoring Method utilizes an approved method to extract and analyze exhaust gaseous concentrations. In addition, various engine and ambient condition parameters are recorded and correlated under a specified test condition. The data extracted is then matched against current regulations to determine compliance.

Validation by any one of the methods listed above is currently sufficient to demonstrate compliance, but requires the ship to halt all shipping operations for performing the test before receiving verification of operating within NOx emissions limits. It should be noted that these annual certification methods provide only a "single point in time" validation of emissions compliance and a vessel whose engines marginally pass may not stay within compliance until the next yearly inspection.

Continuous Emissions Monitoring

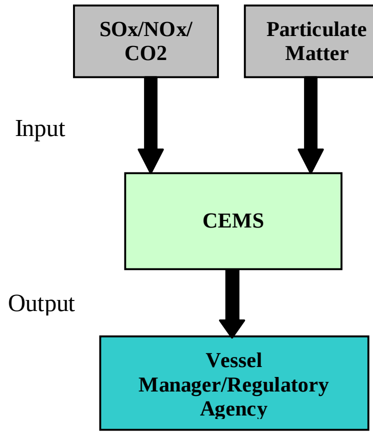
The third approach to ensure compliance with the upcoming MARPOL Annex VI regulations is to continuously measure emissions in the stacks/exhaust piping for each engine with appropriate sensors to monitor gas and particulate matter levels. Actual sensor data is quantifiable and provides a record specific to those vessels' engines.

This sensor data can be recorded and stored via an automated process which would remove the variable of human error. Correlated with ship's location information, the determination of compliance would become much easier and reports could easily be produced for audit purposes. Additionally, a continuous emissions monitoring system (CEMS) could easily store and maintain records with historical data, providing an audit trail for emissions throughout the vessel's voyage. This historical data might also be useful for ship owners and operators for trend analysis to aid in engine performance optimization.

The key elements that would comprise a CEMS are:

- Gas sensor input (SOx, NOx, etc.)
- PM sensor input
- Logging the above parameters
- Correlating the above parameters to zone emissions requirements
- Ability for auditors to review actual emissions data

See below for a high-level diagram of a continuous emissions monitoring system:



Continuous Emissions Monitoring System Diagram

Benefits of a Continuous Emissions Monitoring System

A continuous emissions monitoring system would provide a valuable, high-quality, highly accurate system that:

- Is a cost-effective solution to comply with upcoming MARPOL Annex VI emission requirements
- Offers actual sensor data for traceability and assessment of compliance to ECA zone requirements
- Has no recurring fees or loss of operations for annual certification
- Has low life-cycle maintenance cost
- Provides value-add by assistance in engine optimization for fuel savings
- Future system scalability to integrate other sensor-based systems

Particulate Matter Sensing

In addition to the regulation of noxious gases, the upcoming MARPOL regulations will impose limits on particulate matter emissions. PM contained in emissions are not all of uniform size. Almost all of the particle mass is in the fine range of 10 microns or less (PM_{10}), with approximately 94% of the particles being less than 2.5 microns ($PM_{2.5}$) [4]. The issue with most available real-time PM sensor technologies that differentiate between PM_{10} and $PM_{2.5}$ is that most are geared towards ambient air measurements, opposed to source (i.e., stack) measurements. These ambient air sensors measure PM in $\mu g/m^3$ by using sampling methods that combine the use of filtering, nephelometry, and/or beta attenuation. Trying to integrate such sensors to a continuous stream of source emissions, such as in a maritime vessel stack, will result in high maintenance as these devices are not designed for high volume emissions. In addition to high maintenance cycles, sensing systems using the above sampling methods are quite expensive and not cost-effective for use in this application.

On the other hand, there are real-time PM sensors available with technologies that have specifically been developed to measure source emissions. Such sensors are low maintenance, and can tolerate higher temperatures for In-Situ measurement. These sensors use lasers to perform a back light scattering method to determine concentrations of PM in $\mu g/m^3$ across the stack. The only drawback to such devices is their inability to differentiate between PM sizes, as they measure total suspended particulate matter.

Ultimately, the only clear sampling method that would fit a deployable continuous emissions monitoring system is to use the technology that measures total suspended particulate matter. Until more cost effective technologies become available that can differentiate between PM sizes in In-Situ applications, using such a sampling method that measures total suspended particulate matter is a fair trade-off.

Table 2 - Comparison of Monitoring Approaches

Approach	Advantages	Disadvantages	Cost
Theoretical Model	• No continuous monitoring equipment or installation costs	• Hard to concretely correlate results across all engines in a class due to different variables (i.e., sea state, hull drag) on that specific vessel • Manual entry of voyage data parameters (opportunity of presenting human error within process) • Model calculates gas emissions only and not particulate matter emissions	Low
Annual Certification	• No equipment or installation costs • Certification accomplished by independent authorized body	• Recurring yearly cost for certification • Represents "point of time" measurement and emissions and engine may fall out of compliance before next yearly certification • Loss of operations during time it takes to demonstrate compliance	Med/High
Continuous Emissions Monitoring	• Sensor data provides actual readings in near real-time • Automated determination of compliance based on sensor data and ship's location information • Facilitates easy report generation for auditors • No recurring certification costs	• Initial cost of equipment and installation	Med/High

Conclusions

Currently, there is no clear insight as to which direction the IMO and amended MARPOL Annex VI regulations will take regarding mandated emissions compliance methodology. The three anticipated candidates include theoretical models, annual certification, and continuous emissions monitoring. Each method has its own advantages and disadvantages with associated trade-offs. Once the regulations take effect with the compliance enforcement methodologies defined, it is also unclear as to how long of a grace period will be allotted to ship owners and operators.

Knowing that these regulations are an imminent reality, however, should prompt ship owners and operators to research all available technologies and solutions and to understand the benefits of each. A final thing to be considered is that even though there will soon be a mandated method to determine emissions compliance, this may reveal that emissions reduction technologies, such as scrubbers, need to be employed to bring the vessel's exhaust within compliance.

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Contributing Authors

Andrew Rabiner
Edward Weaver
Reginald Viray
Robert Johns
Megan Jones

<u>For additional information, contact:</u>
Megan Jones (757) 858-6000, Ext. 242
or
Andrew Rabiner (757) 858-6000, Ext. 484