MARITIME EMISSIONS TREATMENT SYSTEM (METS)

ABSTRACT

In January 2014, the California Air Resources Board (CARB) began enforcement of the *"Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port"* Regulation, commonly referred to as the At-Berth Regulation.

Covering all six ports in California, the At-Berth Regulation requires a 50% reduction in emissions from auxiliary diesel engines of ships at-berth. Through 2020, those reductions will be periodically increased to a maximum of 80%.

Initially, the only available technology approved to comply with the At-Berth Regulation was the shore power option, AMP. All California ports have installed significant shore power infrastructure; however, cases exist in which an equivalent emissions reduction option will be required. Those would include ships and or berths that are not AMP capable.

Clean Air Engineering Maritime (CAEM), in partnership with Tri-Mer Corporation, has developed the Maritime Emissions Treatment System (METS), a CARB certified alternative to achieve compliance with the At-Berth Regulation.

A CARB-certified emissions treatment system is now available for ships and berths that are not AMP-capable

The METS system is comprised of two components. First, the emissions capture device effectively transports the exhaust from the ship's exhaust stack to the treatment system. Second, the Catalytic Ceramic Filter (CCF) technology treats the emissions for diesel particulate matter (diesel PM) and NOx. Low density ceramic filters are embedded with catalyst that facilitates the selective catalytic reduction of NOx to harmless nitrogen and water vapor. Nitrogen is the most common gas in earth's atmosphere. The combination of these components constitutes a significant advance in treating large-scale diesel exhaust from ships.

The performance of the METS system is assessed by examining the system's capture efficiency and pollutant removal efficiencies: 91.0% for capture efficiency, 91.4% for NOx removal, and 99.5% for PM capture as demonstrated averages over multiple vessels. **METS performance exceeds CARB requirements and has gained CARB approval for use at California ports.**

BACKGROUND

In December 2007, the California Air Resources Board (CARB) approved the *"Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels At-Berth in a California Port"* Regulation (At-Berth Regulation).

The At-Berth Regulation aims to reduce emissions from diesel auxiliary engines on container ships, passenger ships, and refrigerated-cargo ships while berthing at any of California's six ports including the Ports of Los Angeles, Long Beach, Oakland, San Diego, San Francisco, and Hueneme. The pollutants targeted for reduction currently include both NOx and diesel particulate.

Starting in January of 2014, the At-Berth Regulation requires vessel operators of fleet ships calling at any of California's six ports to achieve reductions of at least 50% of at-berth emissions from auxiliary diesel engines used for power generation. The requirements increase to 70% in 2017 and 80% in 2020.

Initially, the only approved and available technology to comply with the At-Berth Regulation was the shore power option, or AMP. All six California ports have installed significant amounts of shore power infrastructure.

In conjunction with the building of port infrastructure, vessel operators either built new ships or retrofitted existing ships to be able to plug into shore power. The cost of conversion for each ship can exceed several million dollars. Due to these high conversion costs, only ships meeting stringent criteria - such as age of the ship and the frequency and duration of port calls - are economically viable.

While shore power access continues to expand today, there remain certain berths and terminals where shore power infrastructure will not be available in the short term, or may not be feasible due to construction restrictions, power availability, and cost issues. Additionally, there is a certain percentage of ships that are not AMP capable. In order to comply with future emissions reduction requirements, all ships will either have to be AMPed or use an equivalent emissions reduction option.

Clean Air Engineering Maritime (CAEM) partnered with Tri-Mer Corporation to engineer and implement an innovative system that allows ships to meet the California Air Resources Board At-Berth regulation.

THE PARTNERSHIP

CAEM, based in San Pedro, California is the principal development partner and operator of the Maritime Emissions Treatment System. With an in-depth knowledge of port protocol, operations and regulatory requirements, CAEM personnel have been involved with ports and shipping for over twenty years.

Figure 1: CAEM crane and capture device

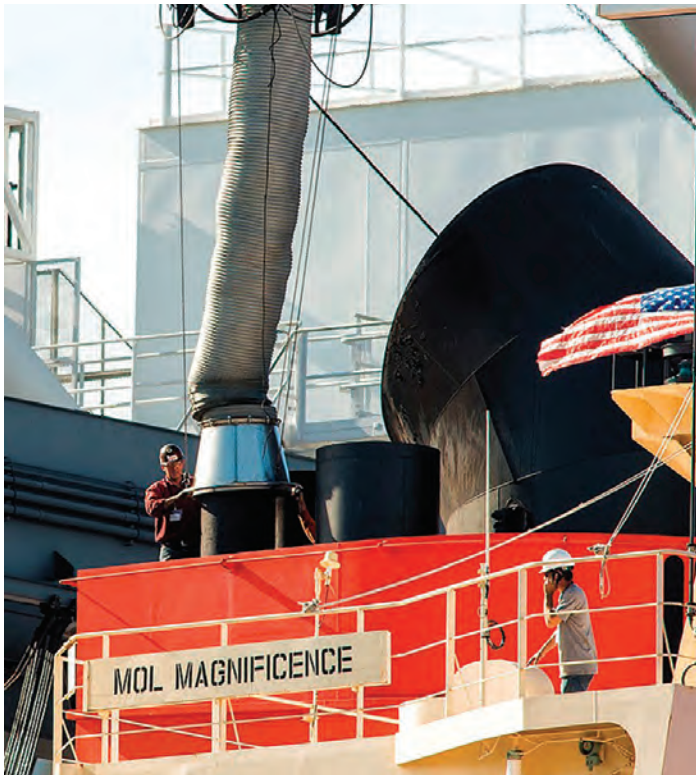

Figure 2: METS Flexible emissions capture device

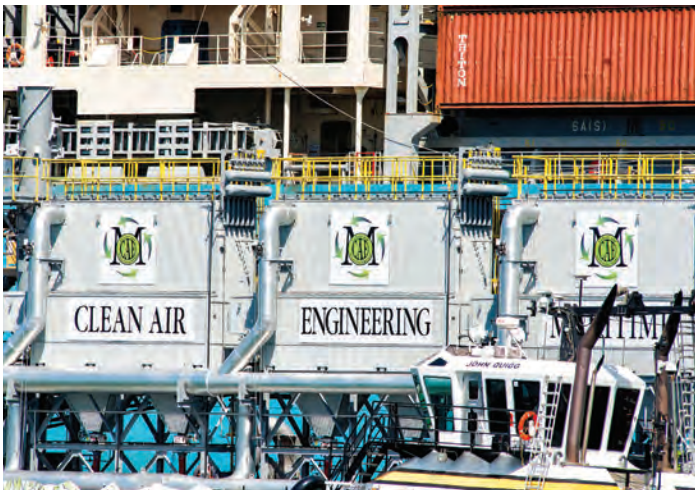

Figure 3: METS Catalytic Ceramic Filter (CCF) system

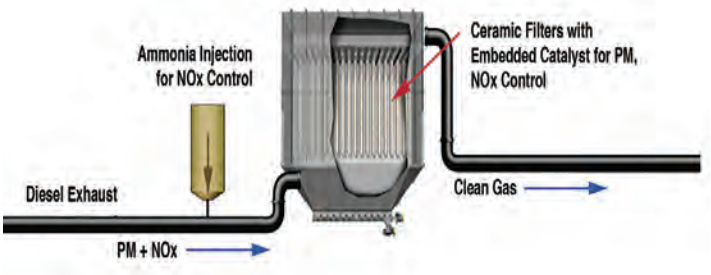

Figure 4: Catalytic Ceramic Filter (CCF) System for both PM and NOX

Tri-Mer Corporation, based in Owosso, Michigan, provides advanced pollution control technology, coupled with turnkey engineering and project delivery capabilities. Established in 1960, Tri-Mer is one of the leading air pollution control companies in the world. Known for innovation, Tri-Mer has delivered thousands of pollution control systems to customers worldwide.

The combination of Tri-Mer's expertise in the air pollution control industry and CAEM's extensive port experience allowed for the design, construction, and implementation of the first generation Maritime Exhaust Treatment System (METS), which is the first alternative control technology approved by CARB.

METS TECHNOLOGY OVERVIEW

Identifying a technology that can capture diesel particulate has been an on-going challenge for the pollution control industry for several decades. Traditional pollution control technologies were found to have operational barriers due to the nature of the diesel particulate and the unique operating environment of the port. These obstacles were complicated by the requirement for high levels of NOx removal at relatively low temperatures.

When applied to ships, these challenges were further compounded by the need to effectively collect the diesel engine exhaust from auxiliary engine smokestacks and convey the exhaust to the treatment system without interrupting the loading/unloading and other operations of the ship at berth.

Together, CAEM and Tri-Mer Corporation have surmounted these formidable scientific and engineering challenges.

The METS system is comprised of two components. The first component is a stack adaptor or flexible emissions capture device that connects the treatment system to the ship exhaust stack via a flexible pipe. It is placed by a crane that sits on the barge. (Figure 1). The specialized capture device connects to the stack in a manner which effectively collects the exhaust while minimizing fugitive outside air (Figure 2).

The second component uses Catalytic Ceramic Filters (CCF) technology to remove the PM and NOx from the exhaust (Figure 3). Tri-Mer is the world's largest manufacturer of multi-pollutant systems employing Catalytic Ceramic Filters. A simplified flow diagram is shown in (Figure 4).

CATALYTIC CERAMIC FILTER (CCF) TECHNOLOGY

Ceramic filters have been used in pollution control for decades, however, the Catalytic Ceramic Filters in Tri-Mer systems are distinctive from any other ceramic filters in the industry.

The filters start as a slurry of refractory fibers and are vacuum formed into tube shapes that are 10 feet long and six inches across. The filters are very lightweight, approximately 90% open with very low pressure drop, robust, self-supporting without any filter cages, and have a useful service life of 7 to 15 years.

The filters have nano-bits of catalyst embedded in their 3/4-inch thick walls to facilitate the selective catalytic reduction of NOx by NH_3 (Figure 5).

The micronized catalyst offers a larger surface area for reaction than conventional catalyst block SCR reactors. In the filters, contact time between the gases and catalyst is not restricted by diffusion of the gases in and out of the catalyst block pores.

The result is a significant increase in the intrinsic catalytic activity. A combination of factors also allows the catalytic process to proceed at much lower temperatures than commonly seen in traditional catalyst block reactors.

All catalysts can be severely compromised by blinding of the surface by particulate and chemical interactions on the surface with particulate.

With the Tri-Mer CCF, particulate is captured on the surface of the filters, not inside the filter as in other glass media filters. The nano-catalyst is completely protected inside the filter, eliminating the particulate-type interactions and extending the catalyst life (Figure 6).

Tri-Mer CCF systems have the capability of removing particulate matter (PM), NOx, SO2, HCl, dioxins, and mercury in a single system. The CCF system has been installed and operational is a wide range of industrial applications.

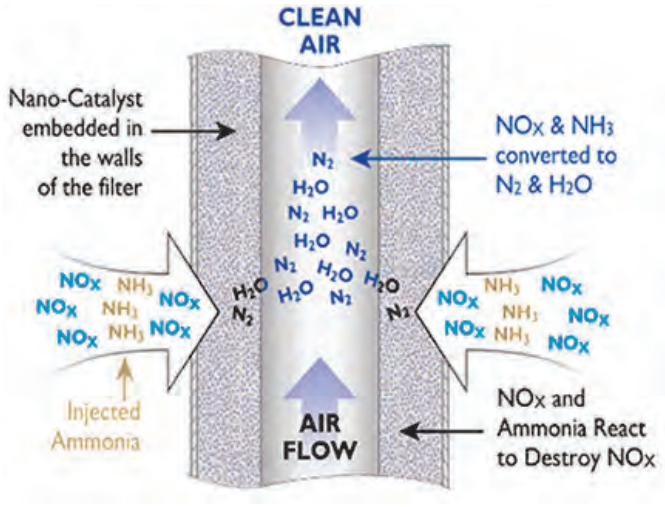

Figure 5: NOx and NH_3 converted to N_2 and H_20

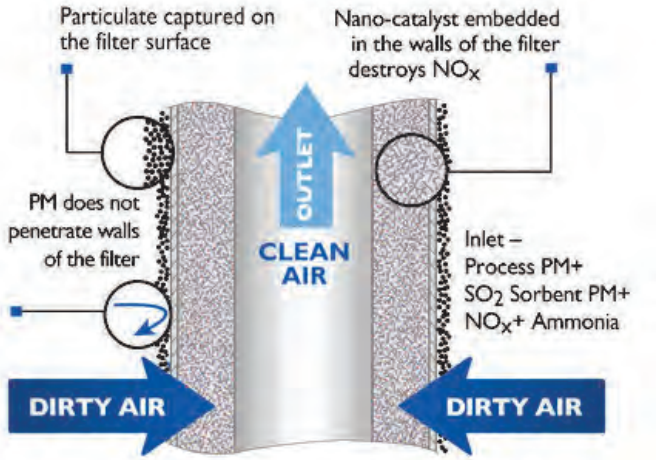

Figure 6: Ceramic fiber filter tube protects catalyst.

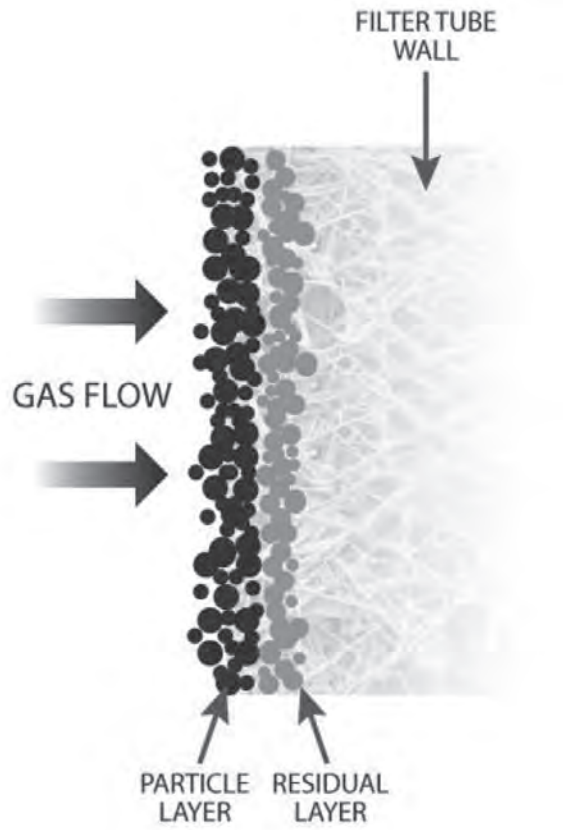

Figure 7: Diesel Particulate Filtration

Filtration Mechanism

The CCF Technology filters diesel particulate with extremely high efficiency. Diesel particulate builds on the residual layer of the filter, without penetrating the filter media. This produces a cake of particulate on the filters that is periodically removed with a brief reverse pulse of air (Figure 7).

The reverse pulse jet method sends a pulse of compressed air down the center of the tube, and cleans the accumulated PM from the outer surface of the tube. Filters are cleaned while on-line.

Benefits to the utilization of CCF for PM and NOx removal include the ability to handle very high loading conditions with high removal efficiency. Additionally, there is negligible penetration of particulate through the filter, which significantly extends catalyst life when compared to conventional SCR methods.

Contrasting Technologies

Diesel particulate traps were developed for smaller engines and mobile diesel sources such as semi-trucks operating Tier 3 and Tier 4 engines. When adapted for ship usage, this equipment combines a diesel particulate trap and a conventional SCR to remove PM and NOx. The CCF technology is far more robust than diesel particulate trap technology.

From the beginning, the CCF system was designed to handle very high PM and NOx loads and to operate on a continuous basis, as it does in many industrial applications. CCF takes advantage of lower catalyst activation temperatures to minimize any re-heat costs associated with NOx conversion. Other pollutants such as SOx that may be regulated in the future can also be treated by CCF.

The METS design eliminates a number of operational issues that are typical for a diesel particulate trap + conventional SCR system. While the diesel particulate trap + conventional SCR system combination may be effective in removing pollutants, there are multiple operational and utility inefficiencies compared to CCF technology used by METS.

The diesel particulate trap + conventional SCR combination has a high energy requirement for particulate incineration, increased complexity of operational and safety requirements, increased potential for catalyst poisoning and contamination, and a much greater service demand for catalyst replacement.

METS operates continuously, ensuring uninterrupted compliance with regulations and can operate on any engine of any age, burning any fuel type at any load. The METS system is extremely versatile; if there is the need to remove SOx and other pollutants from the exhaust, the METS system can easily be configured to provide this capability.

MARINE EMISSIONS TREATMENT SYSTEMS (METS) APPLICATIONS

CAEM and Tri-Mer Corporation have successfully developed and deployed an innovative alternative to allow ships to reach compliance with At-Berth Regulations. CAEM currently has the first generation of a Marine Emissions Treatment System (METS) designed, constructed, certified by CARB, and in commercial operation. Multiple configurations are available that provide options for various terminal configurations and vessel berthing logistics.

Barge-Mounted METS

The first generation of METS is a barge mounted mobile emissions treatment system that can be deployed in a variety of applications where shore power is not available

Figure 8: Maritime Emissions Treatment System (METS-1)

or where the ship is not equipped for connection to shore power (Figure 8). Once the ship is docked, the METS can quickly connect and capture emissions from the ship's existing auxiliary diesel power generator. No additional modifications either on shore or on the ship are necessary.

Shore-Mounted METS

CAEM/Tri-Mer offers a mobile shore-mounted version of the METS. Building upon the same highly efficient multi-pollutant capture technology as barge-mounted METS, the shore-mounted option will provide terminal operators the ability to move the emissions control system where it's needed, anywhere on the terminal berth.

Ship-Mounted METS

The ship-mounted design is an on-board, ship-mounted METS configuration that provides vessels operators ultimate flexibility during calls. Vessel location, berthing direction and other terminal logistics challenges are eliminated. The METS unit is permanently installed on-board the ship, is directly connected to the vessel's auxiliary engine exhaust system, and uses ship power for operation. As soon as the vessel is berthed, the auxiliary engine exhaust is automatically diverted through the on-board METS unit.

With the ship-mounted METS, there are no shore power connections, no external attachments, and no interference with any berth-side activities. Compliance with the At-Berth Regulation begins within minutes.

The availability of barge, shore, and ship-mounted METS configurations allows vessel and terminal operators an emissions control system to meet the vast majority of applications they are likely to encounter with any fleet ship calling at the port.

For container ships, the barge-mounted METS will be effective to achieve compliance with At-Berth regulations. In the case where berth-side access is more desirable, the shore-mounted METS might be the best option. Ship-mounted systems are the best fit when maximum flexibility is desired.

METS PERFORMANCE RESULTS

All METS Systems are comprised of two principal components: a stack adaptor or flexible emissions capture device, and a CCF system configured for treating PM and NOx. The performance of the adaptor or emissions capture device can be assessed by determining the capture efficiency, while the CCF system performance is assessed by determining removal efficiencies. Performance data is currently available for the first generation of METS.

Capture Efficiency

Capture efficiency is monitored continuously by the METS system. As part of the CARB verification process, capture efficiency was directly measured through the use of a method known as tracer gas dilution.

A known quantity of inert tracer gas, perfluoro-1,2-dimethylcyclobutane is injected at a known mass rate into the stack of the auxiliary engine. The mass rate of the tracer gas is measured at the inlet of the treatment system and compared by mass balance to the inlet concentration of the stack in order to evaluate the capture efficiency of the system.

The capture efficiency of the METS system was demonstrated on a group of vessels over a 6 month period of time (Figure 9).

The average capture during the CARB verification process was 91.0%. The METS is certified by CARB for 90% capture.

NOx Performance

The METS design includes Continuous Emission Monitoring data based on CARB Method 100 with all data being permanently logged and stored during operations. Instrument calibration and maintenance is based on CARB Method 100. NOx is measured on both the inlet and outlet along with volumetric flow rate and oxygen. The data was used to generate inlet and outlet mass emission rates in order to determine reduction efficiency.

The METS system NOx performance was demonstrated on vessels over a 6 month period. (Figure 10).

The average NOx removal during the CARB verification process was 91.4%. The METS is certified by CARB for 90% NOx removal. The average ammonia slip was less than 5 ppmv.

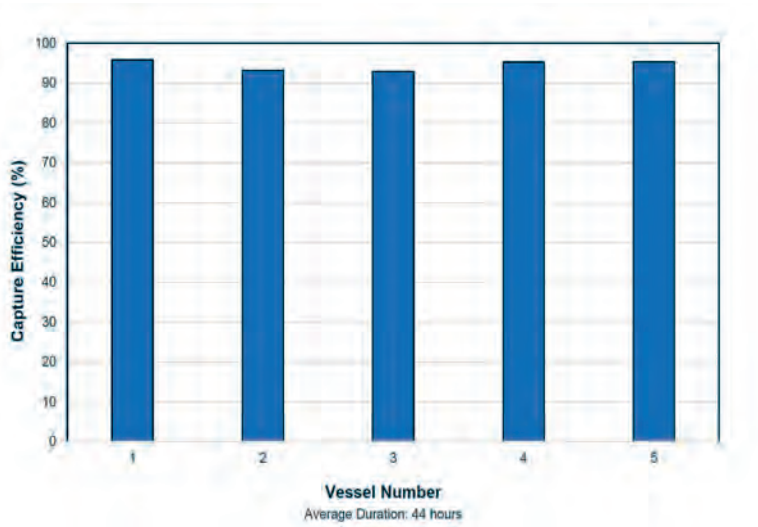

Figure 9: METS-1 Capture Efficiency – Sample of capture data for 5 vessel calls

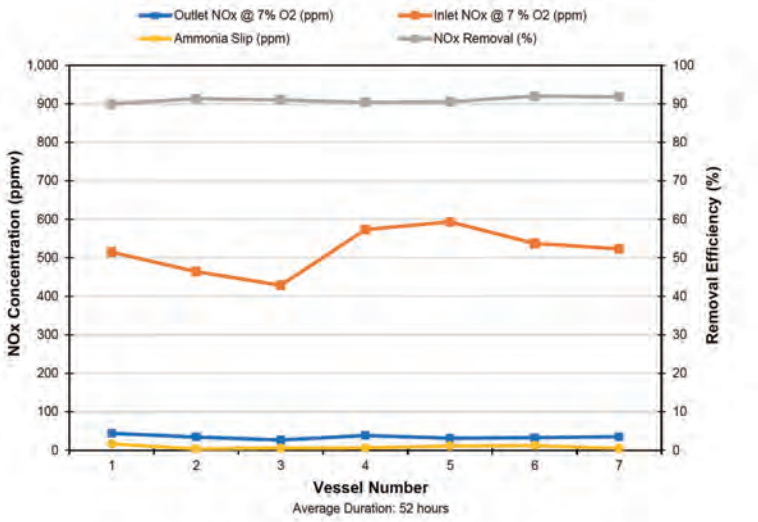

Figure 10: METS-1 NOx Performance - Sample of capture data for 7 vessel calls

PM Performance

Since there are no CARB approved methods for the continuous measurement of PM, CAEM developed an approach based on methods used for the determination of PM from ocean-going vessels. The measurement system produces a PM concentration for both the inlet and outlet, and is reported in mg/Nm3.

This concentration data is then combined with the flow rate measurements to generate mass based loads and emission rates which were used to determine reduction efficiency during in-use performance and durability testing.

The performance of the METS system was demonstrated on multiple vessels across a 6 month period (Figure 11).

The average PM removal efficiency during the CARB verification process was 99.5%. The METS-1 is certified by CARB for 90% PM removal.

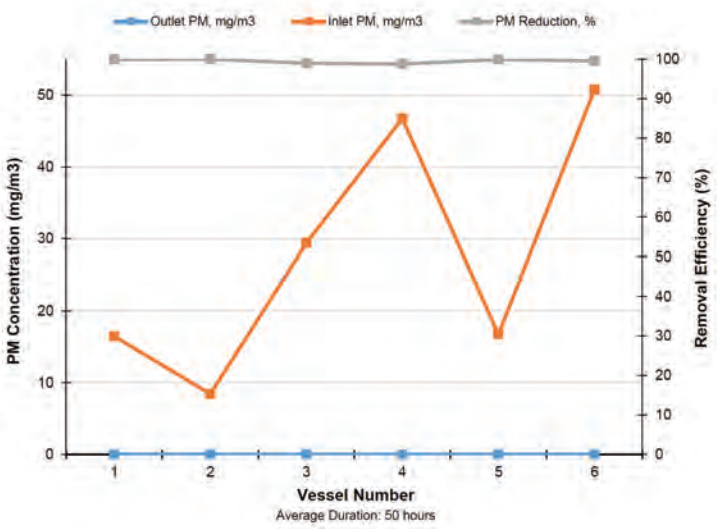

Figure 11: METS-1 PM Performance - Sample of capture data for 6 vessel calls

CONCLUSION

The METS system is a technically advanced and economically superior alternative control technology, approved by CARB, and already being deployed and demonstrating consistent performance and compliance with regulations.

METS removes both PM and NOx in a single, effective system that is straightforward and easy to operate. Unlike other emissions control technologies, METS is able to operate continuously, has lower re-heat costs due to lower CCF NOx activation temperature, and can be easily altered to provide the capability of SOx removal.

With barge, shore, and ship-mounted configurations of METS, vessel and terminal operators will have technical options available to them to meet the vast majority of applications they encounter with any fleet ship calling at the port. While shore power will remain the preferred method for emissions reduction, the addition of METS will allow operators to effectively meet the At-Berth Regulation well past the 2020 reduction limits.

The combination of CAEM's extensive experience in port protocol, operations and regulatory requirements, and Tri-Mer's expertise in advanced pollution control technology makes them the perfect professional team to provide CARB approved alternative control systems that ensure compliance with current and future regulations.