Golden Bear
Baseline Emission Characterization

Draft Final Report

Prepared for

California Maritime Academy (CMA)
United States Maritime Administration (MARAD)

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Executive Summary

Background: Emissions from marine engines (container vessels, cruise ships, and other heavy industrial applications) represent a significant contribution of particulate matter (PM), sulfur oxide (SO_x) and nitrogen oxide (NO_x) emissions. To control these emissions, the IMO Annex VI regulations include limits on NOx emissions, caps on the sulfur content of fuel oil which indirectly also reduces PM emissions, and is planning limits on greenhouse gases (GHG) and black carbon (BC) both to mitigate global warming concerns. The Golden Bear vessel was evaluated for NO_x, PM, GHGs, BC and other pollutants as part of this project.

Methods: Emissions measurements were conducted from one main and one auxiliary engine on the Golden Bear vessel as it cruised along the coast of California from Los Angeles to Oakland. Testing followed the ISO 8178 E2 and D2 steady state test cycle protocols to determine the emissions rate of gaseous and particulate pollutants for the main engine (ME) and auxiliary engines (AE) respectively. Emissions were measured following ISO and CFR methods for gaseous and PM (total mass, elemental, and organic carbon) measurements. Upgrades were performed to meet EPA requested 1065 dilution ratios and filter temperatures. Dilution ratios and filter temperatures as specified in 1065 were met during this testing.

Objectives: The primary aim of this work was to characterize the baseline emissions from the Golden Bear while operating ECA compliant low sulfur fuels (MGO) while at-sea.

Results: Emissions measurements were performed at four load points that represented MCR of 19%, 49%, 77%, and 97% load for the ME and 23%, 50%, 74%, and 80% for the AE. The measured weighted emission factors for the ME and AE were calculated and summarized in this report.

The measured emissions were stable and the results in this report are representative of a properly operating vessel. The ISO weighted main engine (ME) NO_x emissions are 14.07 g/kWhr (see Table ES-1) which is lower the Category 3 Tier 2 standards. The ISO weighted auxiliary engine (AE) NO_x emissions are 6.4 g/kWhr which is also below the Category 2 Tier 3 engine certification standard. The ME NOx emissions were relatively flat on a g/kWhr basis (~14 g/kWhr), but on a distance basis the emissions were lowest at low vessel speed and highest at high vessel speed.

Table ES-1 Summary of ISO weighted emission factors (g/kWhr)

Engine	ISO Weighted Emission Factors (g/kWh)							
	NO_x	CO	CO_2	SO_2	$PM_{2.5}$	PM_EC	PM_OC	PM_S
ME	14.07	0.55	660	-0.10	0.20	0.03	0.15	0.001
AE	6.40	2.03	696	-0.08	0.34	0.16	0.14	0.001

[1] SO_2 emissions were at the detection limit of the analyzer (1-2 ppm) thus the values presented are representative of a non-detectable value (nd). Sulfate PM (PM_S) emissions were estimated from the fuel sulfur level and were not measured as is common for low sulfur fuels.

The $PM_{2.5}$ emissions did not show a strong trend with respect to load for the ME, but a slight trend for the AE where higher PM was emitted at higher loads (opposite to what is typically found). On a distance basis the ME $PM_{2.5}$ emissions were lowest at 11 knots (19% load) and highest at 14.9 knots (50% load). The PM composition for both engines showed that the PM is predominantly composed of OC and EC, with only trace amouts of sulfate PM.

The global warming potential was evaluated where the CO_2 emissions increased with decreasing load for the ME (from 625 to 715 g/kWhr) and were relatively constant for the AE (at 695 g/kWhr). On a distance basis the CO_2 emissions show the lowest emission rate is at 11 knots (19% load) and highest emission rate is at 14.9 knots (50% load). This suggests biggest reduction for GHG emissions can be realized by lowering vessel speed. The short lived black carbon (BC) emissions were quantified where emissions ranged from 0.019 to 0.046 g/kWhr for the ME and up to 0.465 g/kWhr for the AE. This is consistent with other ME and AE tests where the ME emits significantly lower BC emissions compared to an AE engine. On a distance basis the ME BC emissions were lowest at 11 knots (19% load) and higest at 18.8 knots (97% load).

In summary the results from this testing were performed at-sea and are representative of a properly operating vessel. These results can, thus, be sued for the evaluation of future control technologies. Additional control measures will be needed for this vessel to meet the ME Tier 3 and AE Tier 4 standards.

1 Background

1.1 Marine emissions

America's seaports generate more than $4.6 trillion in economic activity, support the employment of more than 23 million people and handle some 2.2 billion tons of import, export and domestic cargo annually, but this activity leads to environmental and energy consequences (Dalsøren et al., 2009). Marine ocean going vessels (OGV) are a critical component of the U.S. freight movement system to deliver goods from port to port; however, these OGVs consume large amounts of fuel and emit significant contribution to the global anthropogenic inventory, namely the greenhouse gas carbon dioxide (CO_2), and the air pollutants particle matter (PM) with aerodynamic diameter less than 2.5 µm ($PM_{2.5}$), sulfur oxide (SO_x), and oxides of nitrogen (NO_x). OGV emissions are reported to represent a significant contribution to the global anthropogenic inventory (Eyring et al., 2005; Endresen et al., 2007). The shipping industry is continuing to evolve where regulations are continuing to tighten the allowable emissions from OGV.

The IMO (International Maritime Organization) Annex VI of MARPOL 73/78, which entered into force in May 2005, established the first set of regulations for marine engines exhaust emissions (IMO Tier 1 emission limits) and it has been revised to further reduce pollutant emissions from ships. IMO Tier 2 became effective on January 1st 2011, requiring further reduction of nitrogen oxide (NOx) emissions levels by about 20% from current IMO Tier 1 limits. The IMO Tier 3, entering into force on January 1st 2016, continue to impose NO_x emissions reductions by about 80% from current IMO Tier 1 limits, although it will apply only in designated special areas, named Emission Control Areas (ECAs), as shown in Figure 1-1. IMO NO_x emission limits (Tier 1, Tier 2, and Tier 3 levels) are shown in Figure 1-2 (IMO).

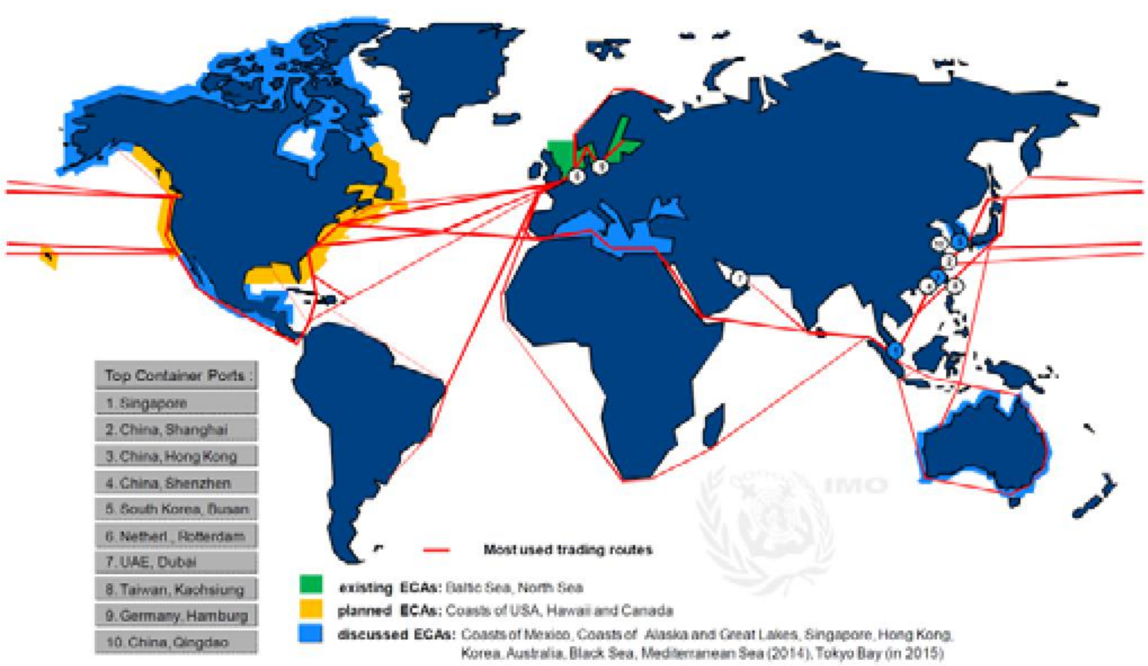

Figure 1-1 Emission control areas (ECAs) (adapted from Millo et al., 2011)

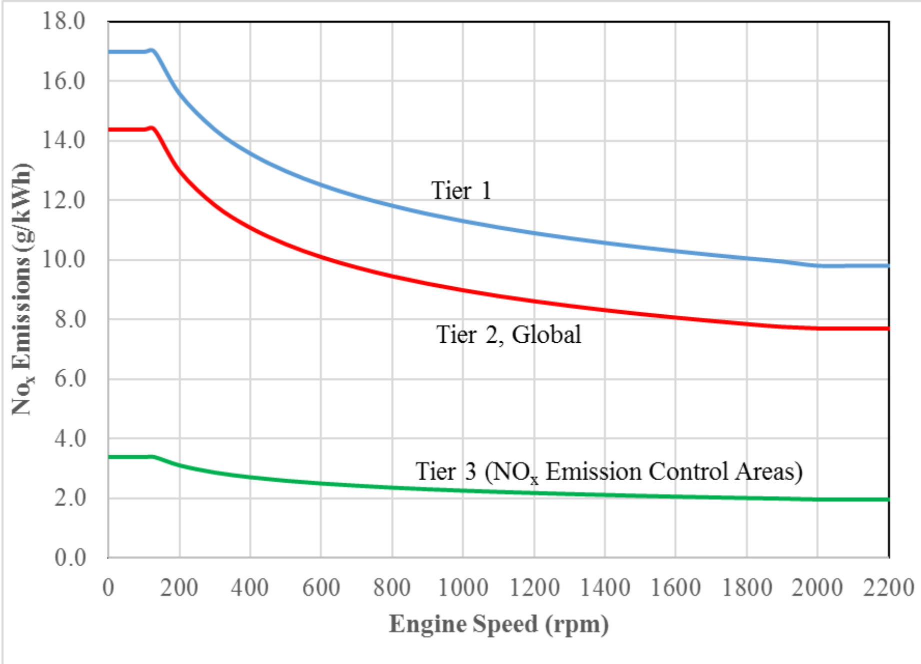

Figure 1-2 IMO Tier 1, Tier 2, and Tier 3 NOx emission limits

Ships typically burn high sulfur residual fuel oil which results in high sulfur emissions in both gas phase and particle phases. Sulfur has a relatively short atmospheric lifetime, 1-2.5 days for gaseous SO_2 and 4-6 days for particle sulfate (Berglen et al., 2004). This implies that the highest and strongest deposition of sulfur is found close to the sources. Emissions of SO_x are a major contributor to acid deposition, which have harmful effects to the natural environment as well as building structures. High sulfur residual fuel oil conatin polycyclic aromatic hydrocarbons and transition metals, and thus emissions of PM are of particular concern due to the formation of sulfate and soot particles. These non-sulfur based PM fractions are of concern to health. International shipping has been linked with increased mortality in coastal regions, with an estimated 60,000 deaths from cardiopulmonary and lung cancer per annum attributed to PM emissions from ship exhaust (Corbett et al., 2007).

To control SO_x emissions, the IMO Annex VI regulations include caps on the sulfur content of fuel oil, which indirectly reduces PM emissions. IMO does not have any explicit PM emission limits. For the Emission Control Areas (SO_x ECA or SECA) IMO has special fuel quality provisions, see Figure 1-3 for ECA global zones. The sulfur limits and implementation dates are illustrated in Figure 1-3. Providing it meets the applicable sulfur limit, Heavy Fuel Oil (HFO) is allowed even in the SO_x ECAs and globally if alternative technology is used to limit SO_x emissions to a SO_2/CO_2 ratio of 4.3 which is equivalent to 0.1% S fuel.

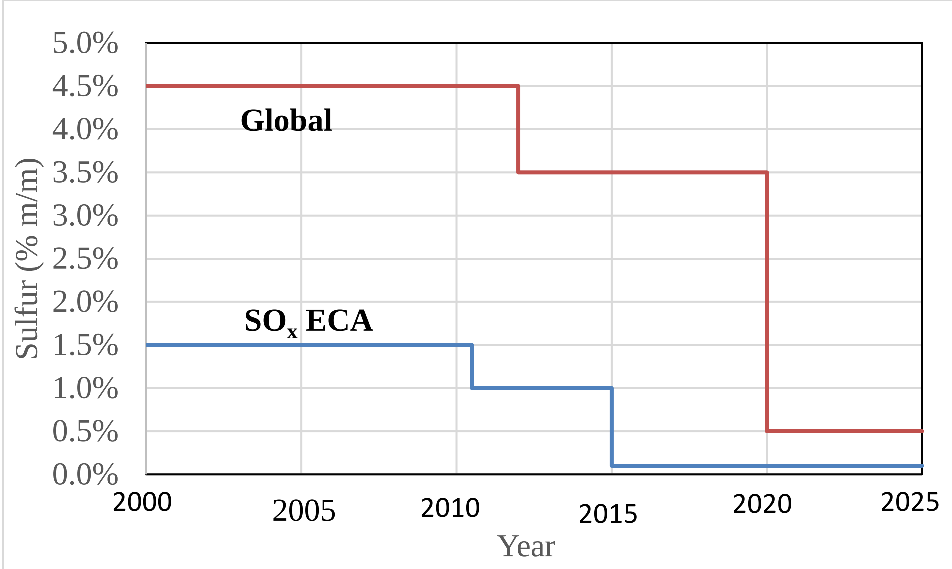

Figure 1-3 Global and ECA fuel Sulfur Limits

1.2 Objective

California Maritime Academy (CMA) and the United States Maritime Administration (MARAD) are interested in characterizing the emissions of their ocean going vessel called the Golden Bear. The purpose in obtaining these emissions is to characterize the baseline emission factors prior to conducting emission reduction projects on the Golden Bear. The University of California Riverside and CMA/MARAD have entered into several proposals where it is expected advanced emissions control devices could be evaluated on the Golden Bear as a pilot size demonstration platform. This opportunity allows for improved characterization, development, and learning while under controlled conditions and while educating future Maritime students.

The goal of the current project is to evaluate the baseline emissions of the Golden Bear while performing real world operating from Los Angeles CA to Oakland CA. The specific goals of this project are to evaluate and characterize the:

- Characterize the main engine while operating on MGO fuels over four engine loads from maximum (80% load) to 25% load that are representative of marine engine certification test points.
- Characterize the auxiliary engine while operating on MGO fuels over four engine loads from maximum (80% load) to 25% load that are representative of marine engine certification test points.
- Follow ISO 8178 and 40 CFR Part 1065 sampling methodologies for the emissions characterization.
- Establish a working relationship between CMA/MARAD and UCR for future opportunities such as, on-board measurement setup, control technology research projects, ballast treatment system testing, autonomous vessel research, and others.

2 Project approach

This section outlines the approach to determining the PM emission changes across the emission control system. The test plan includes the ISO 8178-4 cycles for up to five test modes in triplicate (three repeats samples collected at each mode) for both gaseous and PM measurements. This section describes the test article (vessel, engine, fuels, and load points), emissions systems (sample location, gaseous and PM measurement methods, and exhaust flow determination), and the calculations. The test article sections cover details on the specifics of the vessel and any details of importance to the stability of the emission and the validity of the testing. The sampling approach describes the vessel operation, where the samples were collected from the exhaust, the test matrix, and the test protocol. The measurements section describes the measurement methods for the gaseous, PM (including its components), exhaust flow, and engine load methods. The calculations section provides details on the exhaust flow, emission factors, and in-use estimated calculations.

2.1 Test article

The test engine, vessel, fuel and load points are described in this section.

2.1.1 Vessel details

The vessel tested was the Third TS Golden Bear, IMO number 8834407, Class T-AGS, which had its keel laid in 1986 and was commissioned in 1987, see Figure 2-1. The purpose was an oceanographic information gathering ship for the Navy and was transferred to CMA in 1996 and rechristened as the TS Golden Bear. The vessel weighs 10,939 long tons and is 152 meters long, 46 m high and a beam of 22 m. The vessel is powered by a single 5-blade propeller that can achieve speed up to 20 knots (37 km/h; 23 mph). The range is 17,820 mi (28,680 km).

The tank capacities includes: 7205 m^3 for ballast, 3,939 m^3 for MGO and 137 m^3 for fresh water. The fuel system was modified to be dedicated to MGO fuels. The test vessel is equipped with two main engines (ME), three auxiliary engines (AEs), and two boilers. Experience shows emission factors don’t vary significantly for similar model year, model number and maintenance practices diesel engines. Thus, only one of the ME and AEs were tested as part of this research project. The boilers were not tested as part of this research.

Figure 2-1 At-sea ocean going vessel tested

2.1.2 Engine

The Golden Bear is equipped with two main engines (ME) both Enterprise R5 V-16 four stroke diesel engines and three MAK 6 M 332, 0.9 MW auxiliary engines (AEs), see Table 2-1. The MEs were rated at 9,321 kW at 514 rpm ea, but were later depowered to run at 440 rpm (estimated maximum power is 5,592 kW). The vessel normally operates "at sea" with one ME at 25% load and two AEs at 40% load where the third AE is at 0% load. With these normal conditions the emissions from the vessel could be weighted by the exhaust fractions where the ME would represent 90% of the total exhaust volume (45% each) and the AEs would represent 10% of the total exhaust volume, see Table 2-1.

Table 2-1 Specifications of emissions sources on the Golden Bear [1]

Source	Engine Mfg.	MY and Model	Run Hours	BSFC	Engine Load %	Exhaust Fraction [2]
ME_s	Enterprise	R5-V16	25,985	196.5	41%	76%
ME_p	Enterprise	R5-V16	46,453	196.5	0%	0%
AE_1	Krupp-MAK	6M332	-	223.0	0%	0%
AE _2	Krupp-MAK	6M332	-	223.0	40%	11%
AE _3	Krupp-MAK	6M332	14,550	223.0	40%	11%
Boiler	n/a	n/a	-	-	n/a	n/a

[1] Records obtained from Golden Bear shop trials; See Appendix F. Note MEs were repowered to 440 rpm with an estimated maximum load of 9,320 kW. The ME_s tested is the starboard ME and the AE_3 were tested. ME is a category 3 (78 L/cyl.) and the AE is a category 2 (15 L/cyl.).

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PM emissions are known to vary with the condition and age of diesel engines. OGVs accumulate some of the highest engine hours where PM emissions may be significantly impacted by the status of the engine age and maintenance. After an overhaul some 2-

stroke engines utilize increased lubrication during the running-in period where it is expected PM emissions will be elevated. In general, the ME and AE maintenance records at the time of testing show the last overhaul and PM was than 200 hours prior to testing . This suggests the PM emissions from the test engine should be representative of a properly operating OGV. For more details on maintenance records see Appendix D Sub-section 1 “Maintenance Record Summary”.

2.1.3 Test fuels and lubricants

Fuel and lubricants are known to impact emissions from vessel where their identification is important for the context of the emissions presented. Standard commercial marine gas oil (similar to #2 diesel) and lubricants were used during testing. For the testing campaign, the vessel was operated in the ECA zone using low sulfur fuels (MGO). The vessel as tested used Chevron Taro 20 DP 40 for the ME and AE lubrication oil. No oil samplers were taken as part of this project.

2.2 Sampling approach

There are three unique combustion sources on most OGVs: ME, MGs, and a boiler. The sampling approach considered here was for the stack measurements only since no after treatment system was utilized.

The sampling approach section provides a discussion of the vessel operation, selection of sample locations (PM representativeness and accessibility), the load points (achievable and practical), the test matrix (proposed load points to meet objectives), and the test protocol (methods of sampling).

2.2.1 Vessel operation

The vessel is a training vessel where it is at its home port for 8 months and at sea training for four months. At home there is shore power so the AEs and ME are at 0%. During training, the common operational modes for the vessel include normal at-sea conditions (fully loaded and partially loaded), entering and exiting ports, and in port. Table 2 2 shows typical ME and AE operation for the vessel. While at sea, a single ME typically operates at 40% load (2300 kW for one engine). Higher ME loads are uncommon, but are possible for short durations if requested. While on a voyage, 2 AE are operated for ship services, hotel, and maneuvering. The generator load typically varies from 40% to 60% and depends on the hoteling needs. During berth entry and exit maneuvers, the ME (two engines while maneuvering) power is reduced to 0% to 40% load while the AEs remained at 40%-60% load. While in port (loading and unloading cadets), the AEs are typically at a load between 30% and 45% (i.e., without shore power) with the ME off at 0%. Most of the vessels operation is based on at-sea conditions that are estimated to be 90% of the vessel operation, while approximately 1% (or less) is representative of berth exit and entry and 9% is representative of dock conditions.

Table 2-2 Expected Vessel Emissions Source Operations

Operation	ME_s	ME_p	AE_1	AE_2	AE_3	Relative Usage
At Sea full	75	0	50	50	0	90%
At Sea partial	75	0	75	0	0	
Berth maneuver full	45	0	75	60	0	1%
Berth maneuver partial	45	0	50	50	0	
At Dock full	0	0	50	50	0	9%
At Dock partial	0	0	75	0	0	

[1] Full refers to having most of the rooms occupied where hoteling loads are highest and partial refers to when the vessel is only partial occupied.

2.2.2 Sample locations

Emissions sampling for PM can be affected by the sample location. This section discusses some issues that are common on the sampling of exhaust from OGV.

Sampling around an economizer is confounded because PM adsorption and desorption processes occur on the heat exchanger surfaces. During waste heat recovery (heating water to make steam for the ship's needs), the heat exchanger surfaces cool the exhaust gas constituents and PM (predominantly EC and BC) adsorbs on the cool surfaces. The adsorption of PM on a cool surface can be described by thermophoretic loss models. When PM is adsorbed onto the surface, stack PM emission factors can be underestimated (by about 10%) over short periods of time (measured in hours). To prevent the economizer from fouling, ships employ a periodic (at best daily) cleaning process of the heat exchanger surfaces. During cleaning, large amounts of PM (>20%) can be expected to be released that, if sampled, would overestimate the PM emissions factors of the ship.

The selection of a sampling location around the economizer is often determined by space constraints and desired measurement practices (e.g., the potential to sample from straight sections of exhaust). There was no economizer on the test vessel so this issue did not impact the PM sampling system.

The sampling locations were performed on straight sections of the exhaust system for both the ME and AE engine tested, see Figure 2-2 for the setup on the ME. For both setups there was sufficient distance from bends and systems for the sample location (ten diameters is ideal). The PM emissions results are representative of the vessels in-use emissions given the straight sections and lack of an economizer.

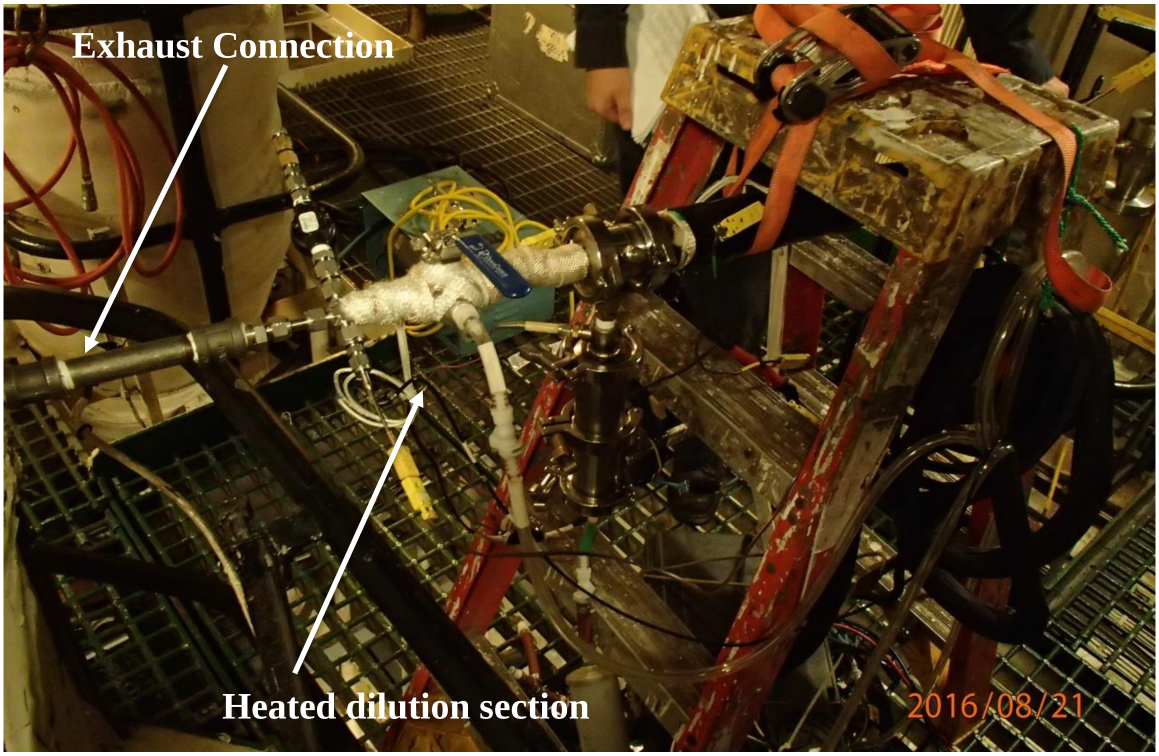

Figure 2-4 ME measurement sample location setup

2.2.3 Test matrix

The test matrix subsection covers the engine certification cycles, test modes, and the sequence of performing these tests.

Engine certification: New engines are certified following prescribed cycles which varies depending on the application of the main and auxiliary engine, see Table 2-3. The main engine is directly connected to a fixed pitch propeller where the engine speed varies with vessel speed varies (Variable-Speed Propulsion Engine). These types of engines are typically certified per the ISO 8178-4 E3 variable speed engines which follow the propeller law, see Table 2-4 and constant speed AEs follow the ISO-8178-4 D2 auxiliary cycle (Table 2-5), see Appendix C for more details. The maximum achievable load may be less than 100% and can depend on several factors including constraints by navigational details, engine configurations, currents, wave patterns, wind speed and direction, and loads allowed by the Chief Engineer or ship Master.

Table 2-3 Test Cycles for Certifying Marine Diesel Engines Application

Application	Test Cycle
Variable-Speed Propulsion Engines	ISO 8178 E3
Constant-Speed Propulsion Engines	ISO 8178 E2
Constant-Speed Auxiliary Engines (Generators)	ISO 8178 D2

The matrix of test points tested on the voyage is provided in Table 2-6. Efforts were made in consulting with the Master and Chief to target loads as close as possible to those in Table 2-4 and Table 2-5. This included testing the ME at 97%, 77%, 49%, and 19% load and the AE at 80%, 74%, 50%, and 23% load. The AE was not operated at 100% load due to possible concerns about overloading the engine, as such the AE was limited to a maximum of 80% load, see Table 2-5. Also the AE 10% load point was not performed. Although slight deviations from the target loads occurred, due the constraints of the in-use ship operations, overall the actual loads were found to be very representative of the target loads. Thus, the results will be representative of the vessels emission factors during in-use operation.

Table 2-4 Test cycle for Main Engine variable speed (E3)

Main engine testing (ISO 8178-E3)				
Mode	1	2	3	4
Speed (%)	100	91	80	63
Torque (%)	100	75	50	25
Weight Factor	20%	50%	15%	15%

Table 2-5 Test cycle for constant-2peed auxiliary engines (D2)

Generator engine testing (ISO 8178-D2)					
Mode	1	2	3	4	5
Speed (%)	Rated RPM				
Torque (%)	100	75	50	25	10
Weight Factor	5%	25%	30%	30%	10%

Table 2-6 Summary of test points for the ME and AE engines.

Date	Project Name	Fuel	Source	Mode	Start Time	Engine Load	
mm/dd/yyyy	name				hh:mm	MW	% MCR
8/20/2016	CMA Golden Bear	MGO	ME	1	10:45	9.01	97%
8/20/2016	CMA Golden Bear	MGO	ME	2	18:10	7.18	77%
8/20/2016	CMA Golden Bear	MGO	ME	3	19:15	4.52	49%
8/20/2016	CMA Golden Bear	MGO	ME	4	14:40	1.79	19%
8/18/2016	CMA Golden Bear	MGO	AE	1	10:00	0.72	80%
8/18/2016	CMA Golden Bear	MGO	AE	2	11:15	0.67	74%
8/18/2016	CMA Golden Bear	MGO	AE	3	13:00	0.45	50%
8/18/2016	CMA Golden Bear	MGO	AE	4	14:00	0.21	23%

Dilution ratio: Other OGV tests have sampled at high dilution ratios (~20) as allowed by ISO 8178 methods. EPA 1065 recommendations are to target 6:1 at your maximum load point where dilution varies from high to low load (from 6:1 to about 20:1). During this testing the dilution ratio was targeted at 6:1 following the EPA recommendations as specified in Appendix A. Dilution was verified using a flow based method from accurate mass flow controllers, see Appendix A for details.

2.2.4 Test protocol

When following the ISO cycles, the engine was operated for about 30 minutes at the highest power possible to warm the engine and stabilize emissions. Repeats of the same load are performed prior to changing loads (ie mode 1, 1, 1 change load, mode 2, 2, 2 load change…). Based on experience testing OGVs, repeating test points with this approach is needed to manage the time it takes between different load points and to prevent issues when navigating in areas with speed restriction. At each steady state test mode, the protocol requires the following:

- Allow the gaseous emissions to stabilize before measurement at each test mode (minimum 10 minutes as per ISO).
- Measure gaseous and PM concentrations for at least 3 minutes and no longer than 30 minutes (such that approximately 500µg of filter mass is collected at a minimum dilution ratio of 4:1).
- Record engine RPM, boost pressure, and intake manifold temperature in order to calculate the mass flow rate of the exhaust via the air pump methods. Additionally UCR records engine fuel consumption, or brake specific fuel consumption (bsFC), where available to calculate exhaust flow by an alternate method for the verification of both exhaust flow methods.
- Record engine load, and if available.
- Calculate emission factors from the measured pollutant concentration data and calculated mass flow rates.

2.3 Measurements

The sampling approach includes selecting sample locations (PM representativeness and accessibility), load points (achievable and practical), test matrix (proposed load points to meet EPA desires), and test protocol (methods to use for sampling).

2.3.1 Gaseous and PM emissions

Best recommended practices for OGV exhaust gas measurements follow 40 CFR Part 1065 for PM measurements with specific details following ISO 8178-1 for dilution and exhaust gas sampling. The measurement approach is summarized here, with more details available in Appendix A.

Gaseous: The PM emission measurements used a partial dilution system that was developed based on the ISO 8178-1 protocol and detailed information is provided in Appendix A. The concentrations of gases in the raw exhaust and the dilution tunnel were measured using a Horiba PG-350 portable multi-gas analyzer. The PG-350 can simultaneously measure up to five separate gas components. Major features of the PG-350 include a built-in sample conditioning system with sample pumps, filters, and a thermoelectric cooler. The performance of the PG-350 was tested and verified under the U.S. EPA and ETV programs. The signal output of the instrument was interfaced directly with a data acquisition system to record measured values continuously. Emissions for CO, CO_2, NO_x, and SO_2 gases were measured from the raw exhaust gases (O_2 was also measured), see Table 2-7.

PM Mass: Total PM mass less than 2.5 µm ($PM_{2.5}$) is the PM mass measured that is less than 2.5 um in diameter as collected after a cyclone separator (40 CFR Part 1065 and ISO 8178). The $PM_{2.5}$ was measured from the diluted exhaust gas stack as per recent 40 CFR Part 1065 recommended practices (more stringent than ISO 8178 methods, but consistent with) which utilizes Teflon filters weighed offline and after conditioning. During previous testing on OGV, UCR dilution and filter temperature control was found to produce variable results where dilution factor and filter face temperature varied (as allowed by ISO). Updates were performed to control dilution ratio and filter face temperature as shown in the revised schematic in Figure 2-2.

PM Composition: PM composition is determined by the diluted batched NIOSH/IMPROVE 5040 method for PM composition (elemental and organic carbon species). Diluted samples (same conditions as the $PM_{2.5}$ samples) are collected on Quartz filters and then later analyzed at an offsite laboratory. Diesel $PM_{2.5}$ primarily consists of EC, OC, sulfate and ash. $PM_{2.5}$ mass were collected on Tissuquartz filters after a cyclone and elemental and organic carbon fractions were determined off-line using the thermal optical reflectance IMPROVE/NIOSH filter method.

Greenhouse Gases: Greenhouse Gases (GHGs) are represented as the CO_2 and black carbon (BC) emissions from ocean going vessels. Other GHGs may exists (such as methane), but these other species are small enough to not be considered. CO_2 is measured as described earlier and the BC is measured using the PM elemental composition NIOSH method (see previous description). The BC measured via EC is representative of BC emissions when the $EC/PM_{2.5}$ ratio is greater than 0.5% (Johnson et al 2016). The EC concentrations were greater than 10% for all test points, thus the EC emission factors reported are representative of BC emission factors.

Real-time PM concentration: The DustTrak light scattering PM (PM_{ls}) Nephelometer (TSI DustTrak 8520 Nephelometer measuring 90° light scattering at 780nm) was used in addition to the PM mass measurements to evaluate the stability of the PM signal during batched $PM_{2.5}$ and EC/OC sampling. Nephelometers are fairly simple and compact instruments with excellent sensitivity and time resolution. Nephelometers measure light scattered by aerosol introduced into their sample chamber. However, scattering per unit mass is a strong function of particle size and refractive index. If particle size distributions and refractive indices in diesel exhaust strongly depend on the particular engine, fuel, and operating condition, where light scattering may not be an effective way to measure exhaust particle mass. As such the purpose of the instrument is to show a qualitative stability in the PM emissions at each load point and should not be used to quantify $PM_{2.5}$ emissions

PM dilution: UCR has implemented active dilution air and sample heating system on all OGV tests, see details in Figure 2-2. The heating section was added to accommodate post scrubber cool exhaust conditions. The design of the system has around a one second residence time (recommended) and has a heated sample line section followed by a heated dilution air system. Both heated systems were designed to target a 47˚C (±5˚C) filter face temperature for all conditions include post scrubber samples. During non-scrubber sampling, the active heating section may be operated at a lower temperature to prevent over heating the PM filter during sustained high load conditions, as the non-scrubber exhaust temperatures are high.

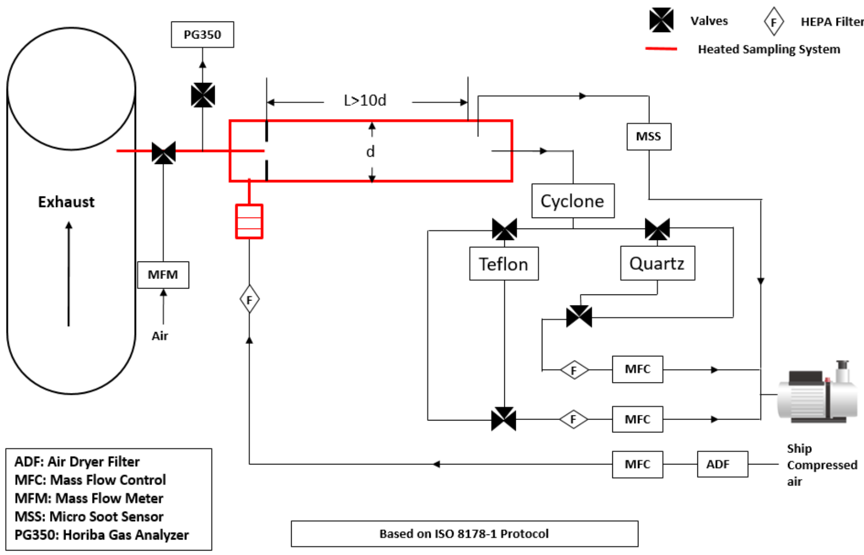

Figure 2-2 Schematic of the dilution sampling system

Table 2-7 Summary of Emissions Measured by UCR

Species Sampled			
NDIR CO	NDIR CO_2	CLD NO_x	NDIR SO_2
Total **$PM_{2.5}$** Gravimetric method	PM **EC/OC** by NIOSH method	PM **Sulfate** not measured for MGO fuels	Black Carbon (BC) Thermal optical elemental carbon
Light scattering PM (PM_{ls}) via real time dustrak			

2.3.2 Exhaust flow

The calculated emission factor requires the measurement of the engines exhaust flow rate. The exhaust gas flow can be determined by the following methods:

1. Direct Measurement Method
2. Carbon Balance Method
3. Air and Fuel Measurement Method
4. Air Pump method

For the work presented in this study the exhaust flow is determined by the Carbon Balance Method and by the Air Pump Method. The emission factors reported are based on using the exhaust flow calculated by the Air Pump Method. For specific calculation details see Appendix A.

2.3.3 Engine

Chapter 6 of the NO_x Technical Code "Procedures for demonstrating compliance with NO_x emission limits on board" provides detailed instructions for the required measurements for on-board testing. Some of the engine performance parameters measured or calculated for each mode during the emissions testing are shown in Table 2-8. The records vary depending on available information for the ME and MG.

Table 2-8: Engine Parameters Measured and Recorded [1]

Parameter	Units
Engine load, speed, and fuel cons.	kW, RPM, and kg/kWhr
Vessel speed	Knots
Generator output	amps, volts, kW, PF (where avail.)
Fuel consumption	kg/hr
Air intake pressure, temperature	Psi, °C
Exhaust stack pressure, temperature	inH20, °C
Ambient pressure, temperature	kPa, °C

[1] Engine and vessel measurements are reported where available and estimated if not available using good engineering judgment.

2.4 Calculations

The testing results include details of the engine loads utilized, the measured emissions, the calculated flow rates, and emission factors for the individual loads and the weighted emissions factors. Brake specific, time specific, and fuel specific emission factors are also provided.

2.4.1 Exhaust flow rate

Since the analytical instruments measure the concentration in the exhaust, it is essential to have an accurate measure of the exhaust mass flow in order to calculate emission rates and factors. UCR calculated the exhaust flow rate from the reported displacement volume of the diesel engine cylinder and from the following measured values: engine rpm, intake temperature, and intake manifold air pressure. This ISO 8178 approved "air pump" method has been used in combination with possible fuel consumption carbon balance comparisons, and possible on-vessel bsFC comparisons.

2.4.2 Emission factors

The emissions were collected at each mode in triplicate to allow for the determination of confidence intervals for the reported means. The triplicate measurements were performed by collecting three samples (ie triple or three repeated measurements) at each load point for all the species of interest (gaseous continuous and integrated PM samples). Because the testing was performed with triple measurements while holding one load (as required for at-sea testing) the mode averaging was performed prior to applying the ISO weighting function. The weighted result is the reported with engine load in kilowatts (kW) and the calculated mass flow in the exhaust. An overall single emission factor representing the engine has been determined by weighting the modal data according to an estimate of the ISO 8178 E2, D2 and the weighting fractions as described below. The equation used for the overall emission factor is as follows:

$$A_{WM} = \frac{\sum_{i=1}^{i=n}\left(g_i \times WF_i\right)}{\sum_{i=1}^{i=n}\left(P_i \times WF_i\right)}$$

Where:

A_{wm} = Weighted mass emission level (CO, CO_2, $PM_{2.5}$, EC/OC, BC, SO_2 and NO_x) in g/kWhr
n = The number of test modes (for the E3 cycle n ranges from 1 to 5)
g_i = Mass flow in grams per hour (g/hr)
P_i = Power measured during each mode (kW)
WF_i = Effective weighing factor.

3 Results

The results are presented in this section and are organized by gaseous pollutants, PM, and lastly GHGs. These sections were organized to be representative of their regulatory, health, and climate impacts respectively.

Figure 3-1 shows the real time NO_x, CO_2, and PM_{ls} concentrations for the main engine. The emissions were stable for all load points (mode 1 through 4) for the gaseous and PM samples measured, as shown in Figure 3-1. The AE emissions were also stable for all load points and species, see Appendix F for details. In general the emissions from the vessel were stable and the results in this report are representative of a properly operating vessel without exhaust aftertreatment. A summary of all the gaseous, PM and GHG emissions are listed in Table 3-2 with detailed engine and sampling condition details in Table 3-1.

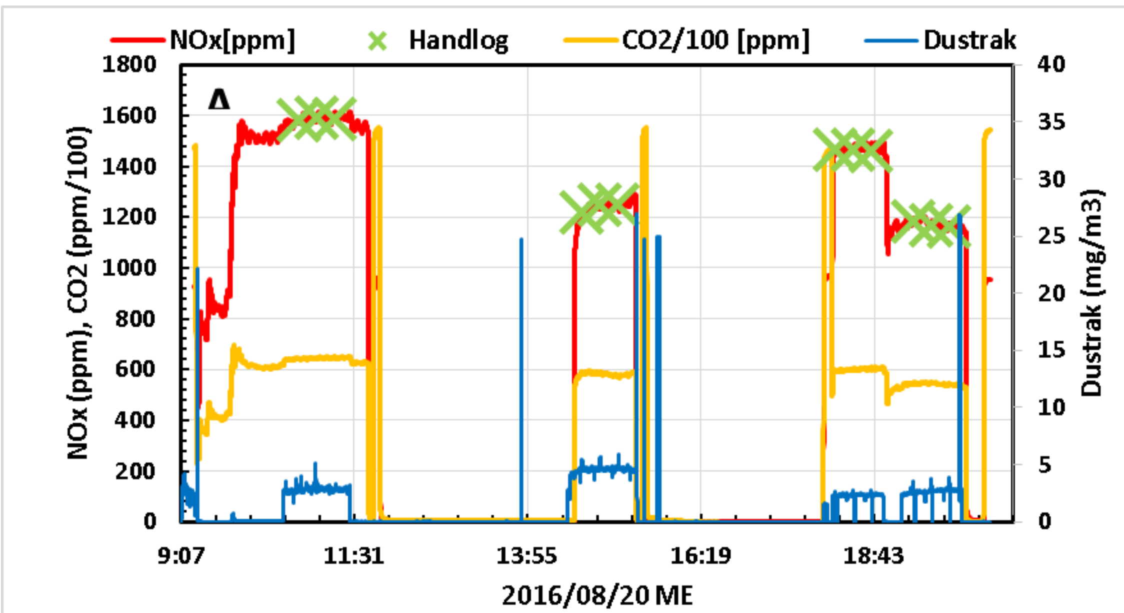

Figure 3-1 Real time response for selected emissions species with test notes [1]

[1] PM_{ls} is the light scattering measurement of PM (PM_{ls}) and is not equivalent to PM mass as defined by EPA 40CFR Part 1065, but is a representative indicator of PM stability for quality assurance purposes. The stable PM signal shows that when the PM samples were taken the engine PM emissions were stable and reproducible, see Section 2.3 for details.

3.1 Gaseous

The NO_x emissions are shown in Figure 3-2 in units of g/kWhr as a function of engine percent load (maximum continuous rating – MCR), Figure 3-3 in units of g/knot, and in Table 3-2. The results show four test points representing load points comparable to those used in the ISO 8178-E3 certification test. The NO_x emissions ranged from 13.5 to 14.6 g/kWh for the ME and 5.6 to 10.0 g/kWHr for the AE over the different load points. The results show a relatively flat NOx emission factor from high to low load for the ME and a slight decreasing EF for the AE from high to low load. The flat trend is different than most large diesel engines tested where EF tend to decline with increasing load (as noted for the AE). This doesn't suggest there is a problem with the ME operation or measurement, just an interesting observation. These baseline results will be useful for the dosing and integration of future NOx control systems such as selective catalytic reduction (SCR) systems where urea injection as a function of NOx concentration is required.

Although the ME NOx emissions were relatively flat from high to low load, the distance specific emissions were lowest at slow speeds and highest at high speeds, see Figure 3-3. Although emissions are certified on a work specific basis (g/kWhr) it is intersting that for the Golden Bear the emissions are lowest at 11 knots which is equivelent to the vessel speed reduction program utilized by the Air Resrouces Board off the state of california.

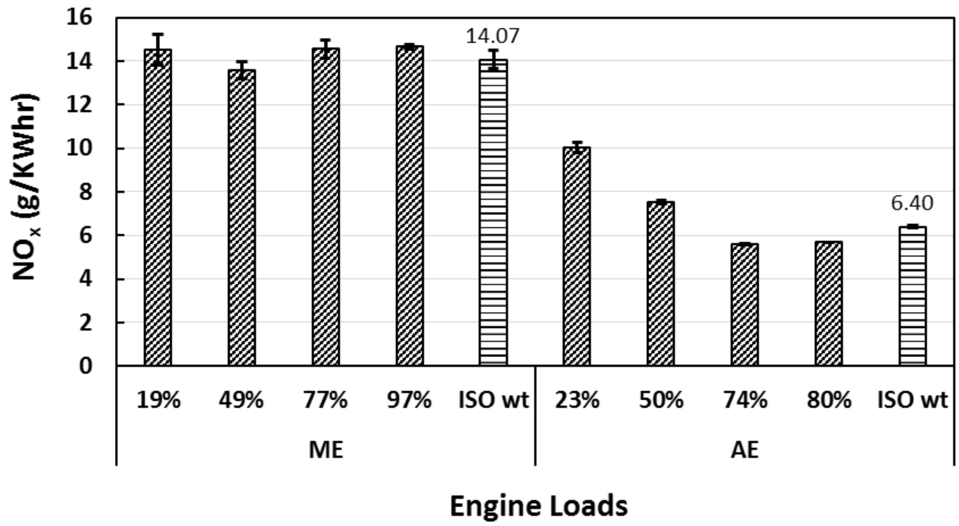

Figure 3-2 NO_x Emissions for the ME and AE Tests in g/kWhr

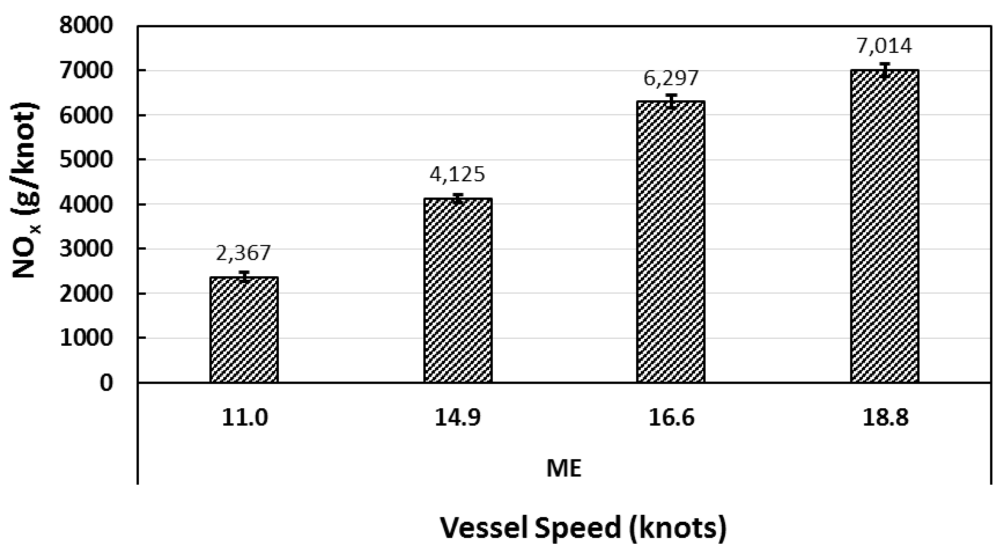

Figure 3-3 NO_x Emissions for the ME Tests in g/knot

Table 3-1 Summary of emission loads, fuel rates, and other sample conditions

Date	Project Name	Fuel	Source	Mode	Start Time	Engine Load		cor. Fuel Rate	bsFC FuelRate	Fuel Rate Carb.	bsFC Carb.	Sample Duration	DR	Exhaust Flow	
mm/dd/yyyy	name				hh:mm	MW	% MCR	kg/hr	g/kWhr	(kg/hr)	(g/kWh)	min	n/a	(scfm)	(m3/hr)
8/20/2016	CMA Golden Bear	MGO	ME	1	10:45	9.01	97%	1801	200	1,773	197	10	6.0	20,895	44,273
8/20/2016	CMA Golden Bear	MGO	ME	2	18:10	7.18	77%	1438	200	1,414	197	10	8.0	17,916	37,963
8/20/2016	CMA Golden Bear	MGO	ME	3	19:15	4.52	49%	955	211	937	207	10	12.0	13,080	27,715
8/20/2016	CMA Golden Bear	MGO	ME	4	14:40	1.79	19%	411	229	404	225	10	8.0	5,259	11,143
8/18/2016	CMA Golden Bear	MGO	AE	1	10:00	0.72	80%	160	223	158	220	10	6.0	2132	4516
8/18/2016	CMA Golden Bear	MGO	AE	2	11:15	0.67	74%	149	223	147	220	10	8.0	2011	4261
8/18/2016	CMA Golden Bear	MGO	AE	3	13:00	0.45	50%	100	223	99	220	10	12.0	1400	2967
8/18/2016	CMA Golden Bear	MGO	AE	4	14:00	0.21	23%	47	225	47	221	10	8.0	775	1642

Table 3-2 Summary of emission brake specific emission factors (g/kWHr)

Date	Source	Mode	Time	Load	Emission Factors (g/kWh)										
mm/dd/yyyy	n/a	n/a	hh:mm	% MCR	NOx	CO	CO2	SO2	PM2.5	PM_EC	PM_OC	PM_S	PM_t	PM_OCcor	PM_TCcor
8/20/2016	ME	1	10:45	97%	14.65	0.60	625	-0.07	0.122	0.019	0.090	0.000	0.110	0.108	0.128
8/20/2016	ME	2	18:10	77%	14.56	0.59	626	-0.07	0.132	0.023	0.109	0.001	0.133	0.130	0.154
8/20/2016	ME	3	19:15	49%	13.56	0.48	658	-0.10	0.238	0.032	0.192	0.001	0.226	0.231	0.264
8/20/2016	ME	4	14:40	19%	14.52	0.65	715	-0.11	0.192	0.046	0.141	0.001	0.188	0.170	0.216
				ISO wt	14.42	0.58	644	-0.08	0.155	0.027	0.122	0.001	0.150	0.147	0.175
8/18/2016	AE	1	10:00	80%	5.68	2.38	696	-0.04	0.465	0.193	0.163	0.001	0.356	0.195	0.388
8/18/2016	AE	2	11:15	74%	5.59	2.10	695	-0.09	0.352	0.187	0.144	0.001	0.332	0.173	0.361
8/18/2016	AE	3	13:00	50%	7.51	1.38	696	-0.10	0.184	0.102	0.100	0.001	0.203	0.120	0.223
8/18/2016	AE	4	14:00	23%	10.02	2.82	699	-0.12	0.298	0.141	0.147	0.001	0.289	0.176	0.318
				ISO wt	7.71	2.12	697	-0.10	0.284	0.144	0.131	0.001	0.276	0.158	0.302

[1] SO_2 emissions were at the detection limit of the analyzer (1-2 ppm) thus the values presented are representative of a non-detectable value (nd). Sulfate PM emissions were estimated from the fuel sulfur level and were thus not measured as is common for low sulfur fuels.

The NOx results show good repeatability at each of the load points with a slightly higher variability at the 19% ME load, see error bars in Figure 3-2 and coeficient of variation in Appendix F. Although the variability was larger than the other modes it was still a low value of around 5% as reported by the coefficient of variation (COV), see Appendix F Table F-11. COVs equal to and less than 5% suggest good repeatability for the test points. The good repeatability at each load points indicates the emission factors are representative of a properly operating OGV.

The ME NO_x emission results are comparable to the certification values for a Tier 2 engine. The ISO weighted NO_x emissions are 14.07 g/kWhr, see Figure 3-2 and Table 3-2. The weighted value is less than the Tier 2 standard for the Category 3 Tier 2 NO_x regulation (14.4 g/kWhr). Note also the results are within reasonable in-use allowances and reasonable measurement uncertainties (Note there is an EPA 20% in-use measurement allowance for on road heavy duty trucks). Future regulations will require more than a 75% NO_x reduction in order to meet the 2016 Tier 3 NO_x regulation for category 3 engines in ECA zones. It is expected a 75% reduction cannot be met with engine control and NO_x aftertreatment will probably be required. The AE engine showed an ISO weighted NOx estimate of 6.4 g/kWhr which is also below the Category 2 Tier 2 engine less than 3300 kW engine certification of 8.7 g/kWhr. The Tier 3 and Tier 4 AE emission certifications reduce to 6.2 g/kWhr and 1.8 g/kWhr, respectively. The Golden Bear AE's actually meet the Tier 3 requirement, but will needed additional clean up to meet the Tier 4 regulations.
The ME and AE CO emissions results are shown in Table 3-1 in units of g/kWhr. The ME and AE CO emissions were relatively constant as a function of load, with test points in the range of 0.5 to 0.6 g/kWhr for the ME and 1.4 to 2.8 g/kWhr for the AE. The ME and AE CO emissions are comparable to those found from other testing campaigns for similar sized engines.

The SO_2 emissions were very low, as would be expected when testing MGO low sulfur fuels. The emission factors were at or below detection limits of the NDIR SO_2 analyzer (1-2 ppm). As such, the reported valuves are presented to show detection limits and are represetative of a non-detected value.

3.2 $PM_{2.5}$ and Composition

The $PM_{2.5}$ mass emission and PM composition results for the ME and AE engines are shown in Figure 3-4 and Figure 3-5 respectively in units of g/kWhr. The ME $PM_{2.5}$ emissions ranged from about 0.24 to 0.12 g/kWhr where the highest EF was at 49% load. The $PM_{2.5}$ emissions did not show a strong trend with respect to load for the ME, but a slight trend for the AE where higher PM was emitted at higher loads (opposite to most EF AE trends). The PM composition results show that the PM is predominantly composed of OC and EC, with only trace amouts of sulfate PM, see Figure 3-5 and Table 3-1 for details. On a distance basis the $PM_{2.5}$ emissions show the lowest emission rate is at 11 knots (19% load) and highest emission rate is at 14.9 knots (50% load). The ME has been derated where its percent load is higher at 11 knots compard to what would be at the full rating of the engine. Typical 11 knots is equivelent to 9% load and 14.9 knots is equivlement to 30% load. Recent testing on a Tier 2 vessel showed the highest PM EF at 30% load which agrees with the results presented here.

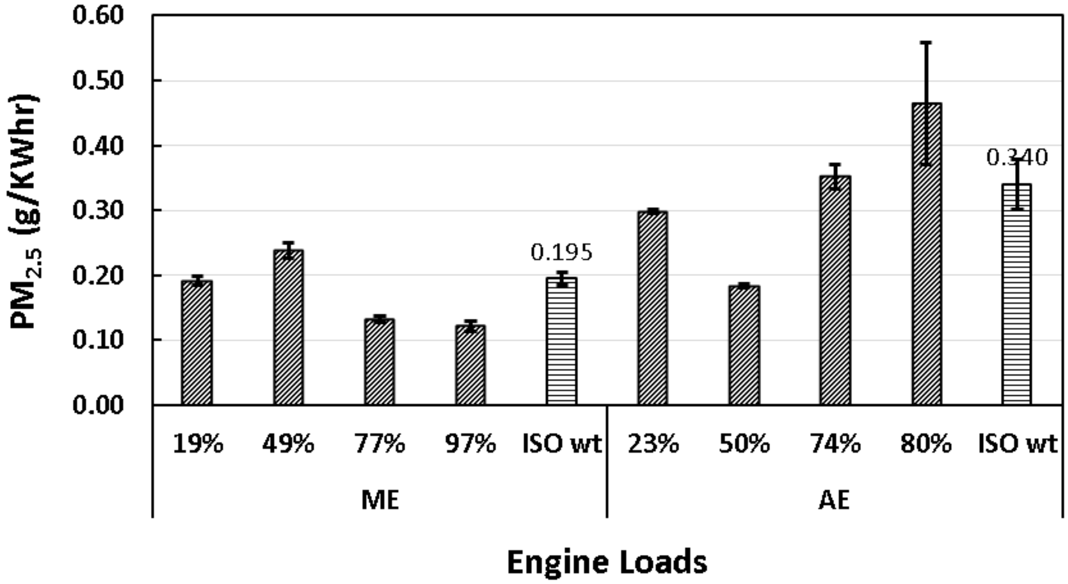

Figure 3-4 PM$_{2.5}$ emissions for the ME and AE Tests in g/kWhr

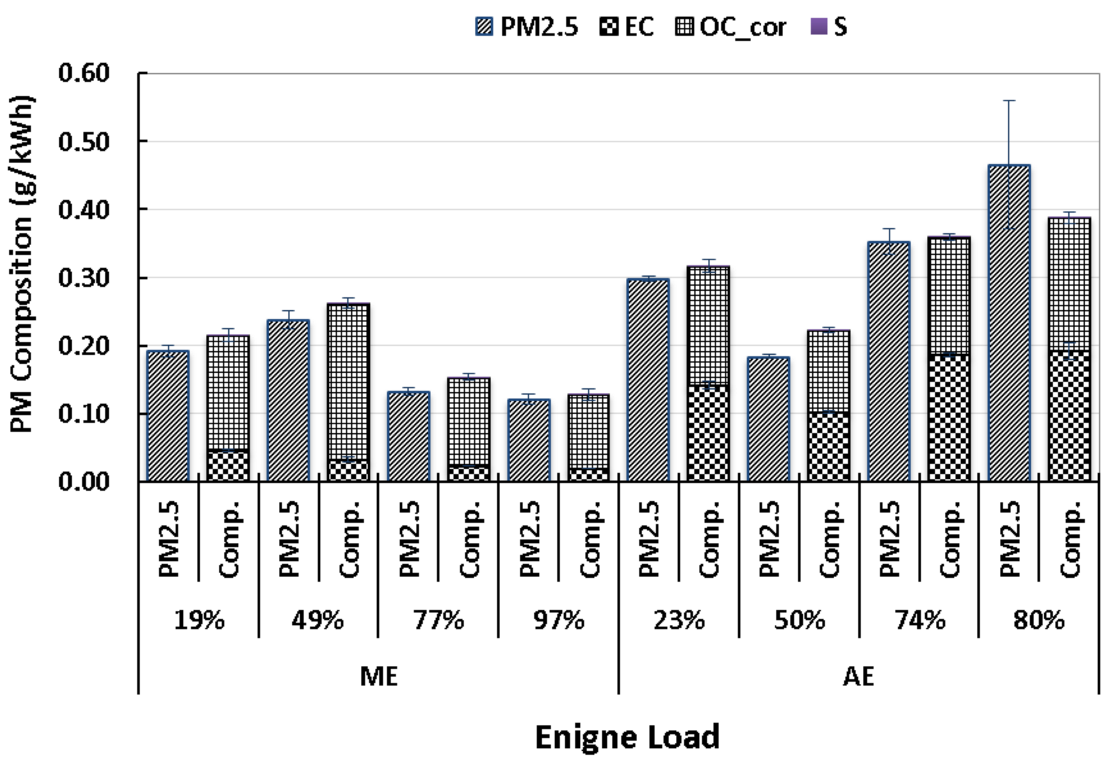

Figure 3-5 PM composition emissions for the ME and AE Tests in g/kWhr [1]

[1] Sulfate PM estimated from fuel sulfur levels and SO_2 measurements (it was not measured)

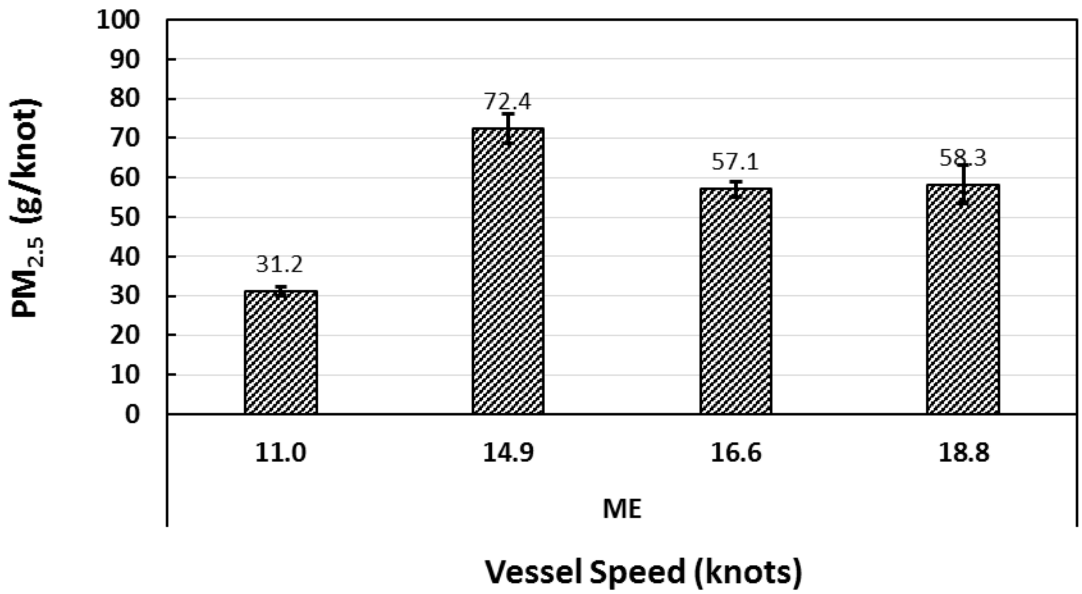

Figure 3-6 PM composition emissions for the ME in g/knots

3.3 Global warming potential

There are two primary sources of global warming pollutants from ship combustion, CO2 and BC. The CO_2 emissions from the shipping have recently been identified as a concern internationally where IMO is considering regulator efficiency standards. Additional IMO is considering some type of BC emissions limit from marine vessels. This section discusses the EF from the Golden Bear for both CO2 and BC global warming potentials.

3.3.1 Carbon dioxide (CO_2)

The CO_2 emissions results increased with decreasing load for the ME (from 625 to 715 g/kWhr) and were relatively constant for the AE (at 695 g/kWhr), see Table 3-1 and Figure 3-7. These values also agree with previous testing of similarly sized engines. As reported, AE's tend to have higher fuel consumption than ME's due to lower thermal efficienices and higher operating engine speeds. On a distance basis the CO_2 emissions show the lowest emission rate is at 11 knots (19% load) and highest emission rate is at 14.9 knots (50% load), see Figure 3-8. This suggests biggest reduction for GHG emissions can be realized by lowering vessel speed.

Additionally, CO_2 emissions are directly proportional to fuel consupmtion where one could look at CO_2 trends and identy fuel consumption trends. Figure 3-7 shows that the amout of fuel used per unit work is constant for the AE, but more fuel is burned per unit work when the ME load decreases. Thus, this suggest operating at higher loads would be more benifitial for the CO2 emissions of the vessel.

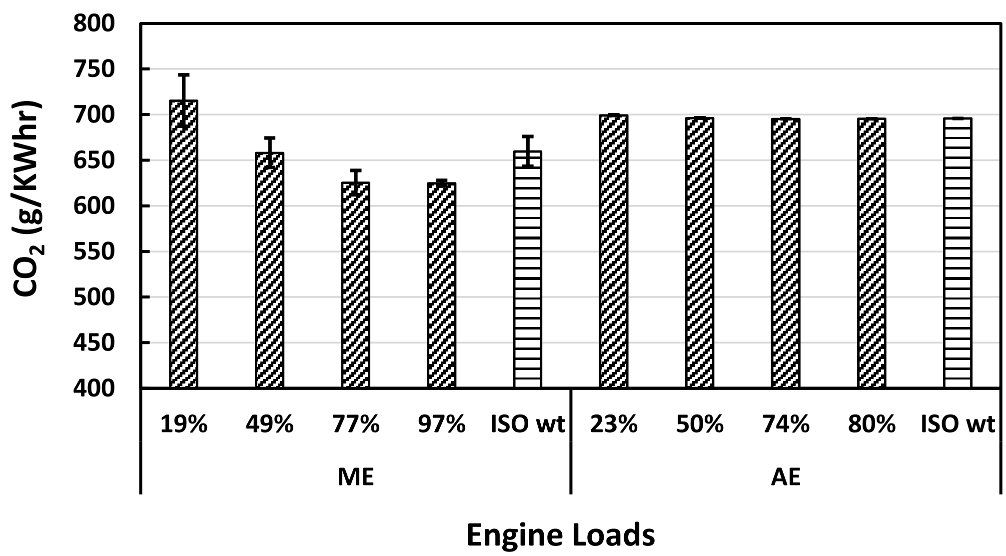

Figure 3-7 CO_2 Emissions for the ME and AE Tests in g/kWhr

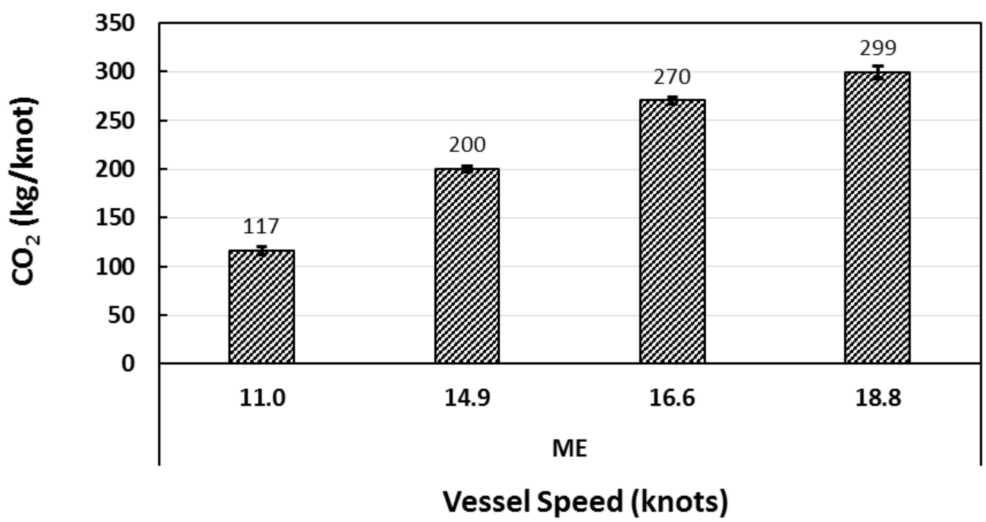

Figure 3-8 CO_2 Emissions for the ME Tests in g/knot

3.3.2 Black Carbon (BC)

The BC emissions reported in this section are based on the EC measurment from the thermal optical method. This method has been provent to be reliable for BC quantification when the EC fractioin is greater than 1% of the total measured PM (as was reported in this study). Thus the reported BC in this section is represnative for the vessel tested. The BC emissions results for the ME and AE tests are shown in Figure 3-9 in units of g/kWhr for the EC measurement method. The results show that ME BC emissions ranged from 0.019 to 0.046 g/kWhr over the different loads and up to 0.465 g/kWhr for the AE. This is consistent with other ME and AE tests where the ME emits significantly lower BC emissions compared to an AE engine. On a distance basis the BC emissions show the lowest emission rate is at 11 knots (19% load) and highest emission rate is at

14.9 knots (50% load) similar to the PM emissions. This suggest the lowest BC emissions can be obatined by operating at low vessel speeds as desired by the VSR program.

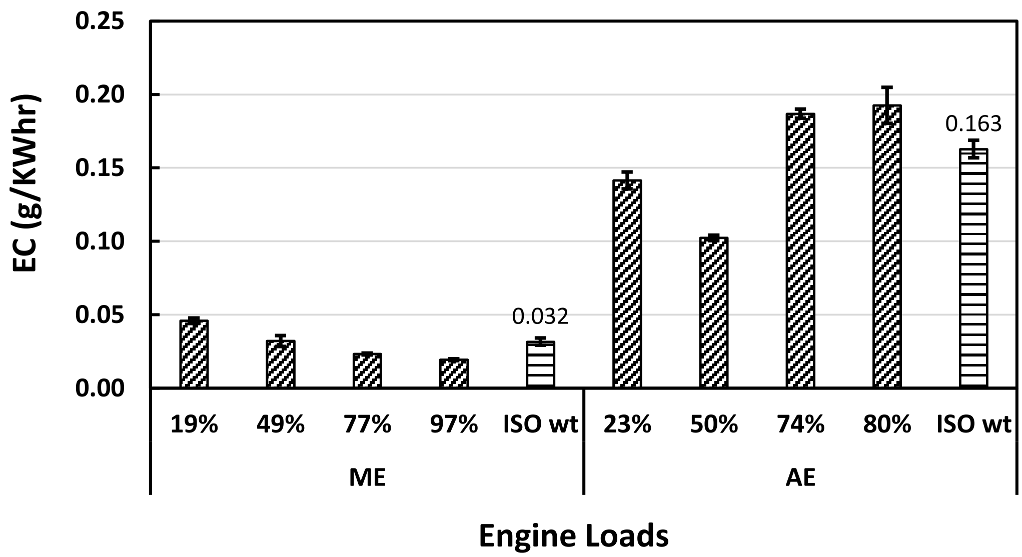

Figure 3-9 Equivalent black carbon (EC) emissions for the ME and AE Tests in g/kWhr

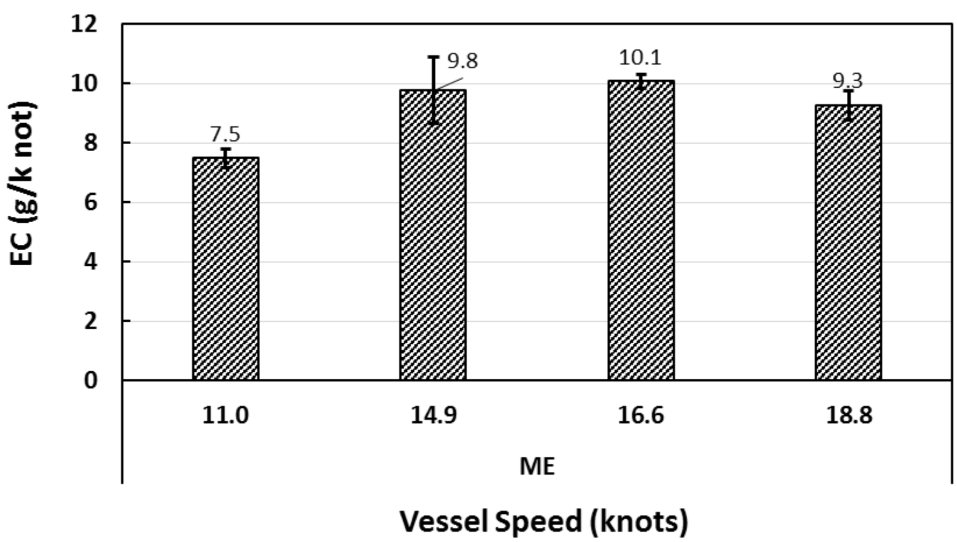

Figure 3-10 Equivalent black carbon (EC) emissions for the ME Tests in g/knot

Summary

Emissions measurements were conducted from one main and one auxiliary engine on the Golden Bear vessel as it cruised along the coast of California from the Port of LA to the Port of Oakland. Testing followed the ISO 8178 E2 cycle for the ME and the D2 for the AE steady state test cycle protocol to determine the emissions rate of gaseous and particulate pollutants. Emissions were measured following ISO and CFR 1065 methods for gaseous and PM (total mass, elemental, and organic carbon species, sulfated PM) measurements. Upgrades were performed to meet EPA requested 1065 dilution ratios and filter temperatures on an exhaust that was cooled with sea water. Dilution ratios and filter temperatures as specified in 1065 were met during this testing.

Emissions measurements were performed at four load points that represented MCR of 19%, 49%, 77%, and 97% load for the ME and 23%, 50%, 74%, and 80% for the AE. The measured weighted emission factors for the ME and AE were calculated and summarized as follows:

- The gaseous and PM emissions from the vessel were stable and the results in this report are representative of a properly operating vessel.
- The ISO weighted ME NO_x emissions are 14.07 g/kWhr which is lower the Tier 2 standard for the Category 3 Tier 2 NO_x regulation of 14.4 g/kWhr. Additional controls measure will be needed to have the ME meet the Tier 3 standard.
- The ISO weighted AE NO_x emissions are 6.4 g/kWhr which is also below the Category 2 Tier 2 engine certification of 8.7 g/kWhr and even the Tier 3 6.2 g/kWHr, but not the Tier 4 certification of 1.8 g/kWhr. Additional controls measure will be needed to have the AE meet the Tier 4 standard.
- The ME NOx emissions were relatively flat on a g/kWhr basis (~14 g/kWhr), but on a distance basis the emissions were lowest at low vessel speed.
- The CO emissions were similar to other ME and AEs tested.
- The SO_2 emissions were very low, as would be expected when testing MGO low sulfur fuels (< 0.1 g/kWhr).
- The ME $PM_{2.5}$ emissions ranged from about 0.24 to 0.12 g/kWhr where the highest EF was at 49% load. The $PM_{2.5}$ emissions did not show a strong trend with respect to load for the ME, but a slight trend for the AE where higher PM was emitted at higher loads (opposite to most EF AE trends). On a distance basis the ME $PM_{2.5}$ emissions were lowest at 11 knots (19% load) and highest at 14.9 knots (50% load).
- The PM composition for both engines showed that the PM is predominantly composed of OC and EC, with only trace amouts of sulfate PM.
- The CO_2 emissions results increased with decreasing load for the ME (from 625 to 715 g/kWhr) and were relatively constant for the AE (at 695 g/kWhr). On a distance basis the CO_2 emissions show the lowest emission rate is at 11 knots (19% load) and highest emission rate is at 18.8 knots (97% load).
- The ME BC emissions ranged from 0.019 to 0.046 g/kWhr over the different loads and up to 0.465 g/kWhr for the AE. This is consistent with other ME and AE tests where the ME emits significantly lower BC emissions compared to an AE engine. On a distance basis the ME BC emissions were lowest at 11 knots (19% load) and highest at 14.9 knots (50% load).

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Appendix A – Sample Collection Methods

ISO 8178-1[1] and ISO 8178-2[2] specify the measurement and evaluation methods for gaseous and particulate exhaust emissions when combined with combinations of engine load and speed provided in ISO 8178- *Part 4: Test cycles for different engine applications*. The emission results represent the mass rate of emissions per unit of work accomplished. Specific emission factors are based on brake power measured at the crankshaft, the engine being equipped only with the standard auxiliaries necessary for its operation. Per ISO, auxiliary losses are <5 % of the maximum observed power. IMO ship pollution rules and measurement methods are contained in the "International Convention on the Prevention of Pollution from Ships", known as MARPOL 73/78[3], and sets limits on NO_x and SO_x emissions from ship exhausts. The intent of this protocol was to conform as closely as practical to both the ISO and IMO standards.

Gaseous and Particulate Emissions

A properly designed sampling system is essential for accurate collection of a representative sample from the exhaust and subsequent analysis. ISO points out that particulate must be collected in either a full flow or partial flow dilution system and UCR chose the partial flow dilution system as shown in Figure A-1.

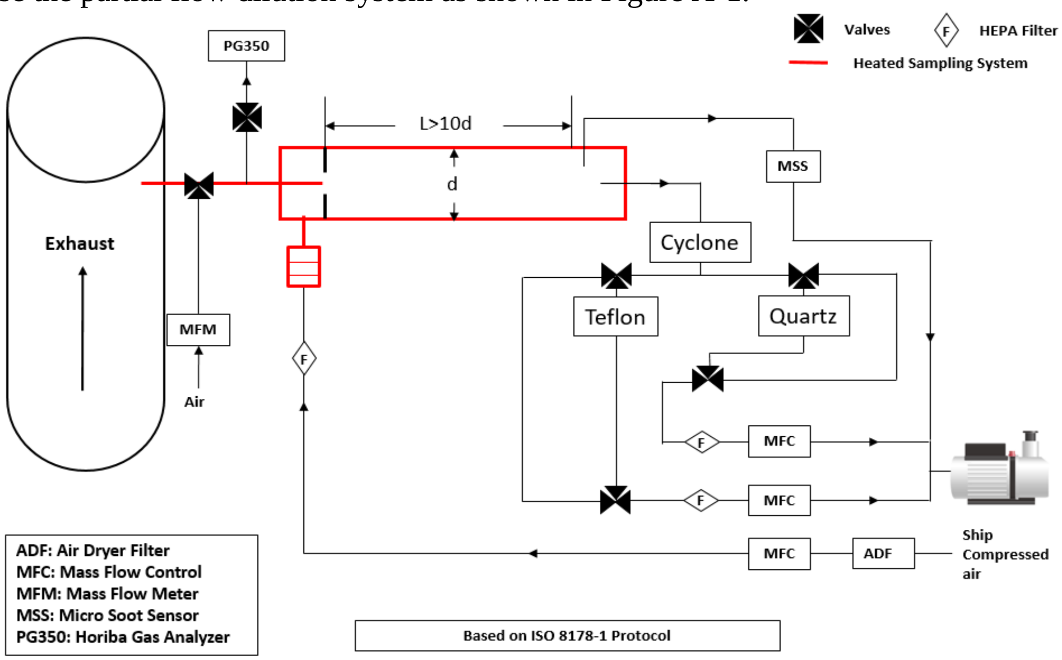


Figure A-1 Partial Flow Dilution System

[1] International Standards Organization, IS0 8178-1, *Reciprocating internal combustion engines - Exhaust emission measurement -Part 1: Test-bed measurement of gaseous particulate exhaust emissions*, First edition 1996-08-l5

[2] International Standards Organization, IS0 8178-2, *Reciprocating internal combustion engines - Exhaust emission measurement -Part 2: Measurement of gaseous and particulate exhaust emissions at site*, First edition 1996-08-l5

[3] International Maritime Organization, *Annex VI of MARPOL 73/78 "Regulations for the Prevention of Air Pollution from Ships and NOx Technical Code*".

The flow in the dilution system eliminates water condensation in the dilution tunnel and sampling systems and maintains the temperature of the diluted exhaust gas at <52°C before the filters. ISO cautions that the advantages of partial flow dilution systems can be lost to potential problems such as: losing particulates in the transfer tube, failing to take a representative sample from the engine exhaust and inaccurately determining the dilution ratio.

An overview of UCR's partial dilution system is shown in Figure A-1. Raw exhaust gas is transferred from the exhaust pipe (EP) through a sampling probe (SP) and the transfer tube (TT) to a dilution tunnel (DT) due to the negative pressure created by the venturi (VN) in DT. The gas flow rate through TT depends on the momentum exchange at the venturi zone and is therefore affected by the absolute temperature of the gas at the exit of TT. Consequently, the exhaust split for a given tunnel flow rate is not constant, and the dilution ratio at low load is slightly lower than at high load. More detail on the key components is provided in Table A-1.

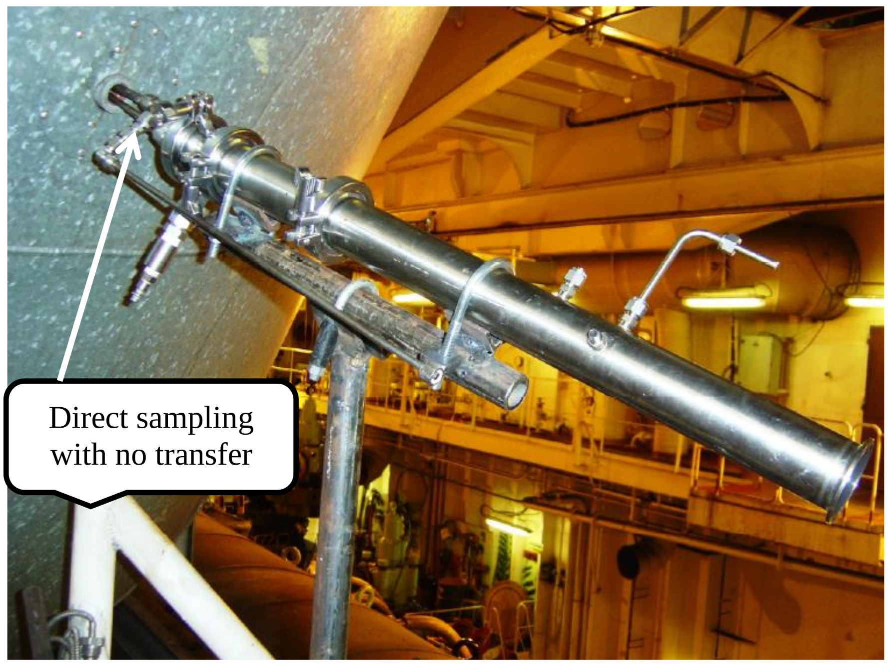


Figure A-2 measurement layout on an engine exhaust stack

Dilution Air System

40 CFR Part 1065 recommends dilution air to be 20 to 30°C and ISO recommends 25 ±5°C. Both also recommend using filtered and charcoal scrubbed air to eliminate background hydrocarbons. The dilution air may be dehumidified. The system can be described as follows: The pressure is reduced to around 40 psig, a liquid knock-out vessel, desiccant to remove moisture with silica gel containing an indicator, hydrocarbon removal with activated charcoal, and a HEPA filter for the fine aerosols that might be present in the supply air. The silica gel and activated carbon are changed for each field campaign. Figure A-3 shows the field processing unit in its transport case. In the field the case is used as a framework for supporting the unit.

Table A-1 Components of a Sampling System: ISO Criteria & UCR Design

Section	Selected ISO and IMO Criteria	UCR Design
Exhaust Pipe (EP)	In the sampling section, the gas velocity is > 10 m/s, except at idle, and bends are minimized to reduce inertial deposition of PM. Sample collection of 10 pipe diameters of straight pipe upstream is recommended and performed where possible. For some tight configurations use good engineering judgment.	UCR follows the ISO recommendation, when practical.
Sampling Probe (SP) -	The minimum inside diameter is 4 mm and the probe is an open tube facing upstream on the exhaust pipe centerline. No IMO code.	UCR uses a stainless steel tube with diameter of 8mm placed near the center line.
Transfer Tube (TT)	• As short as possible and < 5 m in length; • Equal to/greater than probe diameter & < 25 mm diameter; • TTs insulated. For TTs > 1m, heat wall temperature to a minimum of 250°C or set for < 5% thermophoretic losses of PM.	UCR uses a transfer tube of 0.15 m (6 inches). Additionally the sample tube insertion length varies with stack diameter, but typically penetrates at least 10%, but not more than 50% of the stack diameter.
Dilution Tunnel (DT)	• shall be of a sufficient length to cause complete mixing of the exhaust and dilution air under turbulent flow conditions; • shall be at least 75 mm inside diameter (ID) for the fractional sampling type, constructed of stainless steel with a thickness of > 1.5 mm.	UCR uses fractional sampling; stainless steel tunnel has an ID of 50mm and thickness of 1.5mm.
Venturi (VN) --	The pressure drop across the venturi in the DT creates suction at the exit of the transfer tube TT and the gas flow rate through TT is basically proportional to the flow rate of the dilution air and pressure drop.	Venturi proprietary design provided by MAN B&W; provides turbulent mixing.
Exhaust Gas Analyzers (EGA)	One or several analyzers may be used to determine the concentrations. Calibration and accuracy for the analyzers are like those for measuring the gaseous emissions.	UCR uses a 5-gas analyzer meeting IMO/ISO specs

Figure A-3 Field Processing Unit for Purifying Dilution Air in Carrying Case

Calculating the Dilution Ratio

According to ISO 8178, "it is essential that the dilution ratio be determined very accurately" for a partial flow dilution system such as what UCR uses. The dilution ratio is simply calculated from measured gas concentrations of CO_2 and/or NO_x in the raw exhaust gas, the diluted exhaust gas and the dilution air. UCR has found it useful to independently determine the dilution ratio from both CO_2 and NO_x and compare the values to ensure that they are within ±10%. UCR's experience indicates the independently determined dilution ratios are usually within 5%. At systematic deviations within this range, the measured dilution ratio can be corrected, using the calculated dilution ratio. According to ISO, dilution air is set to obtain a maximum filter face temperature of <52°C and the dilution ratio shall be > 4.

Dilution System Integrity Check

ISO describes the necessity of measuring all flows accurately with traceable methods and provides a path and metric to quantifying the leakage in the analyzer circuits. UCR has adopted the leakage test and its metrics as a check for the dilution system. According to ISO the maximum allowable leakage rate on the vacuum side shall be 0.5 % of the in-use flow rate for the portion of the system being checked. Such a low leakage rate allows confidence in the integrity of the partial flow system and its dilution tunnel. Experience has taught UCR that the flow rate selected should be the lowest rate in the system under test.

Measuring the Gaseous Emissions: CO, CO_2, HC, NO_x, O_2, SO_2

Measurement of the concentration of the main gaseous constituents is one of the key activities in measuring emission factors. This section covers the ISO/IMO protocols and that used by UCR. For SO_2, ISO recommends and UCR concurs that the concentration of SO_2 is calculated based on the fact that 95+% of the fuel sulfur is converted to SO_2.

Measuring Gaseous Emissions: ISO & IMO Criteria

ISO specifies that either one or two sampling probes located in close proximity in the raw gas can be used and the sample split for different analyzers. However, in no case can condensation of exhaust components, including water and sulfuric acid, occur at any point of the analytical system. ISO specifies the analytical instruments for determining the gaseous concentration in either raw or diluted exhaust gases.

- Heated flame ionization detector (HFID) for the measurement of hydrocarbons;
- Non-dispersive infrared analyzer (NDIR) for the measurement of carbon monoxide and carbon dioxide;
- Heated chemiluminescent detector (HCLD) or equivalent for measurement of nitrogen oxides;
- Paramagnetic detector (PMD) or equivalent for measurement of oxygen.

ISO states the range of the analyzers shall accurately cover the anticipated concentration of the gases and recorded values between 15% and 100% of full scale. A calibration curve with five points is specified. However, with modern electronic recording devices, like a computer, ISO allows the range to be expanded with additional calibrations. ISO details instructions for establishing a calibration curve below 15%. In general, calibration curves must be < ±2 % of each calibration point and be < ±1 % of full scale zero.

ISO outlines their verification method. Each operating range is checked prior to analysis by using a zero gas and a span gas whose nominal value is more than 80 % of full scale of the measuring range. If, for the two points considered, the value found does not differ by more than ±4 % of full scale from the declared reference value, the adjustment parameters may be modified. If >4%, a new calibration curve is needed.

ISO, IMO, and CFR specify the operation of the HCLD. The efficiency of the converter used for the conversion of NO_2 into NO is tested prior to each calibration of the NO_x analyzer. 40 CFR Part 1065 requires 95% and recommends 98%. The efficiency of the converter shall be >95 % and will be evaluated prior to testing.

ISO requires measurement of the effects of exhaust gases on the measured values of CO, CO_2, NO_x, and O_2. Interference can either be positive or negative. Positive interference occurs in NDIR and PMD instruments where the interfering gas gives rise to the same effect as the gas being measured, but to a lesser degree. Negative interference occurs in NDIR instruments due to the interfering gas broadening the absorption band of the measured gas, and in HCLD instruments due to the interfering gas quenching the radiation. Interference checks are recommended prior to an analyzer’s initial use and after major service intervals.

Measuring Gaseous Emissions: UCR Design

The concentrations of CO, CO_2, NO_x and O_2 in the raw exhaust and in the dilution tunnel are measured with a Horiba PG-350 portable multi-gas analyzer. The PG-350 simultaneously measures five separate gas components with methods recommended by the ISO/IMO and USEPA. The signal output of the instrument is connected to a laptop computer through an RS-232C interface to continuously record measured values. Major features include a built-in sample conditioning system with sample pump, filters, and a thermoelectric cooler. The performance of the PG-350 was tested and verified under the U.S. EPA ETV program.

Figure A-4 Gas analyzer setup with continuous data logging system

Details of the gases and the ranges for the Horiba instrument are shown in Table A-2. Note that the Horiba instrument measures sulfur oxides (SO_2); however, UCR follows the protocol in ISO which recommends calculation of the SO_2 level from the sulfur content of the fuel as the direct measurement for SO_2 is less precise than calculation. When an exhaust gas scrubber is present, UCR recommends measuring the SO_2 concentration after the scrubber since the fuel calculation approach will not be accurate due to scrubber SO_2 removal performance expectations.

Table A-2 Detector Method and Concentration Ranges for Monitor

Component	Detector	Ranges
Nitrogen Oxides (NOx)	Heated Chemiluminescence Detector (HCLD)	0-25, 50, 100, 250, 500, 1000, & 2500 ppmv
Carbon Monoxide (CO)	Non dispersive Infrared Absorption (NDIR)	0-200, 500, 1000, 2000, & 5000 ppmv
Carbon Dioxide (CO_2)	Non dispersive Infrared Absorption (NDIR)	0-5, 10, & 20 vol%
Sulfur Dioxide (SO_2)	Non dispersive Infrared Absorption (NDIR)	0-200, 500, 1000, & 3000 ppmv
Oxygen	Zirconium oxide sensor	0-5, 10, & 25 vol%

For quality control, UCR carries out analyzer checks with calibration gases both before and after each test to check for drift. Because the instrument measures the concentration of five gases, the calibration gases are a blend of several gases (super-blend) made to within 1% specifications. Experience has shown that the drift is within manufacturer specifications of ±1% full scale per day shown in Table A-3. The PG-350 meets the analyzer specifications in ISO 8178-1 Section 7.4 for repeatability, accuracy, noise, span drift, zero drift and gas drying.

Table A-3 Quality Specifications for the Horiba PG-350

Repeatability	±0.5% F.S. (NO_x: </= 100ppm range CO: </= 1,000ppm range) ±1.0% F. S.
Linearity	±2.0% F.S.
Drift	±1.0% F. S./day (SO$_2$: ±2.0% F.S./day)

Measuring the Particulate Matter (PM) Emissions

ISO 8178-1 defines particulates as any material collected on a specified filter medium after diluting exhaust gases with clean, filtered air at a temperature of ≤ 52ºC (40 CFR Part 1065 is 47±5 °C), as measured at a point immediately upstream of the PM filter. The particulate consists of primarily carbon, condensed hydrocarbons, sulfates, associated water, and ash. Measuring particulates requires a dilution system and UCR selected a partial flow dilution system. The dilution system design completely eliminates water condensation in the dilution/sampling systems and maintains the temperature of the diluted exhaust gas at < 52°C immediately upstream of the filter holders (and is typically below 47°C also). IMO does not offer a protocol for measuring PM and thus a combination of ISO and CFR practices are adopted. A comparison of the ISO and UCR practices for sampling PM is shown in Table A-4.

Table A-4 Measuring Particulate by ISO and UCR Methods

	ISO	**UCR**
Dilution tunnel	Either full or partial flow	Partial flow
Tunnel & sampling system	Electrically conductive	Same
Pretreatment	None	Cyclone, removes >2.5µm
Filter material	PTFE coated glass fiber	Teflon (TFE)
Filter size, mm	47 (37mm stain diameter)	Same
Number of filters in series	Two	One
Number of filters in parallel	Only single filter	Two; 1 TFE & 1 Quartz
Number of filters per mode	Single or multiple	Single is typical unless looking at artifacts
Filter face temp. °C	≤ 52	Same
Filter face velocity, cm/sec	35 to 80.	~33
Pressure drop, kPa	For test <25	Same
Filter loading, µg	>500	500-1,000 + water w/sulfate, post PM control ~ 100
Weighing chamber	22±3°C & RH= 45%± 8	22±1 °C & dewpoint of 9.5 °C±1°C (typically < ±0.6°C)
Analytical balance, LDL µg	10	LDL = 3 and resolution 0.1
Flow measurement	Traceable method	Same
Flow calibration, months	< 3months	Every campaign

Sulfur content. According to ISO, particulates measured using IS0 8178 are “conclusively proven” to be effective for fuel sulfur levels up to 0.8%. UCR is often faced with measuring PM for fuels with sulfur content exceeding 0.8% and has adopted the 40 CFR Part 1065 sampling methodologies as no other method is prescribed for fuels with a higher sulfur content.

Calculating Exhaust Flow Rates

The calculated emission factor requires the measurement of the engine's exhaust flow rate. The exhaust gas flow can be determined by the following methods:

1. Direct Measurement Method
2. Carbon Balance Method
3. Air and Fuel Measurement Method
4. Air Pump method

Method 1: Direct Measurement of exhaust
Actual exhaust mass flow rate can be determined from the exhaust velocity, cross sectional area of the stack, and moisture and pressure measurements. The direct measurement method is a difficult technique, and precautions must be taken to minimize measurement errors. Details of the direct measurement method are provided in ISO 5167-1.

Method 2(a)-Carbon Balance
Carbon Balance is used to calculate the exhaust mass flow based on the measurement of fuel consumption and the exhaust gas concentrations with regard to the fuel characteristics. The method given is only valid for fuels without oxygen and nitrogen content, based on procedures used for EPA and ECE calculations. Detailed calculation steps of the Carbon Balance method are provided in annex A of ISO 8178-1. Basically: In…lbs fuel/time * wt% carbon * 44/12 → input of grams CO2 per time Out… vol % CO2 * (grams exhaust/time * 1/density exhaust) → exhaust CO2 per time
Note that the density = (mole wt*P)/(R* Temp) where P, T are at the analyzer conditions. For highly diluted exhaust, M ~ of the atmosphere.

Method 2(b)-Universal Carbon/Oxygen balance
The Universal Carbon/Oxygen Balance is used for the calculation of the exhaust mass flow. This method can be used when the fuel consumption is measurable and the fuel composition and the concentration of the exhaust components are known. It is applicable for fuels containing H, C, S, 0, N in known proportions. Detailed calculation steps of Carbon/Oxygen Balance method is provided in annex A of ISO 8178-1.

Method 3-Air and Fuel Measurement Method
This involves measurement of the air flow and the fuel flow. The calculation of the exhaust gas flow is provided in Section 7.2 of ISO 8178-1.

Method 4-Air Pump Method
Exhaust flow rate is calculated by assuming the engine is an air pump, meaning that the exhaust flow is equal to the intake air flow. The flow rate is determined from the overall engine displacement, and rpm; corrected for temperature and pressure of the inlet air and pumping efficiency. In the case of turbocharged engines, this is the boost pressure and intake manifold temperature. This method should not be used for diesel engines equipped with additional air

input for cylinder exhaust discharge, called purge or scavenger air, unless the additional flow rate is known or can be determined.

Added Comments about UCR's Measurement of PM

In the field UCR uses a raw particulate sampling probe fitted close to and upstream of the raw gaseous sample probe and directs the PM sample to the dilution tunnel. There are two gas streams leaving the dilution tunnel; the major flow vented outside the tunnel and the minor flow directed to a cyclone separator, sized to remove particles >2.5um. The line leaving the cyclone separator is split into two lines; each line has a 47 mm Gelman filter holder. One holder collects PM on a Teflon filter and the other collects PM on a quartz filter. UCR simultaneously collects PM on Teflon and quartz filters at each operating mode and analyzes the quartz filters utilizing the NIOSH or IMPROVE methods. UCR recommends the IMPROVE method over the NIOSH.

Briefly, total PM is collected on Pall Gelman (Ann Arbor, MI) 47 mm Teflon filters and weighed using a Mettler Toledo UMX2 microbalance with a 0.1 ug resolution. Before and after collection, the filters are conditioned for 24 hours in an environmentally controlled room (22±1 °C and dewpoint of 9.5 °C) and weighed daily until two consecutive weight measurements are within 3 µg or 2%. It is important to note that the simultaneous collection of PM on quartz and Teflo^{TM} filters provides a comparative check of PM mass measured by two independent methods for measuring PM mass.

Sulfur in the fuel produces SO_2 in the combustion process and some of the SO_2 becomes SO_3 in the exhaust and subsequently produces $H_2SO4 \bullet 6H_2O$ which is collected on the Teflon filter paper. After the final weights for the particulate laden Teflon filters have been determined a portion of the filter is punched out, extracted with High Performance Liquid Chromatography grade water and isopropyl alcohol and analyzed for sulfate ions by ion chromatography.

Measuring Real-Time Particulate Matter (PM) Emissions-DustTrak 8520

In addition to the filter-based PM mass measurements, UCR uses a Nephelometer (TSI DustTrak 8520) for continuous measurements of steady-state and transient data. The DustTrak is a portable, battery-operated laser photometer that gives real-time digital readout and has a built-in data logger. It measures light scattered (90 degree light scattering at 780nm near-infrared) by aerosol introduced into a sample chamber and displays the measured mass density in units of mg/m^3. As scattering per unit mass is a strong function of particle size and refractive index of the particle size distributions and as refractive indices in diesel exhaust strongly depend on the particular engine and operating condition, some question the accuracy of PM mass measurements. However, UCR always references the DustTrak results to filter based measurements and this approach has shown that

Figure A-5 Picture of TSI DustTrak

mass scattering efficiencies for both on-road diesel exhaust and ambient fine particles have values around $3m^2/g$.

Measuring Non-Regulated Gaseous Emissions

Neither ISO nor IMO provide a protocol for sampling and analyzing non-regulated emissions. UCR uses peer reviewed methods adapted to their PM dilution tunnel. The methods rely on added media to selectively collect hydrocarbons and PM fractions during the sampling process for subsequent off-line analysis. A secondary dilution is constructed to capture real time PM.

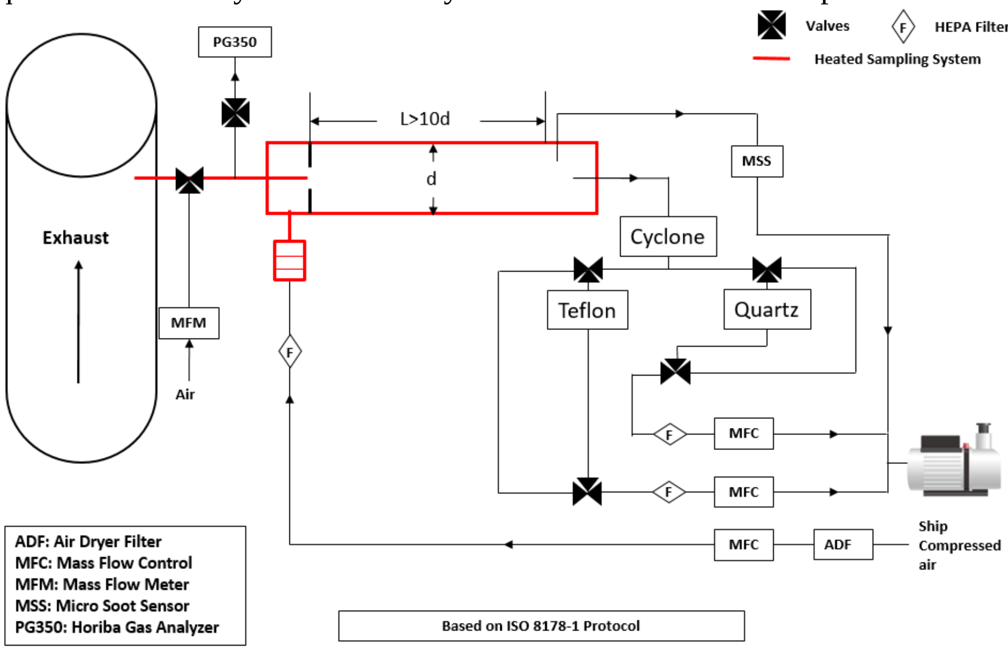


Figure A-5 Extended setup of the PFDS for non-regulated emissions

Appendix B – Quality Control

Pre-test calibrations
Prior to departing from UCR all systems will be verified and cleaned for the testing campaign. This included all instruments used during this testing project.

On-site calibrations
Pre- and post-test calibrations will be performed on the gaseous analyzer using NIST traceable calibration bottles. Dilution ratio was controlled and monitored with real time mass flow control. Hourly zero checks were performed with each of the real time PM instruments. Leak checks were performed for the total $PM_{2.5}$ system prior testing for each setup.

Post-test and data validation
Post-test evaluation includes verifying consistent dilution ratios between points, and verifying brake specific fuel consumption with reported manufacturer numbers. Typically this involves corresponding with the engine manufacturer to discuss the results on an emissions basis of interest. If the brake specific fuel consumption results are within reason this suggests that the load and mass of emissions measured are reasonable and representative. Thus, this suggests the data collected for the test article are accurate and representative of a properly functioning system.

CE-CERT
College of Engineering: Center for Environmental Research and Technology

Analytical Laboratory
University of California, Riverside
Data Results For TEFLON Filters

Project Name: Original AEP River Operations - Kentuck | **Project Fund #:**
PI/Contact: Wayne Miller | **Send Results: Nick Gysel**

Sample ID	**Serial ID**	Date Received	Initial Weight (mg/filter)	Final Weight (mg/filter)	**NET Weight (mg/filter)**	Initials	COMMENTS
AT120473	n/a	2/x/2013	191.2060	192.6972	1.4912	MV	
AT120474	n/a	2/x/2013	189.2139	191.2111	1.9972	MV	
AT120475	n/a	2/x/2013	194.4568	196.2289	1.7721	MV	
AT120476	n/a	2/x/2013	190.1723	191.7284	1.5561	MV	
AT120477	n/a	2/x/2013	153.2872	154.4464	1.1592	MV	
AT120478	n/a	2/x/2013	187.4435	188.9519	1.5084	MV	
AT120479	n/a	2/x/2013	182.9071	184.0064	1.0993	MV	
AT120481	n/a	2/x/2013	178.7453	179.3674	0.6221	MV	
AT120482	n/a	2/x/2013	165.5829	166.2499	0.6670	MV	

Figure B-1 Sample Chain of Custody Form

PRAXAIR.

Praxair Distribution, Inc.
5700 S. Alameda St.
Los Angeles, CA 90058
Tel: 323-585-2154
Fax: 714-542-6689

11/06/2012

UC RIVERSIDE
DIESEL LAB
1200 COLUMBIA AVE
RIVERSIDE, CA 925210000
Attention: LUCI PACOCHA 909-781-5791,

Work Order No. **21895565**
Customer Reference No.

Product Lot/Batch No. **109230503**
Product Part No. **NI CD12CNP18PAS**

CERTIFICATE OF ANALYSIS

Primary Standard

Component	Requested Concentration	Certified Concentration	Analytical Principle	Analytical Accuracy
Carbon dioxide	12 %	11.76 %	L	± 1%
Carbon monoxide	500 ppm	501 ppm	L	± 1%
Nitric oxide	2000 ppm	1929 ppm	U	± 1%
Propane	500 ppm	515 ppm	Q	± 1%
Nitrogen	balance	balance		

Analytical Instruments: **Horiba Instruments Inc.~VIA-510~NDIR~Non-dispersive Infrared**
Thermo Environmental~42i~Nitric Oxide Analyzer~Chemiluminescence
Horiba Instruments Inc.~FIA-510~THC- Total Hydrocarbon Analyzer~FID - Flame Ionization Detector

Cylinder Style:	AS	Filling Method:	Gravimetric
Cylinder Pressure @70F:	2000 psig	Date of Fill:	10/31/2012
Cylinder Volume:	140 ft3	Expiration Date:	11/06/2014
Valve Outlet Connection:	CGA-660		
Cylinder No(s).	CC92665		
Comments:	[NOx] = 1947 ppm for reference only. All values not valid below 150 psig.		

Chas Manning (CMC)

Analyst: **Chas Manning**

Nelson Ma

Approved Signer: **Nelson Ma**

Figure B-2 Sample Protocol Gas Analysis

Appendix C –Test Modes and Load Estimates

Test Cycles and Fuels for Different Engine Applications

Heavy duty engines for non-road use are made in a much wider range of power output and used in more applications than engines for on-road use. The objective of IS0 8178-4[4] is to provide the minimum number of test cycles by grouping applications with similar engine operating characteristics. ISO 8178-4 specifies the test cycles while measuring the gaseous and particulate exhaust emissions from reciprocating internal combustion engines coupled to a dynamometer or at the site. The tests are carried out under steady-state operation using test cycles which are representative of given applications.

Table C-1 Definitions Used Throughout ISO 8178-4

Test cycle	A sequence of engine test modes each with defined speed, torque and weighting factor, where the weighting factors only apply if the test results are expressed in g/kWh.
Preconditioning the engine	1) Warming the engine at the rated power to stabilize the engine parameters and protect the measurement against deposits in the exhaust system. 2) Period between test modes which has been included to minimize point-to-point influences.
Mode	An engine operating point characterized by a speed and a torque.
Mode length	The time between leaving the speed and/or torque of the previous mode or the preconditioning phase and the beginning of the following mode. It includes the time during which speed and/or torque are changed and the stabilization at the beginning of each mode.
Rated speed	Speed declared by engine manufacturer where the rated power is delivered.
Intermediate speed	Speed declared by the manufacturer, taking into account the requirements of ISO 8178-4 clause 6.

Intermediate speed

For engines designed to operate over a speed range on a full-load torque curve, the intermediate speed shall be the maximum torque speed if it occurs between 60% and 75% of rated speed. If the maximum torque speed is less than 60% of rated speed, then the intermediate speed shall be 60% of the rated speed. If the maximum torque speed is greater than 75% of the rated speed then the intermediate speed shall be 75% of rated speed.
The intermediate speed will typically be between 60% and 70% of the maximum rated speed for engines not designed to operate over a speed range on the full-load torque curve at steady state

[1]International Standards Organization, IS0 8178-4, *Reciprocating internal combustion engines - Exhaust emission measurement - Part 4: Test cycles for different engine applications,* First edition IS0 8178-4:1996(E)

conditions. Intermediate speeds for engines used to propel vessels with a fixed propeller are defined based on that application.

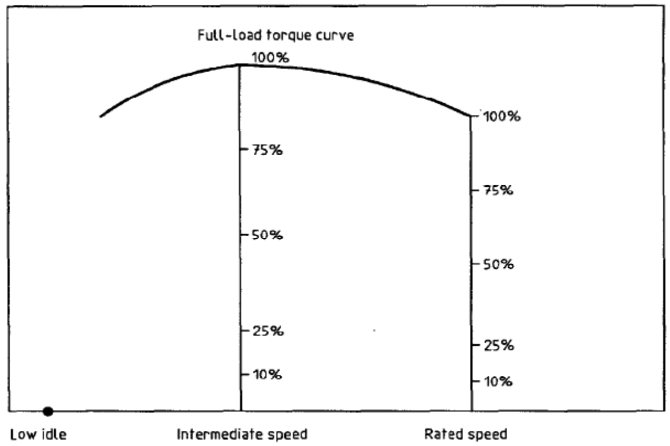


Figure C-1 Torque as a Function of Engine Speed

Engine Torque Curves and Test Cycles

The percentage of torque figures given in the test cycles and Figure C-1 represent the ratio of the required torque to the maximum possible torque at the test speed. For marine test cycle E3, the power figures are percentage values of the maximum rated power at the rated speed as this cycle is based on a theoretical propeller characteristic curve for vessels driven by heavy duty engines. For marine test cycle E4 the torque figures are percentage values of the torque at rated power based on the theoretical propeller characteristic curve representing typical pleasure craft spark ignited engine operation. For marine cycle E5 the power figures are percentage values of the maximum rated power at the rated speed based on a theoretical propeller curve for vessels of less than 24 m in length driven by diesel engines. Figure C-2 shows the two representative curves.

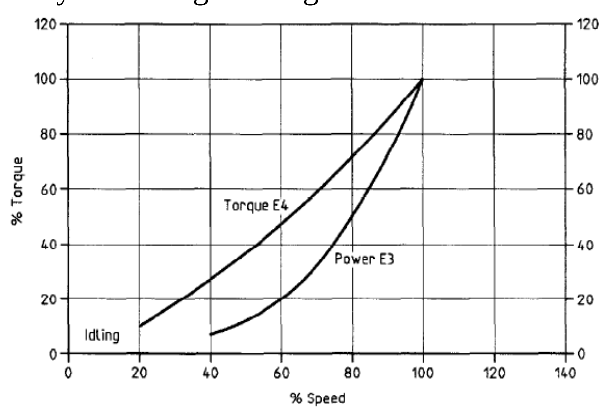


Figure C-2 Examples of Power Scales

Modes and Weighting Factors for Test Cycles

Most test cycles are derived from the 13-mode steady state test cycle (UN-ECE R49). Apart from the test modes of cycles E3, E4 and E5, which are calculated from propeller curves, the test modes of the other cycles can be combined into a universal cycle (B) with emissions values calculated using the appropriate weighting factors. Each test shall be performed in the given sequence with a minimum test mode length of 5 minutes or enough to collect sufficient particulate sample mass. The mode length shall be recorded and reported and the gaseous exhaust emission concentration values shall be measured and recorded for the last 3 min of the mode.

Table C-2 Combined Table of Modes and Weighting Factors

B-Type mode number	1	2	3	4	5	6	7	8	9	10	11
Torque	100	75	50	25	10	100	75	50	25	10	0
Speed	Rated speed					Intermediate speed					Low idle
Off-road vehicles											
Cycle C1	0,15	0,15	0,15		0,1	0,1	0,1	0,1			0,15
Cycle C2				0,06		0,02	0,05	0,32	0,3	0,1	0,15
Constant speed											
Cycle D1	0,3	0,5	0,2								
Cycle D2	0,05	0,25	0,3	0,3	0,1						
Locomotives											
Cycle F	0,25							0,15			0,6
Utility, lawn and garden											
Cycle G1						0,09	0,2	0,29	0,3	0,07	0,05
Cycle G2	0,09	0,2	0,29	0,3	0,07						0,05
Cycle G3	0,9										0,1
Marine application											
Cycle E1	0,08	0,11					0,19	0,32			0,3
Cycle E2	0,2	0,5	0,15	0,15							

Marine application propeller law					
Mode number E3	**1**	**2**	**3**	**4**	
Power (%)	100	75	50	25	
Speed (%)	100	91	80	63	
Weighting factor	0,2	0,5	0,15	0,15	
Mode number E4	**1**	**2**	**3**	**4**	**5**
Speed (%)	100	80	60	40	Idle
Torque (%)	100	71,6	46,5	25,3	0
Weighting factor	0,06	0,14	0,15	0,25	0,4
Mode number E5	**1**	**2**	**3**	**4**	**5**
Power (%)	100	75	50	25	0
Speed (%)	100	91	80	63	Idle
Weighting factor	0,08	0,13	0,17	0,32	0,3

Cycle C1 (also known as the Non-Road Steady Cycle NRSC) and C2 are typically used for off-road vehicles and industrial equipment such as yard tractors and air compressors (C1 for diesel and C2 for spark ignition). D1 and D2 are used for constant speed engines such as generators (marine or land based) and power plants. D1 is for power plants and irrigation pumps, but D2 is for generators and other. The D2 cycle is typically used for marine auxiliary electrical generation. The “E” cycles are for marine application. E1 and E5 are for diesel engines craft less than 24 meters, E2 is for constant speed propulsion (variable prop applications), E3 is for large marine direct drive engines.

Test Fuels

Fuel characteristics influence engine emissions so ISO 8178-1 provides guidance on the characteristics of the test fuel. Where fuels designated as reference fuels in IS0 8178-5 are used, the reference code and the analysis of the fuel shall be provided. For all other fuels the characteristics to be recorded are those listed in the appropriate universal data sheets in IS0 8178-5. The fuel temperature shall be in accordance with the manufacturer's recommendations. The fuel temperature shall be measured at the inlet to the fuel injection pump or as specified by the manufacturer, and the location of measurement recorded. The selection of the fuel for the test depends on the purpose of the test. Unless otherwise agreed by the parties the fuel shall be selected in accordance with Table C-3

Table C-3 Test Fuels

Test purpose	Interested parties	Fuel selection
Type approval (Certification)	1. Certification body 2. Manufacturer or supplier	Reference fuel, if one is defined Commercial fuel if no reference fuel is defined
Acceptance test	1. Manufacturer or supplier 2. Customer or inspector	Commercial fuel as specified by the manufacturer[1)]
Research/development	One or more of: manufacturer, research organization, fuel and lubricant supplier, etc.	To suit the purpose of the test

1) Customers and inspectors should note that the emission tests carried out using commercial fuel will not necessarily comply with limits specified when using reference fuels.

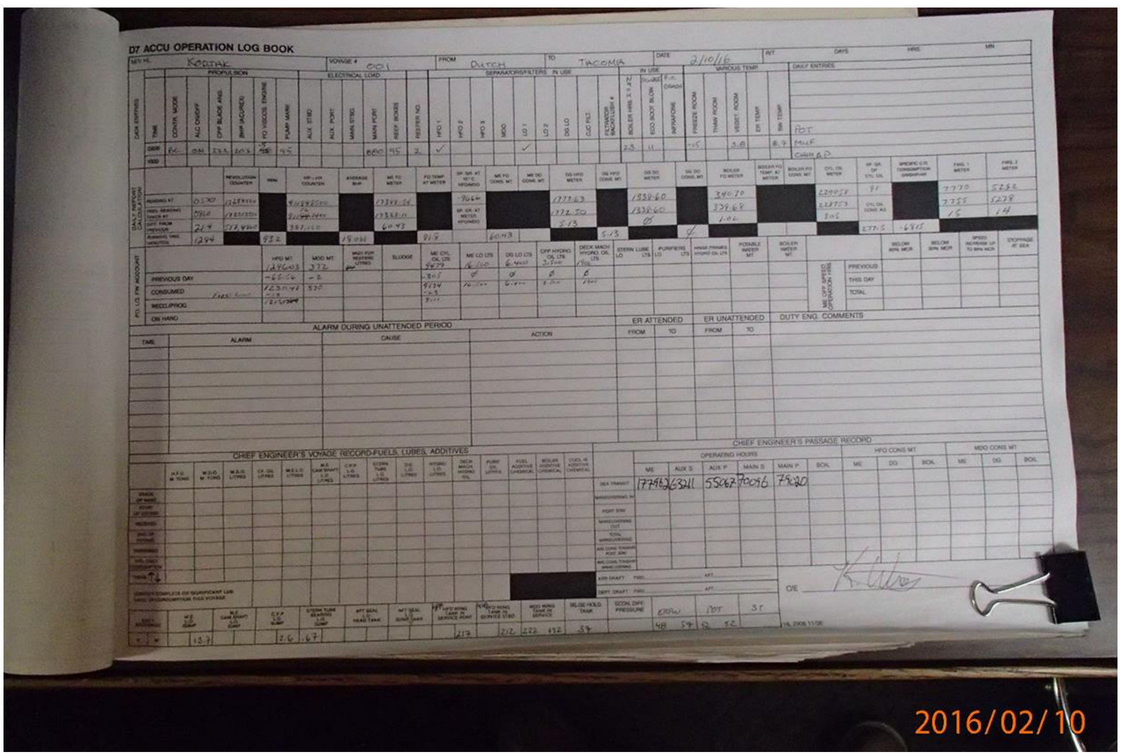
When a suitable reference fuel is not available, a fuel with properties very close to the reference fuel may be used. The characteristics of the fuel shall be declared.

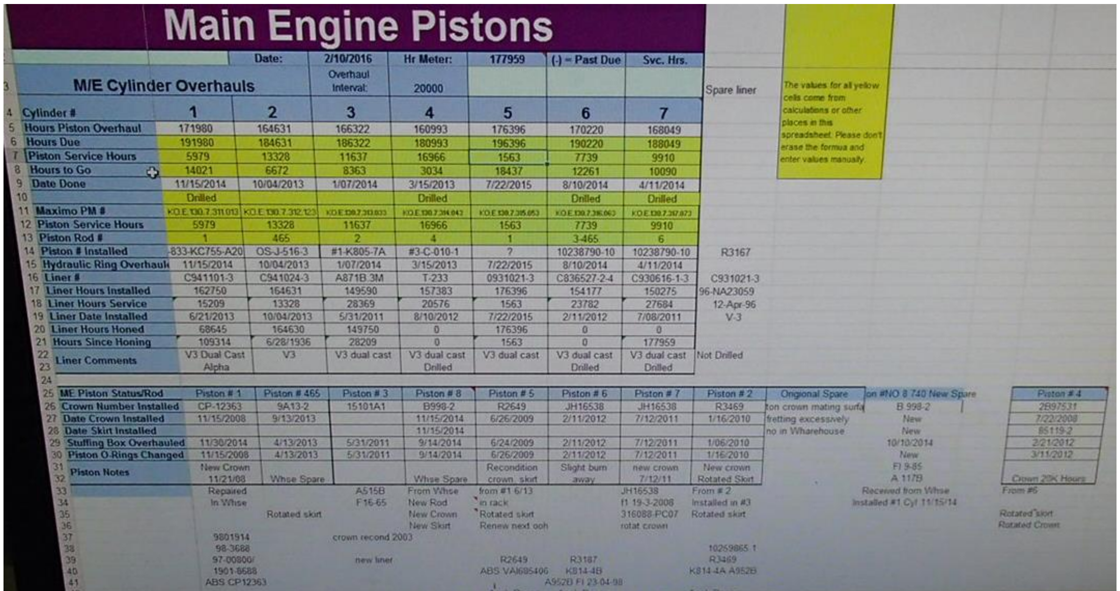
Appendix D –Vessel and Engine Specifics

This Appendix includes details for three important records 1) Maintenance Records, 2) Fuel Certificate, 3) and Engine Load Screen Shots. These records were recorded during testing using a photo logging system. The photo logging system records test point data by capturing an image at the start, middle, and end of a load points. Since real time data collection isn't always possible and is complex to integrate with emissions results, UCR has adopted a photo logging system to capture all important temperatures, loads, fuel rates, and other important engine details during testing. This appendix describes basic records for the vessel and a sample of the photo logs utilized for each test load point.

1: Engine Maintenance Records

These records were collected only once during vessel testing to document the status of the ME and both MGs utilized for the emissions testing. The log book contained the current total recoded generator hours and the screen shows the individual maintenance specific records and plans for repairs.



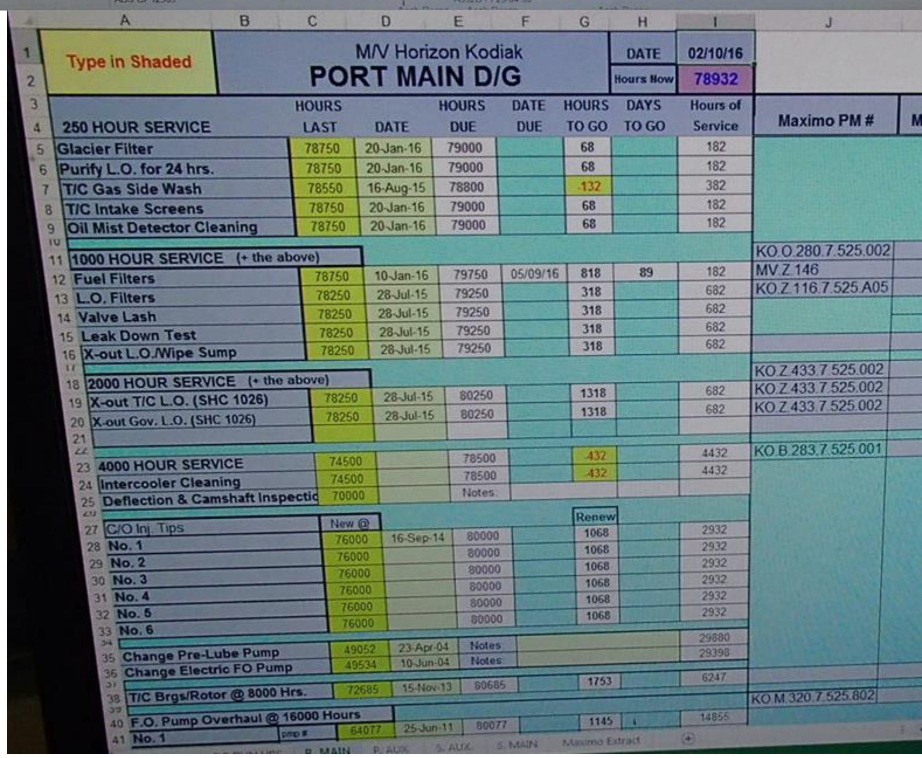


Main Engine Pistons

M/E Cylinder Overhauls	Date: 2/10/2016	Hr Meter: 177959	(-) = Past Due	Svc. Hrs.				
	Overhaul Interval: 20000							Spare liner
Cylinder #	1	2	3	4	5	6	7	
Hours Piston Overhaul	171980	164631	166322	160993	176396	170220	168049	
Hours Due	191980	184631	186322	180993	196396	190220	188049	
Piston Service Hours	5979	13328	11637	16966	1563	7739	9910	
Hours to Go	14021	6672	8363	3034	18437	12261	10090	
Date Done	11/15/2014	10/04/2013	1/07/2014	3/15/2013	7/22/2015	8/10/2014	4/11/2014	
	Drilled			Drilled		Drilled	Drilled	
Maximo PM #	KO.E.130.7.311.013	KO.E.130.7.312.123	KO.E.130.7.313.033	KO.E.130.7.314.043	KO.E.130.7.315.053	KO.E.130.7.316.063	KO.E.130.7.317.073	
Piston Service Hours	5979	13328	11637	16966	1563	7739	9910	
Piston Rod #	1	465	2	4	1	3-465	6	
Piston # Installed	833-KC755-A20	OS-J-516-3	#1-K805-7A	#3-C-010-1	?	10238790-10	10238790-10	R3167
Hydraulic Ring Overhaul	11/15/2014	10/04/2013	1/07/2014	3/15/2013	7/22/2015	8/10/2014	4/11/2014	
Liner #	C941101-3	C941024-3	A871B.3M	T-233	0931021-3	C836527-2-4	C930616-1-3	C931021-3
Liner Hours Installed	162750	164631	149590	157383	176396	154177	150275	96-NA23059
Liner Hours Service	15209	13328	28369	20576	1563	23782	27684	12-Apr-96
Liner Date Installed	6/21/2013	10/04/2013	5/31/2011	8/10/2012	7/22/2015	2/11/2012	7/08/2011	V-3
Liner Hours Honed	68645	164630	149750	0	176396	0	0	
Hours Since Honing	109314	6/28/1936	28209	0	1563	0	177959	
Liner Comments	V3 Dual Cast Alpha	V3	V3 dual cast	V3 dual cast Drilled	V3 dual cast	V3 dual cast Drilled	V3 dual cast Drilled	Not Drilled

The values for all yellow cells come from calculations or other places in this spreadsheet. Please don't erase the formua and enter values manually.

ME Piston Status/Rod	Piston # 1	Piston # 465	Piston # 3	Piston # 8	Piston # 5	Piston # 6	Piston # 7	Piston # 2	Origional Spare	on #NO 8 740 New Spare	Piston # 4
Crown Number Installed	CP-12363	9A13-2	15101A1	B998-2	R2649	JH16538	JH16538	R3469	ton crown mating surfa	B 998-2	2B97531
Date Crown Installed	11/15/2008	9/13/2013		11/15/2014	6/26/2009	2/11/2012	7/12/2011	1/16/2010	fretting excessively	New	7/22/2008
Date Skirt Installed				11/15/2014					no in Wharehouse	New	85119-2
Stuffing Box Overhauled	11/30/2014	4/13/2013	5/31/2011	9/14/2014	6/24/2009	2/11/2012	7/12/2011	1/06/2010		10/10/2014	2/21/2012
Piston O-Rings Changed	11/15/2008	4/13/2013	5/31/2011	9/14/2014	6/26/2009	2/11/2012	7/12/2011	1/16/2010		New	3/11/2012
Piston Notes	New Crown 11/21/08	Whse Spare		Whse Spare	Recondition crown, skirt	Slight burn away	new crown 7/12/11	New crown Rotated Skirt		FI 9-85 A 117B	Crown 20K Hours
	Repaired		A515B	From Whse	from #1 6/13		JH16538	From # 2		Received from Whse	From #6
	In Whse		F16-65	New Rod	in rack		f1 19-3-2008	Installed in #3		Installed #1 Cyl 11/15/14	
		Rotated skirt		New Crown	Rotated skirt		316088-PC07	Rotated skirt			Rotated skirt
				New Skirt	Renew next ooh		rotat crown				Rotated Crown
	9801914		crown recond 2003								
	98-3688							10259865 1			
	97-00800/		new liner		R2649	R3187		R3469			
	1901-8688				ABS VAI685406	K814-4B		K814-4A A952B			
	ABS CP12363					A952B FI 23-04-98					



M/V Horizon Kodiak PORT MAIN D/G

Type in Shaded

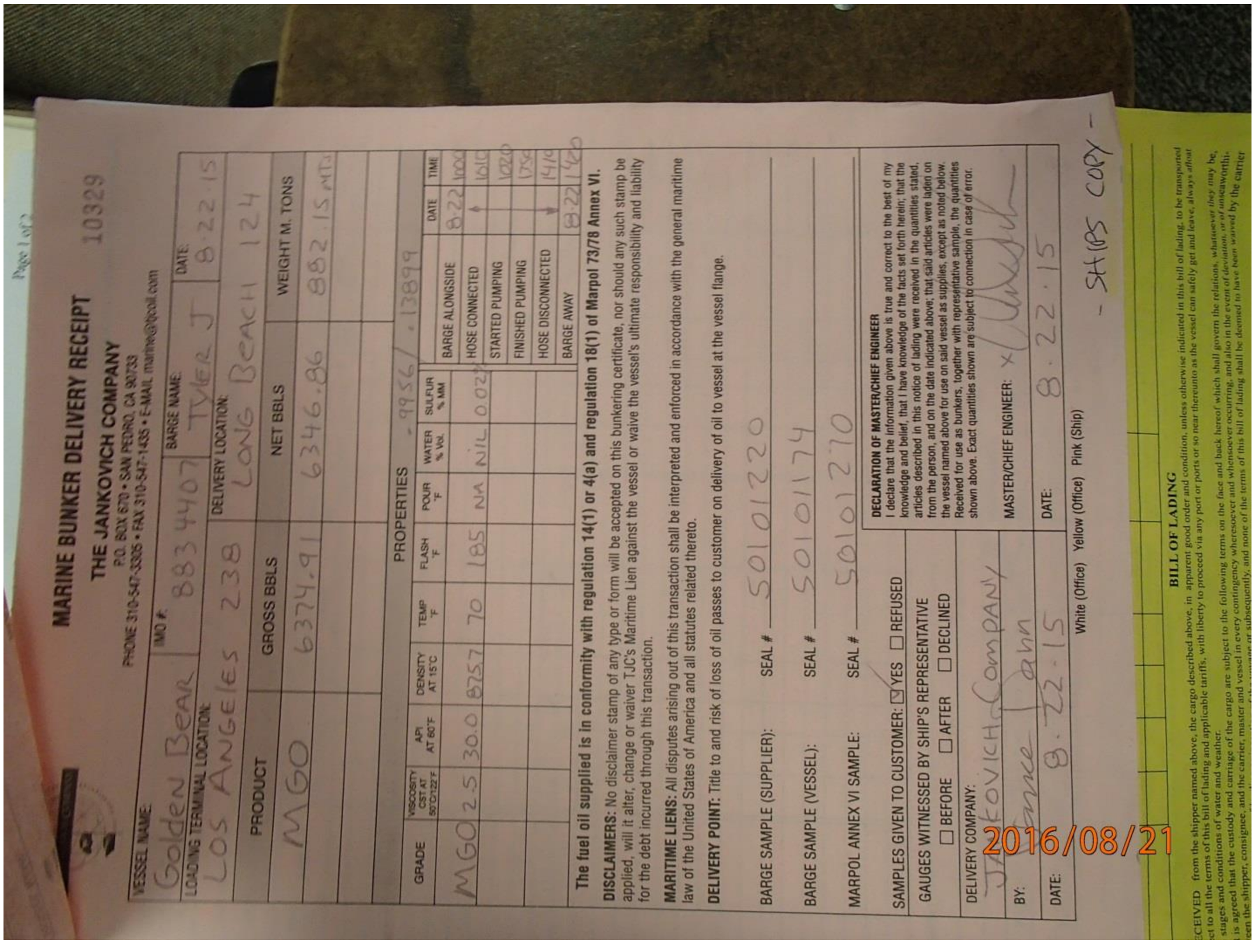
DATE 02/10/16 | Hours Now 78932

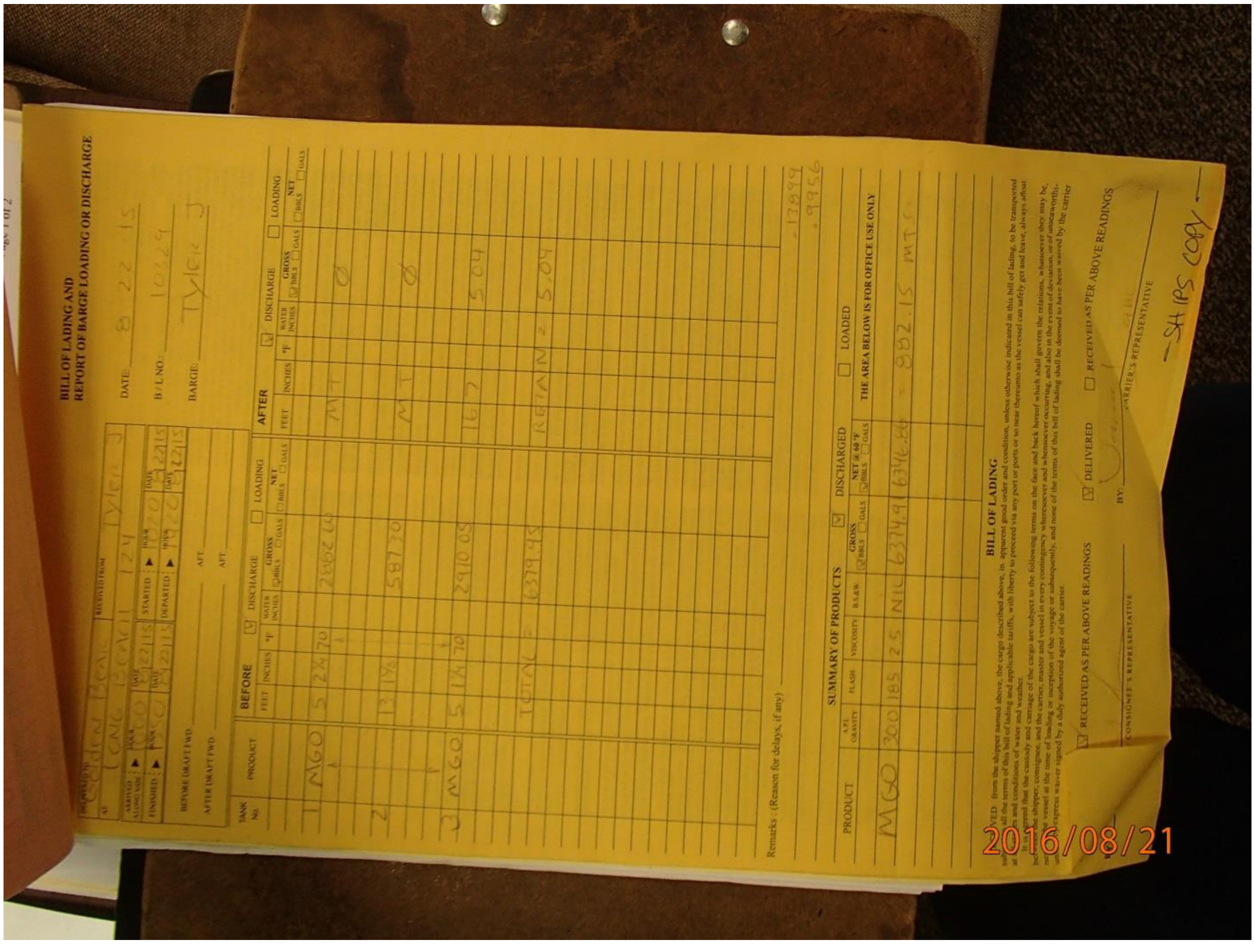
250 HOUR SERVICE	HOURS LAST	DATE	HOURS DUE	DATE DUE	HOURS TO GO	DAYS TO GO	Hours of Service	Maximo PM #
Glacier Filter	78750	20-Jan-16	79000		68		182	
Purify L.O. for 24 hrs.	78750	20-Jan-16	79000		68		182	
T/C Gas Side Wash	78550	16-Aug-15	78800		-132		382	
T/C Intake Screens	78750	20-Jan-16	79000		68		182	
Oil Mist Detector Cleaning	78750	20-Jan-16	79000		68		182	
1000 HOUR SERVICE (+ the above)								KO.O.280.7.525.002
Fuel Filters	78750	10-Jan-16	79750	05/09/16	818	89	182	MV.Z.146
L.O. Filters	78250	28-Jul-15	79250		318		682	KO.Z.116.7.525.A05
Valve Lash	78250	28-Jul-15	79250		318		682	
Leak Down Test	78250	28-Jul-15	79250		318		682	
X-out L.O./Wipe Sump	78250	28-Jul-15	79250		318		682	
								KO.Z.433.7.525.002
2000 HOUR SERVICE (+ the above)								KO.Z.433.7.525.002
X-out T/C L.O. (SHC 1026)	78250	28-Jul-15	80250		1318		682	KO.Z.433.7.525.002
X-out Gov. L.O. (SHC 1026)	78250	28-Jul-15	80250		1318		682	
							4432	KO.B.283.7.525.001
4000 HOUR SERVICE	74500		78500		-432		4432	
Intercooler Cleaning	74500		78500		-432			
Deflection & Camshaft Inspectic	70000		Notes:					
C/O Inj. Tips	New @				Renew		2932	
No. 1	76000	16-Sep-14	80000		1068		2932	
No. 2	76000		80000		1068		2932	
No. 3	76000		80000		1068		2932	
No. 4	76000		80000		1068		2932	
No. 5	76000		80000		1068		2932	
No. 6	76000		80000		1068			
							29880	
Change Pre-Lube Pump	49052	23-Apr-04	Notes:				29398	
Change Electric FO Pump	49534	10-Jun-04	Notes:					
					1753		6247	
T/C Brgs/Rotor @ 8000 Hrs.	72685	15-Nov-13	80685					KO.M.320.7.525.802
F.O. Pump Overhaul @ 16000 Hours					1145		14855	
No. 1 (pmp #)	64077	25-Jun-11	80077					

2. Fuel Certificates

An attempt was made to collect a fuel sample, but due to logistical constraints no sample was collected during testing. The bunker reports for vessels are typically accurate and were used in this study. Two reports were collected and showed a consistent fuel sulfur level of 1.88 and 1.89 % sulfur.

The vessel as tested used Mobilgard 300 for the ME cylinder oil and Mobilgard 560 for the ME system and camshaft oil. Only a ME cylinder oil sample was collected, but this sample was not analyzed because the emission results did not suggest that there was extensive lube-oil exhaust contamination.




BILL OF LADING AND
REPORT OF BARGE LOADING OR DISCHARGE

DATE: 8 22 15
B / L NO.: 10229
BARGE: Tyler J

DELIVERED TO: Golden Bear
AT: Long Beach 124
RECEIVED FROM: Tyler J

ARRIVED ALONGSIDE	HOUR 1700	DATE 8 22 15	STARTED	HOUR 1720	DATE 8 22 15
FINISHED	HOUR 1900	DATE 8 22 15	DEPARTED	HOUR 1920	DATE 8 22 15

BEFORE DRAFT FWD. ______ AFT. ______
AFTER DRAFT FWD. ______ AFT. ______

TANK No.	PRODUCT	BEFORE FEET	BEFORE INCHES	°F	WATER INCHES	GROSS BBLS	AFTER FEET	AFTER INCHES	°F	WATER INCHES	GROSS BBLS
1	MGO	5	2 3/4	70		2882.60	MT				Ø
2			13 1/8			587.30	MT				Ø
3	MGO	5	1 3/4	70		2910.05	1	6 7			5.04
		TOTAL =				6379.95	RETAIN =				5.04

Remarks: (Reason for delays, if any) .13999 .9956

SUMMARY OF PRODUCTS ☒ DISCHARGED ☐ LOADED

PRODUCT	A.P.I. GRAVITY	FLASH	VISCOSITY	B.S.&W.	GROSS BBLS	NET @ 60°F BBLS	THE AREA BELOW IS FOR OFFICE USE ONLY
MGO	30.0	185	2.5	NIL	6374.9	6346.86	= 882.15 MT

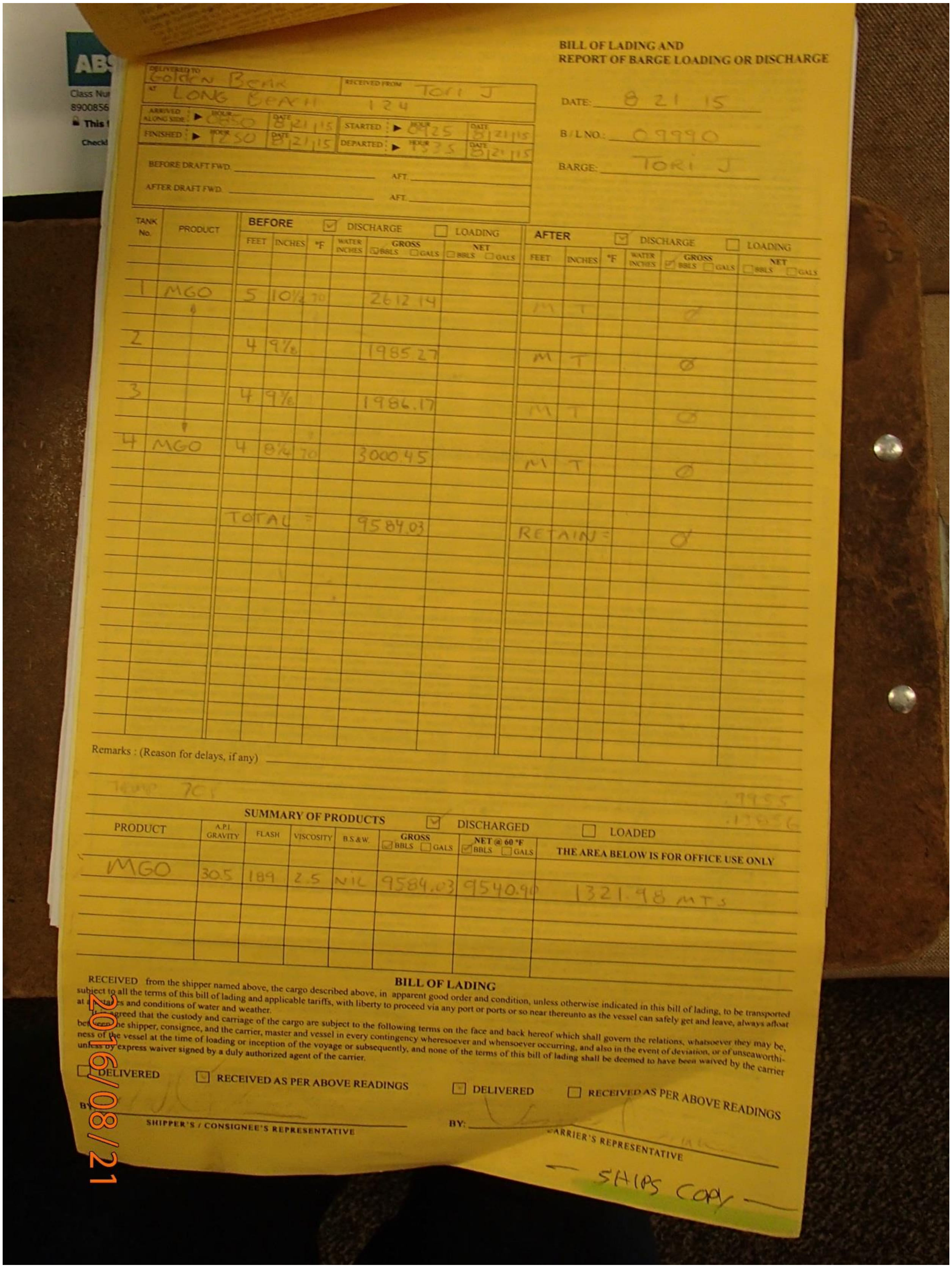
BILL OF LADING

☒ RECEIVED AS PER ABOVE READINGS ☒ DELIVERED ☐ RECEIVED AS PER ABOVE READINGS

CONSIGNEE'S REPRESENTATIVE BY: CARRIER'S REPRESENTATIVE

—SHIPS COPY

2016/08/21



BILL OF LADING AND REPORT OF BARGE LOADING OR DISCHARGE

DELIVERED TO: Golden Bear
AT: Long Beach
RECEIVED FROM: Tori J
124

ARRIVED ALONG SIDE: HOUR 0550 DATE 8/21/15
STARTED: HOUR 0825 DATE 8/21/15
FINISHED: HOUR 1250 DATE 8/21/15
DEPARTED: HOUR 1335 DATE 8/21/15

BEFORE DRAFT FWD. ______ AFT. ______
AFTER DRAFT FWD. ______ AFT. ______

DATE: 8 21 15
B/L NO.: 09990
BARGE: Tori J

TANK No.	PRODUCT	BEFORE FEET	INCHES	°F	WATER INCHES	GROSS BBLS	NET	AFTER FEET	INCHES	°F	WATER INCHES	GROSS BBLS	NET
1	MGO	5	10¼	70		2612.14		M	T			Ø	
2		4	9⅞			1985.27		M	T			Ø	
3		4	9⅞			1986.17		M	T			Ø	
4	MGO	4	8¾	70		3000.45		M	T			Ø	
		TOTAL =				9584.03		RETAIN =				Ø	

Remarks: (Reason for delays, if any)
Temp 70 F

SUMMARY OF PRODUCTS ☑ DISCHARGED ☐ LOADED

PRODUCT	A.P.I. GRAVITY	FLASH	VISCOSITY	B.S.&W.	GROSS BBLS	NET @ 60 °F BBLS	THE AREA BELOW IS FOR OFFICE USE ONLY
MGO	30.5	189	2.5	NIL	9584.03	9540.91	1321.98 MTs

BILL OF LADING

RECEIVED from the shipper named above, the cargo described above, in apparent good order and condition, unless otherwise indicated in this bill of lading, to be transported subject to all the terms of this bill of lading and applicable tariffs, with liberty to proceed via any port or ports or so near thereunto as the vessel can safely get and leave, always afloat at all states and conditions of water and weather.

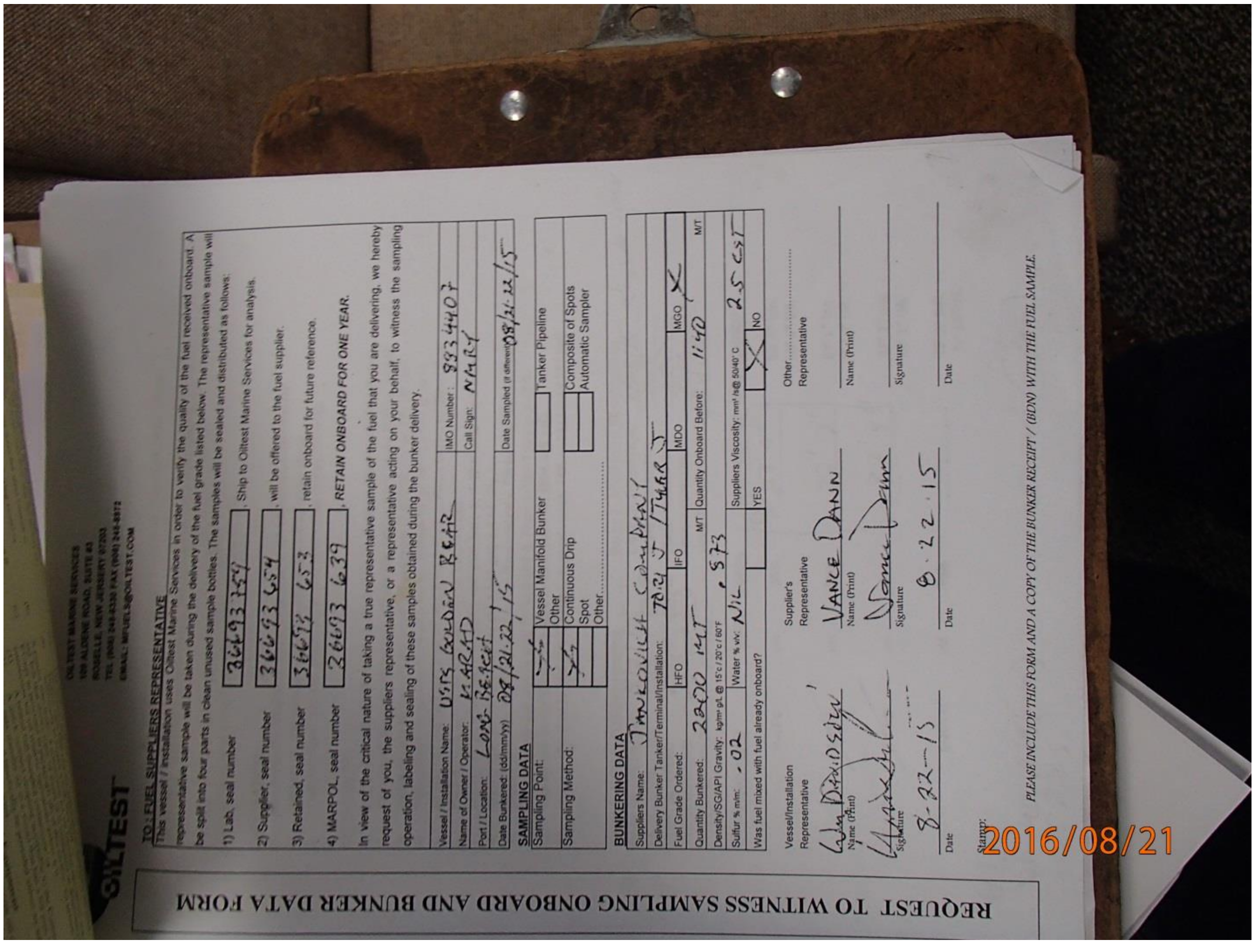
It is agreed that the custody and carriage of the cargo are subject to the following terms on the face and back hereof which shall govern the relations, whatsoever they may be, between the shipper, consignee, and the carrier, master and vessel in every contingency wheresoever and whensoever occurring, and also in the event of deviation, or of unseaworthiness of the vessel at the time of loading or inception of the voyage or subsequently, and none of the terms of this bill of lading shall be deemed to have been waived by the carrier unless by express waiver signed by a duly authorized agent of the carrier.

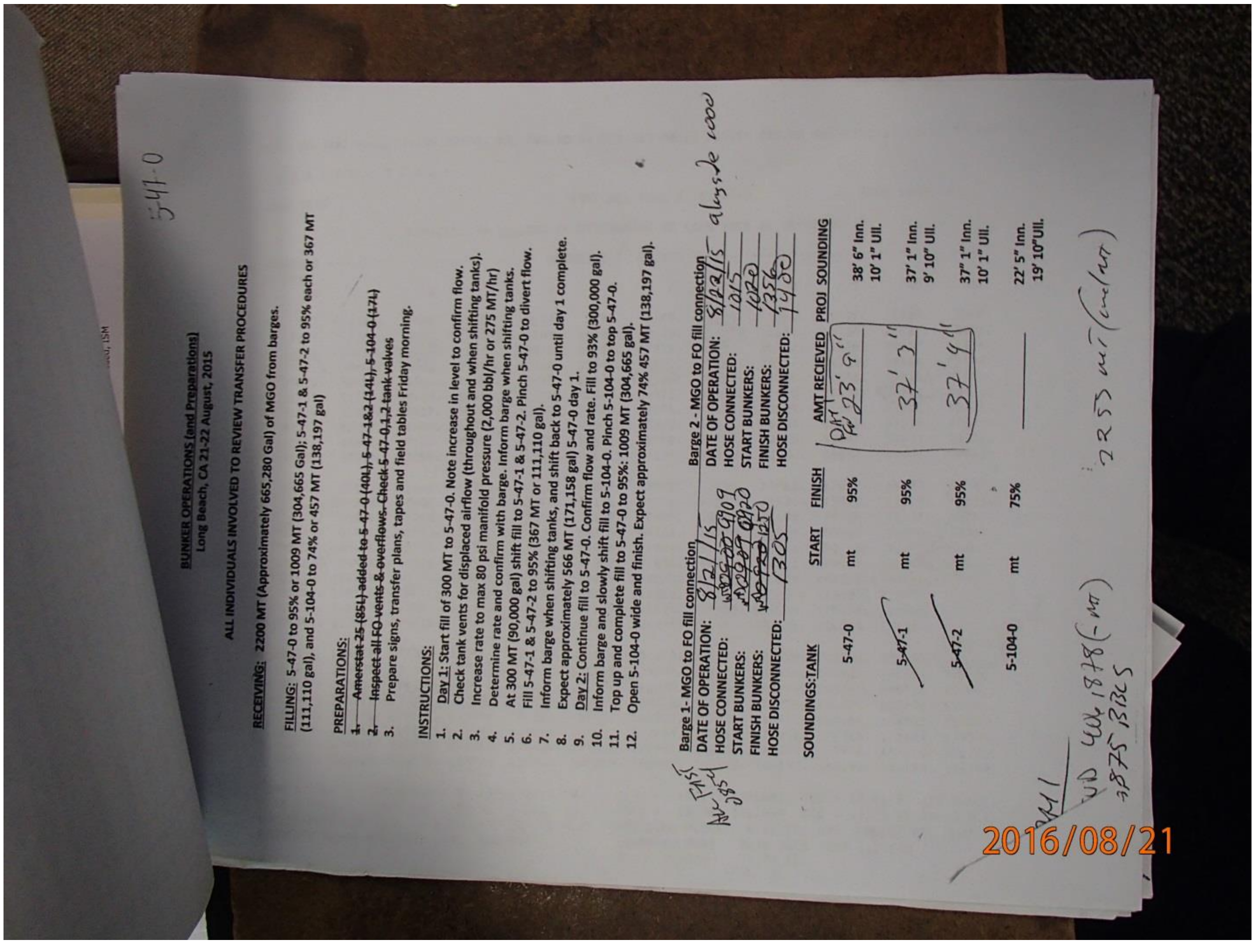
☐ DELIVERED ☑ RECEIVED AS PER ABOVE READINGS ☑ DELIVERED ☐ RECEIVED AS PER ABOVE READINGS

BY: ______ SHIPPER'S / CONSIGNEE'S REPRESENTATIVE BY: ______ CARRIER'S REPRESENTATIVE

SHIPS COPY

2016/08/21


REQUEST TO WITNESS SAMPLING ONBOARD AND BUNKER DATA FORM
OILTEST
OILTEST MARINE SERVICES
109 ALDENE ROAD, SUITE #3
ROSELLE, NEW JERSEY 07203
TEL (908) 245-6330 FAX (908) 245-8972
EMAIL: MFUELS@OILTEST.COM
TO : FUEL SUPPLIERS REPRESENTATIVE
This vessel / installation uses Oiltest Marine Services in order to verify the quality of the fuel received onboard. A representative sample will be taken during the delivery of the fuel grade listed below. The representative sample will be split into four parts in clean unused sample bottles. The samples will be sealed and distributed as follows:
1) Lab, seal number 36693759 , Ship to Oiltest Marine Services for analysis.
2) Supplier, seal number 36693654 , will be offered to the fuel supplier.
3) Retained, seal number 36693 653 , retain onboard for future reference.
4) MARPOL, seal number 26693 639 , RETAIN ONBOARD FOR ONE YEAR.
In view of the critical nature of taking a true representative sample of the fuel that you are delivering, we hereby request of you, the suppliers representative, or a representative acting on your behalf, to witness the sampling operation, labeling and sealing of these samples obtained during the bunker delivery.
Vessel / Installation Name: USTS GOLDEN BEAR
IMO Number: 8934407
Name of Owner / Operator: MARAD
Call Sign: NMRY
Port / Location: LONG BEACH
Date Bunkered: (dd/mm/yy) 08/21-22/15
Date Sampled (if different) 08/21-22/15
SAMPLING DATA
Sampling Point:
Vessel Manifold Bunker
Other
Tanker Pipeline
Sampling Method:
Continuous Drip
Spot
Other
Composite of Spots
Automatic Sampler
BUNKERING DATA
Suppliers Name: JANKOVICH COMPANY
Delivery Bunker Tanker/Terminal/Installation: TORI J / TYLER J
Fuel Grade Ordered: HFO IFO MDO MGO X
Quantity Bunkered: 2200 MT M/T
Quantity Onboard Before: 1140 M/T
Density/SG/API Gravity: kg/m³ g/L @ 15°c / 20°c / 60°F .873
Sulfur % m/m: .02
Water % v/v: NIL
Suppliers Viscosity: mm²/s@ 50/40° C 2.5 CST
Was fuel mixed with fuel already onboard? YES X NO
Vessel/Installation Representative
Supplier's Representative
Other Representative
VANCE DANN
Name (Print)
Signature
8-22-15
8.22.15
Date
Stamp:
PLEASE INCLUDE THIS FORM AND A COPY OF THE BUNKER RECEIPT / (BDN) WITH THE FUEL SAMPLE.
2016/08/21



5-47-0

BUNKER OPERATIONS (and Preparations)
Long Beach, CA 21-22 August, 2015

ALL INDIVIDUALS INVOLVED TO REVIEW TRANSFER PROCEDURES

RECEIVING: 2200 MT (Approximately 665,280 Gal) of MGO from barges.

FILLING: 5-47-0 to 95% or 1009 MT (304,665 Gal); 5-47-1 & 5-47-2 to 95% each or 367 MT (111,110 gal), and 5-104-0 to 74% or 457 MT (138,197 gal)

PREPARATIONS:

1. ~~Amerstat 25 (85L) added to 5-47-0 (40L), 5-47-1&2 (14L), 5-104-0 (17L)~~
2. ~~Inspect all FO vents & overflows. Check 5-47-0,1,2 tank valves~~
3. Prepare signs, transfer plans, tapes and field tables Friday morning.

INSTRUCTIONS:

1. Day 1: Start fill of 300 MT to 5-47-0. Note increase in level to confirm flow.
2. Check tank vents for displaced airflow (throughout and when shifting tanks).
3. Increase rate to max 80 psi manifold pressure (2,000 bbl/hr or 275 MT/hr)
4. Determine rate and confirm with barge. Inform barge when shifting tanks.
5. At 300 MT (90,000 gal) shift fill to 5-47-1 & 5-47-2. Pinch 5-47-0 to divert flow.
6. Fill 5-47-1 & 5-47-2 to 95% (367 MT or 111,110 gal).
7. Inform barge when shifting tanks, and shift back to 5-47-0 until day 1 complete.
8. Expect approximately 566 MT (171,158 gal) 5-47-0 day 1.
9. Day 2: Continue fill to 5-47-0. Confirm flow and rate. Fill to 93% (300,000 gal).
10. Inform barge and slowly shift fill to 5-104-0. Pinch 5-104-0 to top 5-47-0.
11. Top up and complete fill to 5-47-0 to 95%: 1009 MT (304,665 gal).
12. Open 5-104-0 wide and finish. Expect approximately 74% 457 MT (138,197 gal).

All FAST 2854

Barge 1- MGO to FO fill connection		Barge 2 - MGO to FO fill connection	
DATE OF OPERATION:	8/21/15	DATE OF OPERATION:	8/22/15 alongside 1000
HOSE CONNECTED:	~~0900~~ 0909	HOSE CONNECTED:	1015
START BUNKERS:	~~0929~~ 0920	START BUNKERS:	1020
FINISH BUNKERS:	~~1220~~ 1250	FINISH BUNKERS:	1356
HOSE DISCONNECTED:	1305	HOSE DISCONNECTED:	1400

SOUNDINGS:TANK	START	FINISH	AMT RECIEVED	PROJ SOUNDING
5-47-0	mt	95%	DAY 1 23' 9"	38' 6" Inn. 10' 1" Ull.
~~5-47-1~~	mt	95%	37' 3"	37' 1" Inn. 9' 10" Ull.
~~5-47-2~~	mt	95%	37' 4"	37" 1" Inn. 10' 1" Ull.
5-104-0	mt	75%		22' 5" Inn. 19' 10"Ull.

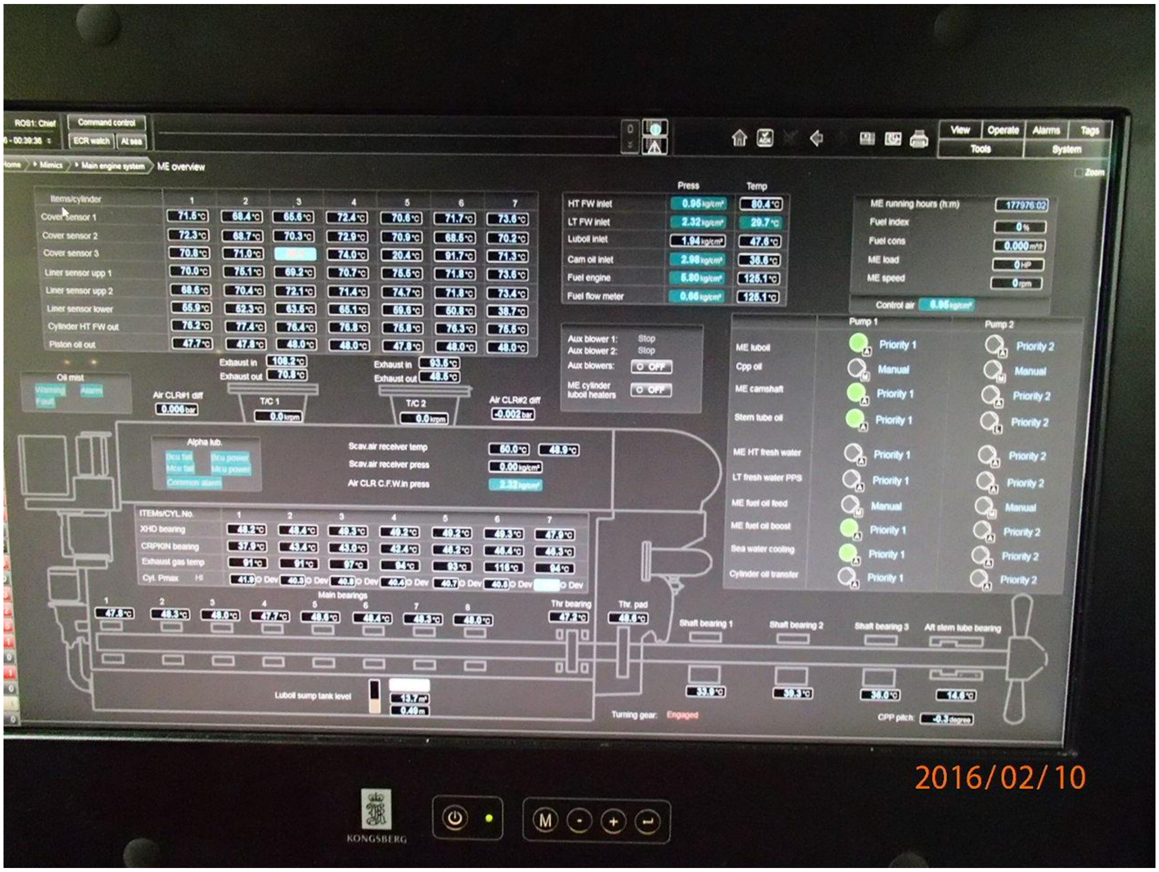
DAY 1
UD 406 1878 (-MT)
3875 BBLS

2253 MT (end MT)

2016/08/21

3. Engine Screen Shot

Engine load for the ME and AE will be collected from screen shot information during testing. Each load test point will capture up to 3 screen shots to quantify stability of readings. More readings will be captured if the load is not stable.



4. Alternator for the AE

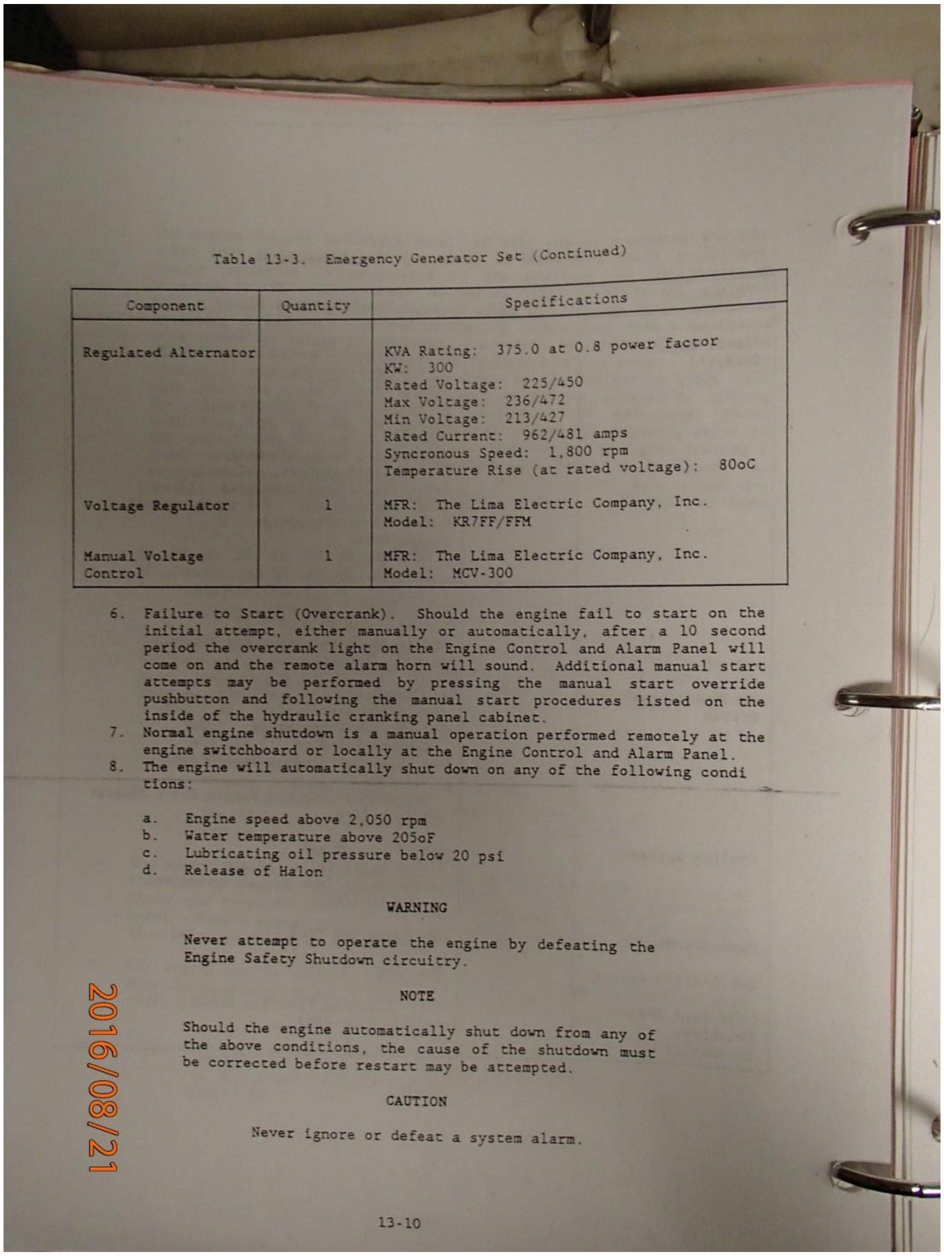


Table 13-3. Emergency Generator Set (Continued)

Component	Quantity	Specifications
Regulated Alternator		KVA Rating: 375.0 at 0.8 power factor KW: 300 Rated Voltage: 225/450 Max Voltage: 236/472 Min Voltage: 213/427 Rated Current: 962/481 amps Syncronous Speed: 1,800 rpm Temperature Rise (at rated voltage): 80oC
Voltage Regulator	1	MFR: The Lima Electric Company, Inc. Model: KR7FF/FFM
Manual Voltage Control	1	MFR: The Lima Electric Company, Inc. Model: MCV-300

6. Failure to Start (Overcrank). Should the engine fail to start on the initial attempt, either manually or automatically, after a 10 second period the overcrank light on the Engine Control and Alarm Panel will come on and the remote alarm horn will sound. Additional manual start attempts may be performed by pressing the manual start override pushbutton and following the manual start procedures listed on the inside of the hydraulic cranking panel cabinet.
7. Normal engine shutdown is a manual operation performed remotely at the engine switchboard or locally at the Engine Control and Alarm Panel.
8. The engine will automatically shut down on any of the following condi tions:

   a. Engine speed above 2,050 rpm
   b. Water temperature above 205oF
   c. Lubricating oil pressure below 20 psi
   d. Release of Halon

WARNING

Never attempt to operate the engine by defeating the Engine Safety Shutdown circuitry.

NOTE

Should the engine automatically shut down from any of the above conditions, the cause of the shutdown must be corrected before restart may be attempted.

CAUTION

Never ignore or defeat a system alarm.

13-10

Appendix E –Test Logs and Records

This appendix present the engine related results collected during the testing and the reference shop trials for the engine. The engine percent load for each mode are presented in Table E-1, the actual loads and calculated exhaust flow are listed in Table E-2, and the shop trial from the ship maker is presented in Figure E-1.

SUMMARY DATA OF SHOP TRIAL

REMARKS

APPROVED	[illegible]
CHECKED	[illegible]
DRAWN	[illegible] Saito

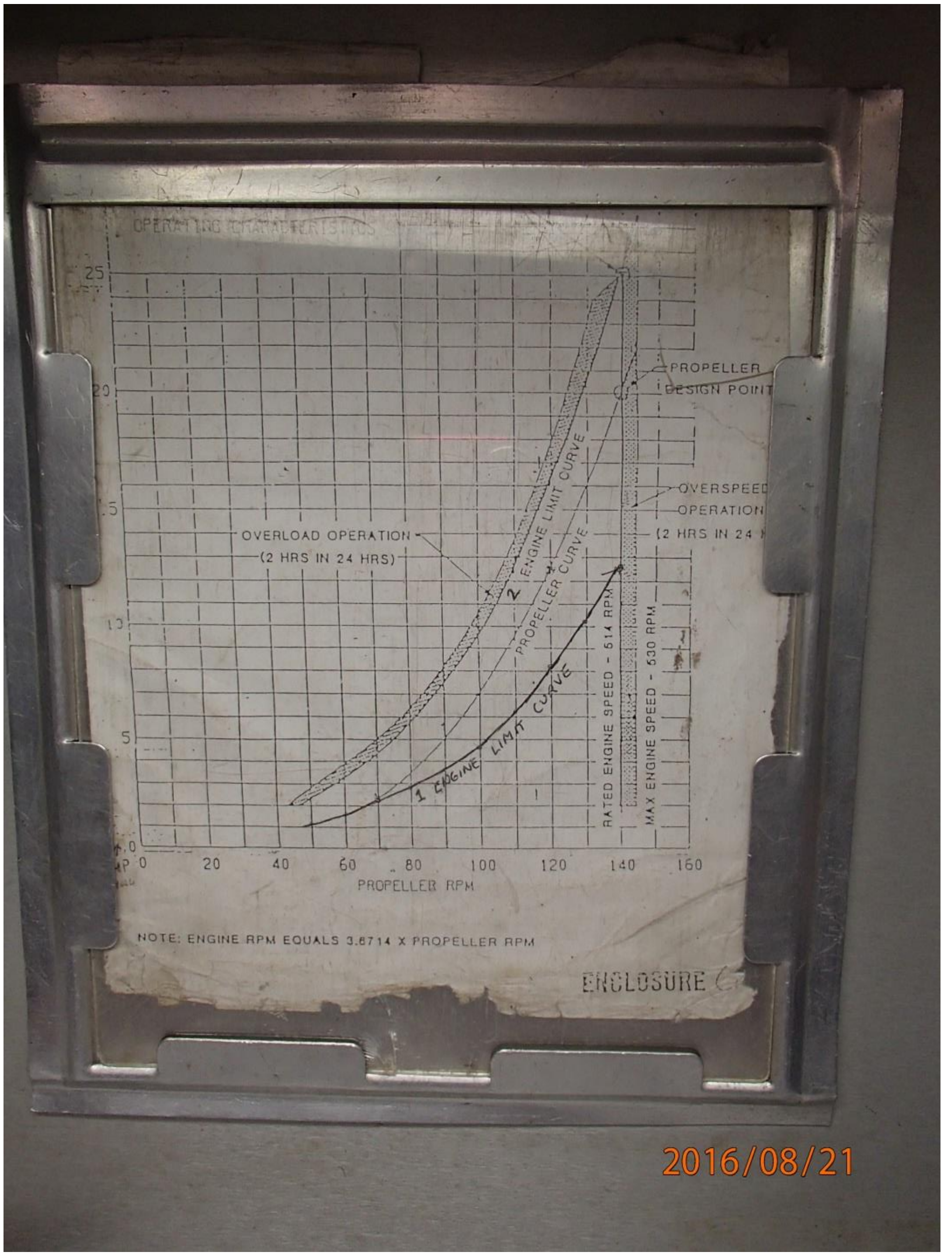
DATE	12th. Feb. 1986							
DATA SHEET NO.	400111	400112	400113	400114	400115	400116	400117	
LOAD %	50	70	80	90	※ 85	100	110	
ROOM TEMP. °C	4.5	5.8	7.7	9.0	8.5	9.0	11	
BAROM. PRESS. mmbar	1022	1022	1022	1022	1022	1022	1021	
ENGINE SPEED rpm	78.4	87.1	90.9	94.4	97.9	98.1	101.6	
OUTPUT (BHP) ps	11329	15765	17998	20296	19188	22563	24943	
FUEL OIL TEMP. °C	10	11	30	35	40	40	40	
SPECIFIC FUEL OIL CONSUMP. g/BHP/Hr — MEASURED	128.5	125.6	125.2	125.9	125.5	127.2	135.0	
SPECIFIC FUEL OIL CONSUMP. g/BHP/Hr — 1) CORRECTED	127.6	124.7	124.3	125.0	124.6	126.3	134.1	
SPECIFIC FUEL OIL CONSUMP. g/BHP/Hr — 2) CORRECTED BY ISO	—	—	—	—	—	126.9	—	
Pmax. bar	97.6	116.4	127.1	134.1	129.1	134.6	136.3	
Pcomp bar	67.9	88.1	95.6	106.4	99.9	117	128.6	
PUMP MARK INDEX	66.9	80	89	96	90	104	112.9	
EXH. GAS TEMP. CYL. OUTLET °C	219	224	230	243	236	260	289	
SCAV. AIR TEMP. °C	32	36	31	35	33	38	43	
SCAV. AIR PRESS. kg/cm²	1.04	1.62	1.86	2.19	2.02	2.54	2.85	
TURBO CHARGER SPEED rpm NO.1	9050	10750	11300	12000	11650	12650	13200	
TURBO CHARGER SPEED rpm NO.2	9050	10750	11300	11950	11600	12600	13150	
EXH. GAS TEMP. T/C INLET °C NO.1	280	300	315	325	325	350	380	
EXH. GAS TEMP. T/C INLET °C NO.2	285	310	310	330	318	350	380	
EXH. GAS TEMP. T/C OUTLET °C NO.1	220	210	215	220	220	235	247	
EXH. GAS TEMP. T/C OUTLET °C NO.2	220	218	215	218	215	230	246	

NOTE : 1) : Corrected SFOC at lower calorific valve 10200 kcal/kg

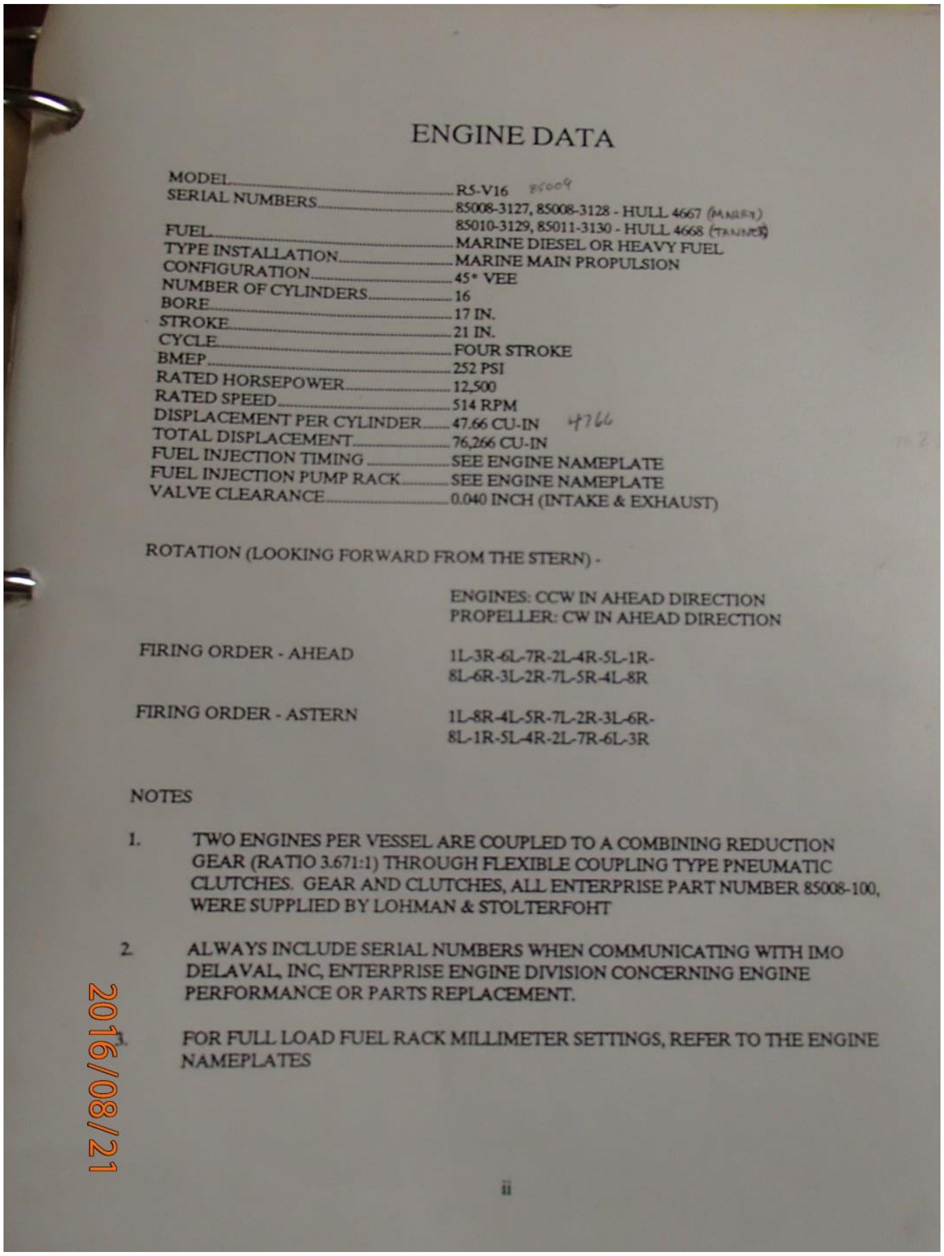
2) : Corrected SFOC by ISO Reference Conditions.

※ : MEASURED BY OWNER'S REQUEST.

Figure E-1 Shop trial data sheet for the engine tested



PROPELLER DESIGN POINT
OVERSPEED OPERATION (2 HRS IN 24
OVERLOAD OPERATION (2 HRS IN 24 HRS)
2 ENGINE LIMIT CURVE
PROPELLER CURVE
1 ENGINE LIMIT CURVE
RATED ENGINE SPEED - 514 RPM
MAX ENGINE SPEED - 530 RPM
25
20
5
0 20 40 60 80 100 120 140 160
PROPELLER RPM
NOTE: ENGINE RPM EQUALS 3.6714 X PROPELLER RPM
ENCLOSURE
2016/08/21



ENGINE DATA

MODEL	R5-V16 85004
SERIAL NUMBERS	85008-3127, 85008-3128 - HULL 4667 (MAURY) 85010-3129, 85011-3130 - HULL 4668 (TANKER)
FUEL	MARINE DIESEL OR HEAVY FUEL
TYPE INSTALLATION	MARINE MAIN PROPULSION
CONFIGURATION	45° VEE
NUMBER OF CYLINDERS	16
BORE	17 IN.
STROKE	21 IN.
CYCLE	FOUR STROKE
BMEP	252 PSI
RATED HORSEPOWER	12,500
RATED SPEED	514 RPM
DISPLACEMENT PER CYLINDER	47.66 CU-IN 4766
TOTAL DISPLACEMENT	76,266 CU-IN
FUEL INJECTION TIMING	SEE ENGINE NAMEPLATE
FUEL INJECTION PUMP RACK	SEE ENGINE NAMEPLATE
VALVE CLEARANCE	0.040 INCH (INTAKE & EXHAUST)

ROTATION (LOOKING FORWARD FROM THE STERN) -

	ENGINES: CCW IN AHEAD DIRECTION PROPELLER: CW IN AHEAD DIRECTION
FIRING ORDER - AHEAD	1L-3R-6L-7R-2L-4R-5L-1R- 8L-6R-3L-2R-7L-5R-4L-8R
FIRING ORDER - ASTERN	1L-8R-4L-5R-7L-2R-3L-6R- 8L-1R-5L-4R-2L-7R-6L-3R

NOTES

1. TWO ENGINES PER VESSEL ARE COUPLED TO A COMBINING REDUCTION GEAR (RATIO 3.671:1) THROUGH FLEXIBLE COUPLING TYPE PNEUMATIC CLUTCHES. GEAR AND CLUTCHES, ALL ENTERPRISE PART NUMBER 85008-100, WERE SUPPLIED BY LOHMAN & STOLTERFOHT

2. ALWAYS INCLUDE SERIAL NUMBERS WHEN COMMUNICATING WITH IMO DELAVAL, INC, ENTERPRISE ENGINE DIVISION CONCERNING ENGINE PERFORMANCE OR PARTS REPLACEMENT.

3. FOR FULL LOAD FUEL RACK MILLIMETER SETTINGS, REFER TO THE ENGINE NAMEPLATES

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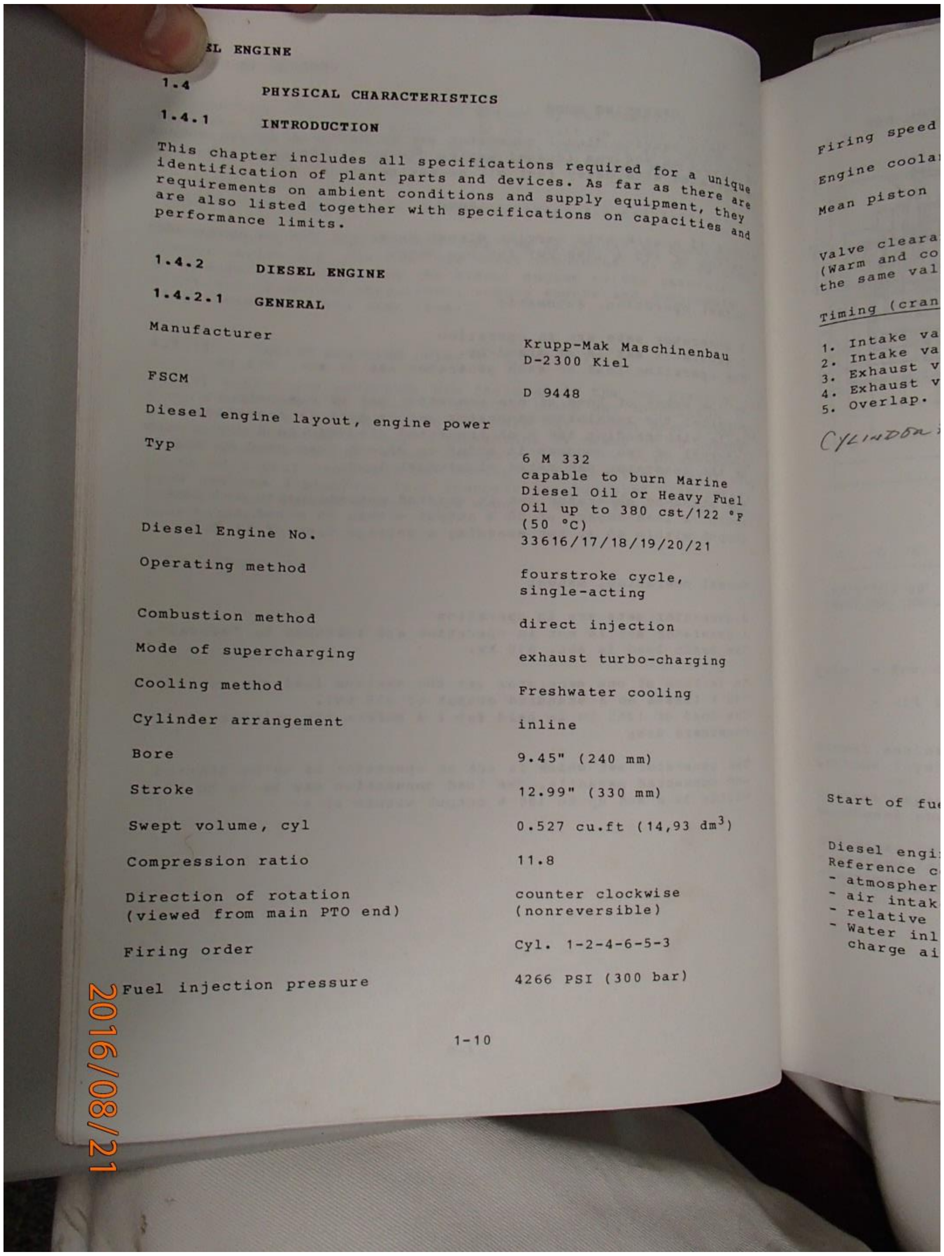
2016/08/21



...EL ENGINE

1.4 PHYSICAL CHARACTERISTICS

1.4.1 INTRODUCTION

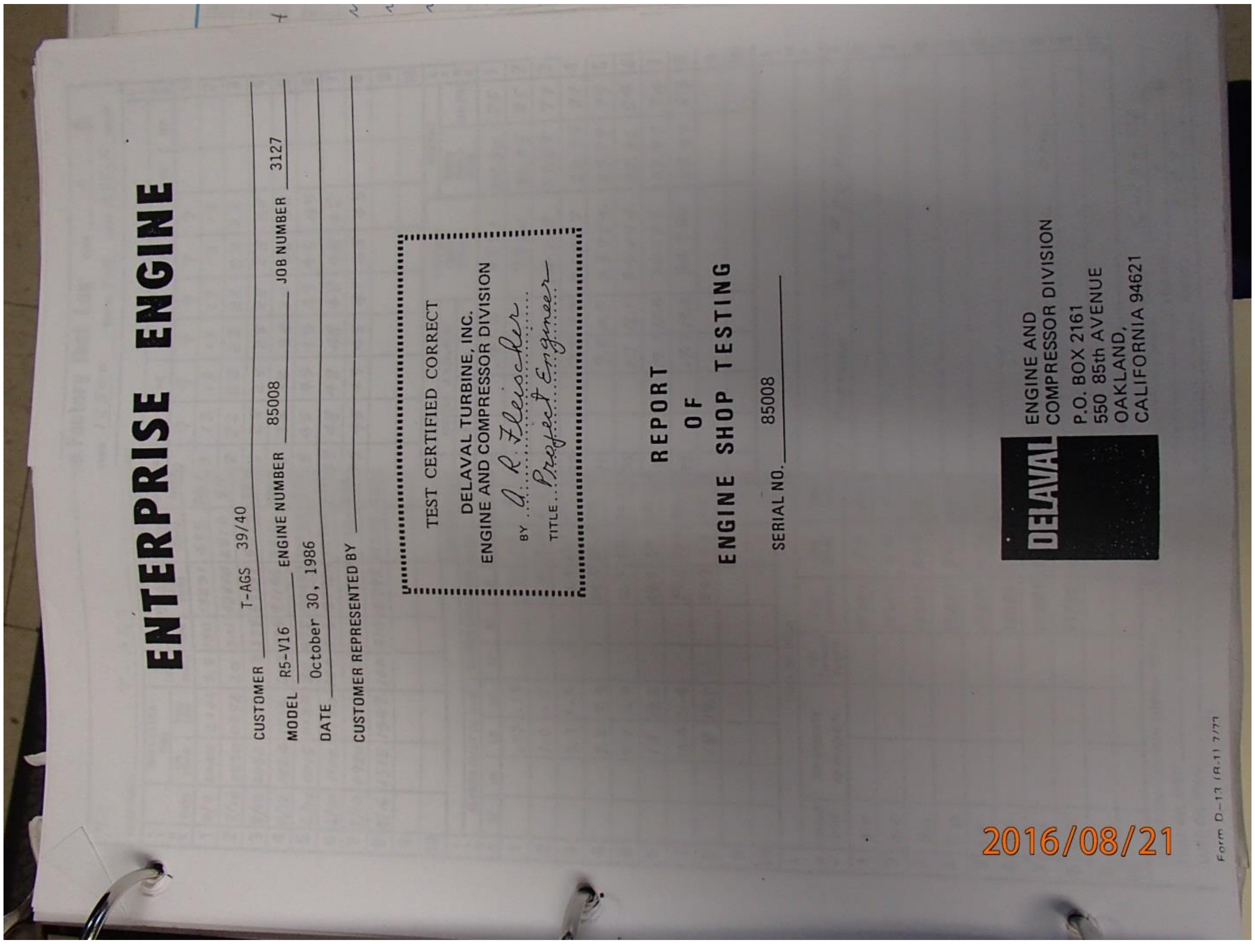
This chapter includes all specifications required for a unique identification of plant parts and devices. As far as there are requirements on ambient conditions and supply equipment, they are also listed together with specifications on capacities and performance limits.

1.4.2 DIESEL ENGINE

1.4.2.1 GENERAL

Manufacturer	Krupp-Mak Maschinenbau D-2300 Kiel
FSCM	D 9448
Diesel engine layout, engine power	
Typ	6 M 332 capable to burn Marine Diesel Oil or Heavy Fuel Oil up to 380 cst/122 °F (50 °C)
Diesel Engine No.	33616/17/18/19/20/21
Operating method	fourstroke cycle, single-acting
Combustion method	direct injection
Mode of supercharging	exhaust turbo-charging
Cooling method	Freshwater cooling
Cylinder arrangement	inline
Bore	9.45" (240 mm)
Stroke	12.99" (330 mm)
Swept volume, cyl	0.527 cu.ft (14,93 dm^3)
Compression ratio	11.8
Direction of rotation (viewed from main PTO end)	counter clockwise (nonreversible)
Firing order	Cyl. 1-2-4-6-5-3
Fuel injection pressure	4266 PSI (300 bar)

1-10



ENTERPRISE ENGINE

CUSTOMER T-AGS 39/40

MODEL R5-V16 ENGINE NUMBER 85008 JOB NUMBER 3127

DATE October 30, 1986

CUSTOMER REPRESENTED BY

TEST CERTIFIED CORRECT

DELAVAL TURBINE, INC.
ENGINE AND COMPRESSOR DIVISION

BY A. R. Fleischer

TITLE Project Engineer

REPORT
OF
ENGINE SHOP TESTING

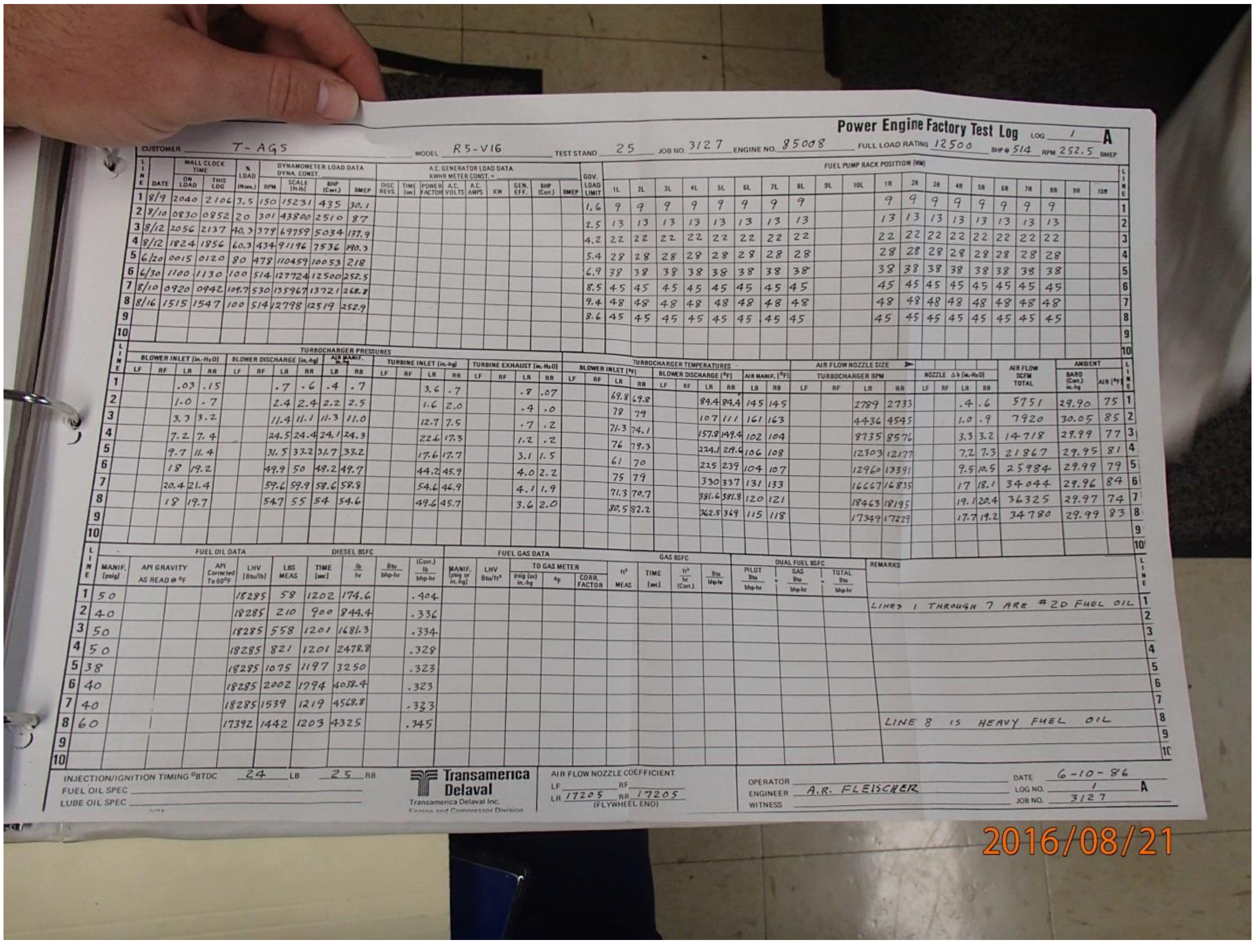
SERIAL NO. 85008

DELAVAL

ENGINE AND
COMPRESSOR DIVISION
P.O. BOX 2161
550 85th AVENUE
OAKLAND,
CALIFORNIA 94621

2016/08/21

Form D-13 (8-1) 7/73



Power Engine Factory Test Log LOG 1 **A**

CUSTOMER T-AGS MODEL R5-V16 TEST STAND 25 JOB NO. 3127 ENGINE NO. 85008 FULL LOAD RATING 12500 BHP @ 514 RPM 252.5 BMEP

LINE	DATE	WALL CLOCK TIME ON LOAD	WALL CLOCK TIME THIS LOG	% LOAD (Nom.)	DYNAMOMETER LOAD DATA RPM	SCALE (ft-lb)	BHP (Corr.)	BMEP	A.C. GENERATOR LOAD DATA DISC REVS.	TIME (sec)	POWER FACTOR	A.C. VOLTS	A.C. AMPS	KW	GEN. EFF.	BHP (Corr.)	BMEP	GOV. LOAD LIMIT
1	8/9	2040	2106	3.5	150	15231	435	30.1										1.6
2	8/10	0830	0852	20	301	43800	2510	87										2.5
3	8/12	2056	2137	40.3	379	69759	5034	137.9										4.2
4	8/12	1824	1856	60.3	434	91196	7536	190.3										5.4
5	6/20	0015	0120	80	478	110459	10053	218										6.9
6	6/30	1100	1130	100	514	127724	12500	252.5										8.5
7	8/10	0920	0942	109.7	530	135967	13721	268.8										9.4
8	8/16	1515	1547	100	514	12798	12519	252.9										8.6
9																		
10																		

FUEL PUMP RACK POSITION (MM)

LINE	1L	2L	3L	4L	5L	6L	7L	8L	9L	10L	1R	2R	3R	4R	5R	6R	7R	8R	9R	10R
1	9	9	9	9	9	9	9	9			9	9	9	9	9	9	9	9		
2	13	13	13	13	13	13	13	13			13	13	13	13	13	13	13	13		
3	22	22	22	22	22	22	22	22			22	22	22	22	22	22	22	22		
4	28	28	28	28	28	28	28	28			28	28	28	28	28	28	28	28		
5	38	38	38	38	38	38	38	38			38	38	38	38	38	38	38	38		
6	45	45	45	45	45	45	45	45			45	45	45	45	45	45	45	45		
7	48	48	48	48	48	48	48	48			48	48	48	48	48	48	48	48		
8	45	45	45	45	45	45	45	45			45	45	45	45	45	45	45	45		
9																				
10																				

TURBOCHARGER PRESSURES

LINE	BLOWER INLET (in.-H2O) LF	RF	LR	RR	BLOWER DISCHARGE (in.-hg) LF	RF	LR	RR	AIR MANIF. (in.-hg) LB	RB	TURBINE INLET (in.-hg) LF	RF	LR	RR	TURBINE EXHAUST (in.-H2O) LF	RF	LR	RR
1			.03	.15			.7	.6	.4	.7			3.6	.7			.8	.07
2			1.0	.7			2.4	2.4	2.2	2.5			1.6	2.0			.4	.0
3			3.3	3.2			11.4	11.1	11.3	11.0			12.7	7.5			.7	.2
4			7.2	7.4			24.5	24.4	24.1	24.3			22.6	17.3			1.2	.2
5			9.7	11.4			31.5	33.2	31.7	33.2			17.6	17.7			3.1	1.5
6			18	19.2			49.9	50	49.2	49.7			44.2	45.9			4.0	2.2
7			20.4	21.4			59.6	59.9	58.6	58.8			54.6	46.9			4.1	1.9
8			18	19.7			547	55	54	54.6			49.6	45.7			3.6	2.0
9																		
10																		

TURBOCHARGER TEMPERATURES / AIR FLOW NOZZLE SIZE / AMBIENT

LINE	BLOWER INLET (°F) LF	RF	LR	RR	BLOWER DISCHARGE (°F) LF	RF	LR	RR	AIR MANIF. (°F) LB	RB	TURBOCHARGER RPM LF	RF	LR	RR	NOZZLE Δh (in.-H2O) LF	RF	LR	RR	AIR FLOW SCFM TOTAL	BARO (Corr.) in.-hg	AIR (°F)
1			69.8	69.8			84.4	84.4	145	145			2789	2733			.4	.6	5751	29.90	75
2			78	79			107	111	161	163			4436	4545			1.0	.9	7920	30.05	85
3			71.3	74.1			157.8	149.4	102	104			8735	8576			3.3	3.2	14718	29.99	77
4			76	79.3			224.1	219.6	106	108			12303	12177			7.2	7.3	21867	29.95	81
5			61	70			225	239	104	107			12960	13391			9.5	10.5	25984	29.99	79
6			75	79			330	337	131	133			16667	16835			17	18.1	34044	29.96	84
7			71.3	70.7			381.6	381.8	120	121			18463	18195			19.1	20.4	36325	29.97	74
8			80.5	82.2			362.5	369	115	118			17349	17229			17.7	19.2	34780	29.99	83
9																					
10																					

FUEL OIL DATA / DIESEL BSFC

LINE	MANIF. (psig)	API GRAVITY AS READ @ °F		API Corrected To 60°F	LHV (Btu/lb)	LBS MEAS	TIME (sec)	lb/hr	Btu/bhp-hr	(Corr.) lb/bhp-hr
1	50				18285	58	1202	174.6		.404
2	40				18285	210	900	844.4		.336
3	50				18285	558	1201	1681.3		.334
4	50				18285	821	1201	2478.8		.328
5	38				18285	1075	1197	3250		.323
6	40				18285	2002	1794	4038.4		.323
7	40				18285	1539	1219	4568.8		.323
8	60				17392	1442	1203	4325		.345
9										
10										

FUEL GAS DATA: MANIF. (psig or in.-hg) | LHV Btu/ft³ | TO GAS METER: psig (or) in.-hg, °F, CORR. FACTOR | ft³ MEAS

GAS BSFC: TIME (sec) | ft³/hr (Corr.) | Btu/bhp-hr

DUAL FUEL BSFC: PILOT Btu/bhp-hr + GAS Btu/bhp-hr = TOTAL Btu/bhp-hr

REMARKS

1 LINES 1 THROUGH 7 ARE #2D FUEL OIL

8 LINE 8 IS HEAVY FUEL OIL

INJECTION/IGNITION TIMING °BTDC 24 LB 25 RB

FUEL OIL SPEC

LUBE OIL SPEC

Transamerica Delaval

Transamerica Delaval Inc.

Engine and Compressor Division

AIR FLOW NOZZLE COEFFICIENT

LF RF

LR 17205 RR 17205

(FLYWHEEL END)

OPERATOR

ENGINEER A.R. FLEISCHER

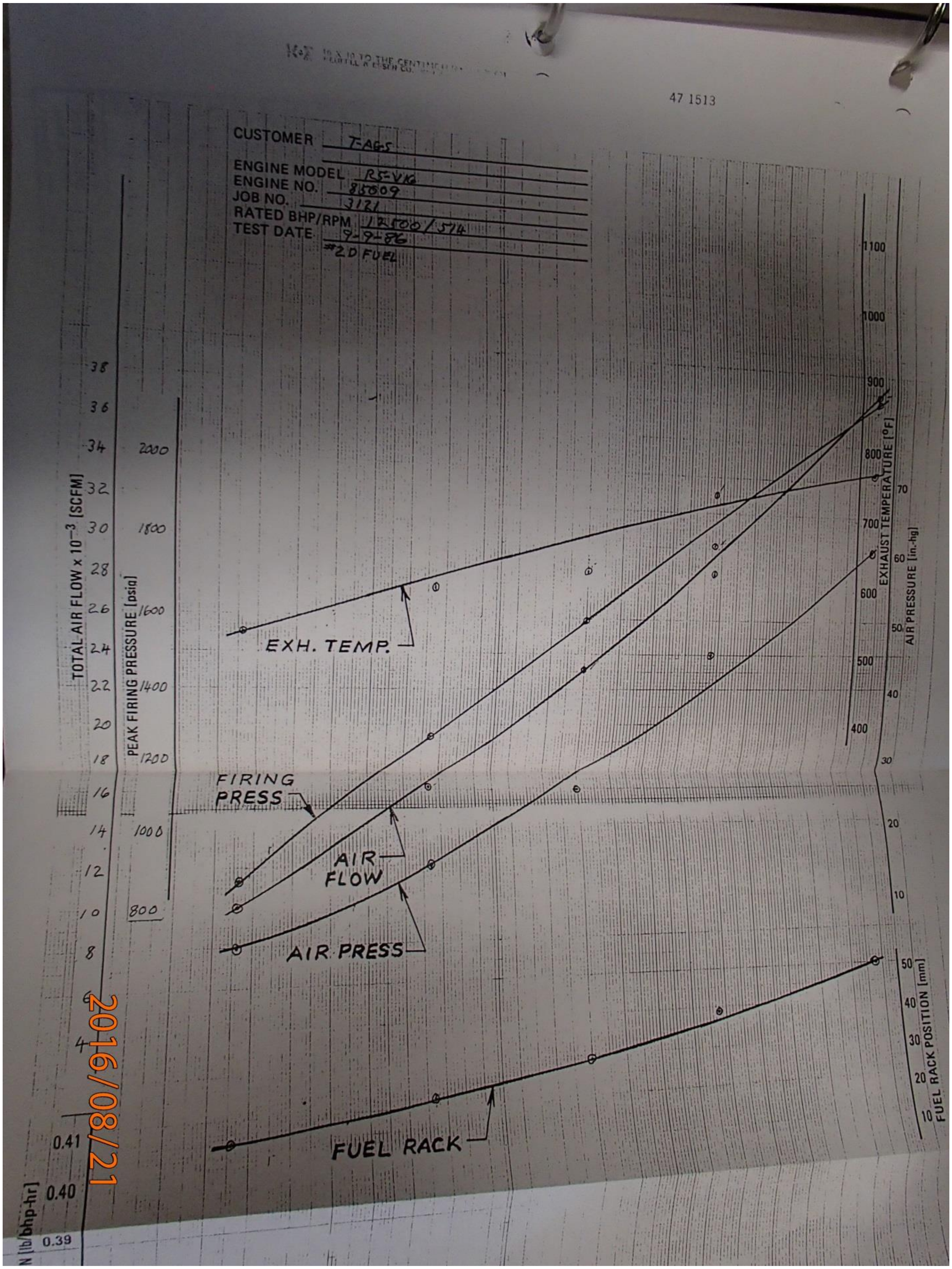
WITNESS

DATE 6-10-86

LOG NO. 1 A

JOB NO. 3127

2016/08/21


47 1513
CUSTOMER T-AGS
ENGINE MODEL RS-V16
ENGINE NO. 85009
JOB NO. 3121
RATED BHP/RPM 12500/514
TEST DATE 9-9-86
#2D FUEL
TOTAL AIR FLOW x 10^-3 [SCFM]
PEAK FIRING PRESSURE [psig]
EXHAUST TEMPERATURE [°F]
AIR PRESSURE [in.-hg]
FUEL RACK POSITION [mm]
EXH. TEMP.
FIRING PRESS
AIR FLOW
AIR PRESS
FUEL RACK
2016/08/21

Appendix F –Testing Raw Data

The summary results in this Appendix include real time figures to show measurement stability followed by a full data set of measured parameters. The green "X" in the figures is representative of the sample modes where filters and integrated values are collected. These sample points represent the main analysis of this report. The tables of data show the results that includes the combined emission factors for AE and ME emissions for the pre and post measurements (not the individual emissions at each load point).

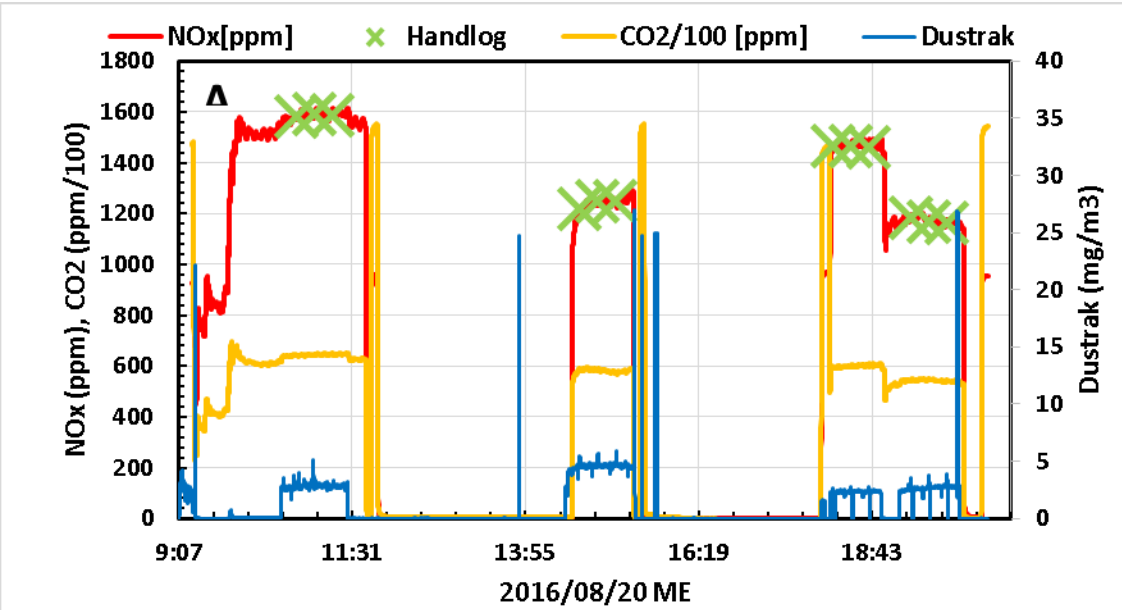


Figure F-1 Real time information for the ME tests

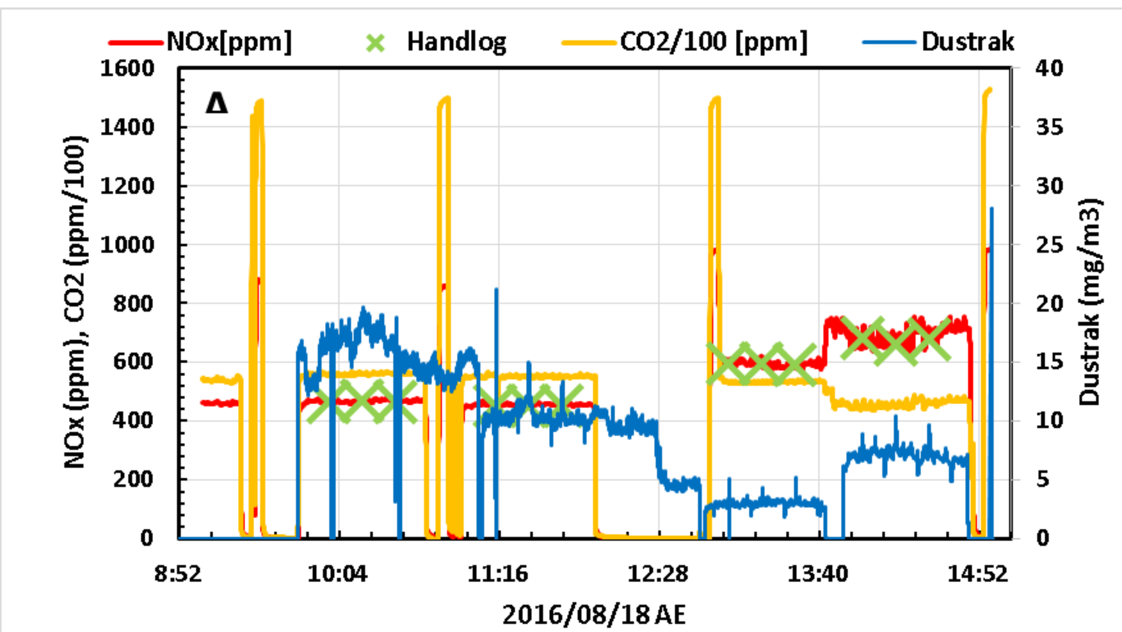


Figure F-2 Real time information for the AE tests

Table F-1 Summary of each test point sample, engine, and vessel conditions

Date	Project Name	Fuel	Source	Mode	Start Time	Engine Load		cor. Fuel Rate	bsFC FuelRate	Fuel Rate Carb.	bsFC Carb.	Sample Duration	DR	Exhaust Flow		H20 Fraction	O2 Conc
mm/dd/yyyy	name	n/a	n/a	n/a	hh:mm	MW	% MCR	kg/hr	g/kWhr	(kg/hr)	(g/kWh)	min	n/a	(scfm)	(m3/hr)	%	%
8/20/2016	CMA Golden Bear	MGO	ME	1	10:45	9.04	97%	1816	201	1,788	198	10	6.0	21,128	44,768	5.81	12.2
8/20/2016	CMA Golden Bear	MGO	ME	1	11:00	9.00	97%	1794	199	1,767	196	10	6.0	20,782	44,035	5.84	12.2
8/20/2016	CMA Golden Bear	MGO	ME	1	11:15	9.01	97%	1794	199	1,766	196	10	6.0	20,773	44,016	5.84	12.2
8/20/2016	CMA Golden Bear	MGO	ME	2	18:10	7.13	77%	1443	202	1,419	199	10	8.0	18,139	38,434	5.34	12.4
8/20/2016	CMA Golden Bear	MGO	ME	2	18:25	7.12	76%	1446	203	1,422	200	10	8.0	17,974	38,086	5.41	12.4
8/20/2016	CMA Golden Bear	MGO	ME	2	18:40	7.29	78%	1424	195	1,400	192	10	8.0	17,636	37,368	5.43	12.4
8/20/2016	CMA Golden Bear	MGO	ME	3	19:15	4.55	49%	965	212	947	208	10	12.0	13,193	27,954	4.88	13.4
8/20/2016	CMA Golden Bear	MGO	ME	3	19:30	4.51	48%	927	206	909	202	10	12.0	12,646	26,794	4.89	13.3
8/20/2016	CMA Golden Bear	MGO	ME	3	19:45	4.51	48%	973	216	955	212	10	12.0	13,402	28,398	4.85	13.3
8/20/2016	CMA Golden Bear	MGO	ME	4	14:40	1.79	19%	402	225	395	221	10	8.0	5,105	10,818	5.29	13.0
8/20/2016	CMA Golden Bear	MGO	ME	4	14:55	1.82	19%	435	240	428	235	10	8.0	5,564	11,790	5.25	12.9
8/20/2016	CMA Golden Bear	MGO	ME	4	15:10	1.77	19%	396	223	389	219	10	8.0	5,107	10,820	5.19	12.9
8/18/2016	CMA Golden Bear	MGO	AE	1	10:00	0.70	77%	155	223	153	220	10	6.0	2071	4388	5.01	13.2
8/18/2016	CMA Golden Bear	MGO	AE	1	10:15	0.75	84%	168	223	165	220	10	6.0	2234	4734	5.02	13.2
8/18/2016	CMA Golden Bear	MGO	AE	1	10:30	0.71	78%	157	223	155	220	10	6.0	2090	4428	5.03	13.2
8/18/2016	CMA Golden Bear	MGO	AE	2	11:15	0.66	73%	147	223	145	220	10	8.0	1991	4218	4.94	13.3
8/18/2016	CMA Golden Bear	MGO	AE	2	11:30	0.66	73%	146	223	144	220	10	8.0	1969	4171	4.96	13.2
8/18/2016	CMA Golden Bear	MGO	AE	2	11:45	0.69	76%	153	223	151	220	10	8.0	2074	4394	4.94	13.2
8/18/2016	CMA Golden Bear	MGO	AE	3	13:00	0.45	50%	100	223	99	220	10	12.0	1405	2976	4.77	13.5
8/18/2016	CMA Golden Bear	MGO	AE	3	13:15	0.45	50%	100	223	99	220	10	12.0	1410	2987	4.75	13.5
8/18/2016	CMA Golden Bear	MGO	AE	3	13:30	0.45	50%	100	223	98	220	10	12.0	1387	2938	4.81	13.4
8/18/2016	CMA Golden Bear	MGO	AE	4	14:00	0.20	22%	45	225	44	221	10	8.0	746	1582	3.97	14.6
8/18/2016	CMA Golden Bear	MGO	AE	4	14:15	0.23	25%	50	225	50	221	10	8.0	827	1753	4.04	14.6
8/18/2016	CMA Golden Bear	MGO	AE	4	14:30	0.21	23%	46	225	46	221	10	8.0	752	1593	4.10	14.5

Table F-2 Summary of each test point emission factors (g/hr)

Date	Source	Mode	Time	Load	Emission Factors (g/hr)											
mm/dd/yyyy	n/a	n/a	hh:mm	% MCR	NOx	CO	CO2	SO2	O2	PM2.5	PM_EC	PM_OC	PM_S	PM_t	PM_OCcor	totalPMcor
8/20/2016	ME	1	10:45	97%	133,172	5,509	5,678,488	-850	7,059,888	1,021	173	753	3.9	930.4	903.7	1,081.0
8/20/2016	ME	1	11:00	97%	131,728	5,379	5,611,451	-586	6,955,672	1,117	170	809	3.8	982.6	971.0	1,144.4
8/20/2016	ME	1	11:15	97%	131,261	5,256	5,608,967	-586	6,958,263	1,149	180	877	3.8	1,061.1	1,052.9	1,236.6
8/20/2016	ME	2	18:10	77%	105,905	4,269	4,505,623	-512	6,174,837	951	170	755	4.4	928.7	905.8	1,079.7
8/20/2016	ME	2	18:25	76%	105,017	4,300	4,517,126	-507	6,118,935	975	168	804	4.4	976.5	964.8	1,137.3
8/20/2016	ME	2	18:40	78%	102,622	4,172	4,446,686	-498	5,998,845	918	164	781	4.3	949.2	937.1	1,105.3
8/20/2016	ME	3	19:15	49%	62,541	2,178	3,008,359	-478	4,833,181	1,017	126	900	4.8	1,030.9	1,079.7	1,210.8
8/20/2016	ME	3	19:30	48%	59,101	2,090	2,888,858	-458	4,612,038	1,105	153	834	4.6	991.8	1,000.9	1,158.6
8/20/2016	ME	3	19:45	48%	62,375	2,238	3,033,915	-485	4,891,743	1,107	156	876	4.9	1,037.5	1,051.8	1,212.8
8/20/2016	ME	4	14:40	19%	24,906	1,114	1,255,462	-185	1,817,460	333	79	237	1.2	317.0	284.7	364.4
8/20/2016	ME	4	14:55	19%	27,780	1,238	1,359,075	-202	1,967,176	364	86	266	1.4	352.9	318.8	406.1
8/20/2016	ME	4	15:10	19%	25,454	1,145	1,234,515	-185	1,803,923	334	83	258	1.2	341.9	309.6	393.5
8/18/2016	AE	1	10:00	77%	3,949	1,651	483,379	-9	747,311	280	125	109	0.4	234.8	130.8	256.6
8/18/2016	AE	1	10:15	84%	4,278	1,838	523,408	-45	806,323	316	145	128	0.4	272.6	153.2	298.1
8/18/2016	AE	1	10:30	78%	3,993	1,641	490,385	-42	753,544	404	145	114	0.4	258.7	136.4	281.4
8/18/2016	AE	2	11:15	73%	3,694	1,400	458,923	-64	723,346	246	126	98	0.5	223.9	117.4	243.5
8/18/2016	AE	2	11:30	73%	3,661	1,365	455,479	-56	712,651	227	121	95	0.5	216.1	113.7	235.0
8/18/2016	AE	2	11:45	76%	3,840	1,442	478,045	-67	751,787	232	128	97	0.5	224.8	115.9	244.1
8/18/2016	AE	3	13:00	50%	3,386	623	313,320	-51	518,465	83	45	44	0.5	89.9	53.1	98.7
8/18/2016	AE	3	13:15	50%	3,415	626	313,296	-45	521,519	83	47	47	0.5	93.9	56.1	103.3
8/18/2016	AE	3	13:30	50%	3,321	610	311,627	-45	510,334	81	46	44	0.5	90.4	52.5	99.1
8/18/2016	AE	4	14:00	22%	2,055	565	139,820	-24	298,747	59	29	27	0.2	56.7	33.0	62.2
8/18/2016	AE	4	14:15	25%	2,209	654	157,356	-27	330,170	68	32	34	0.2	66.5	40.7	73.3
8/18/2016	AE	4	14:30	23%	2,067	568	145,169	-24	298,985	61	28	31	0.2	59.6	37.7	65.9

[1] SO_2 emissions were at the detection limit of the analyzer (1-2 ppm) thus the values presented are representative of a non-detectable value (nd)

Table F-3 Summary of each test point emission factors (g/kg-fuel)

Date	Source	Mode	Time	Load	Emission Factors (g/kg-fuel)											
mm/dd/yyyy	n/a	n/a	hh:mm	% MCR	NOx	CO	CO2	SO2	O2	PM2.5	PM_EC	PM_OC	PM_S	PM_t	PM_OCcor	PM_TCcor
8/20/2016	ME	1	10:45	97%	73.33	3.03	3127	-0.47	3888	0.562	0.096	0.415	0.002	0.512	0.498	0.595
8/20/2016	ME	1	11:00	97%	73.41	3.00	3127	-0.33	3876	0.623	0.095	0.451	0.002	0.548	0.541	0.638
8/20/2016	ME	1	11:15	97%	73.18	2.93	3127	-0.33	3879	0.640	0.100	0.489	0.002	0.592	0.587	0.689
8/20/2016	ME	2	18:10	77%	73.40	2.96	3123	-0.35	4279	0.659	0.117	0.523	0.003	0.644	0.628	0.748
8/20/2016	ME	2	18:25	76%	72.61	2.97	3123	-0.35	4231	0.674	0.116	0.556	0.003	0.675	0.667	0.786
8/20/2016	ME	2	18:40	78%	72.08	2.93	3123	-0.35	4214	0.645	0.115	0.549	0.003	0.667	0.658	0.776
8/20/2016	ME	3	19:15	49%	64.81	2.26	3117	-0.50	5008	1.053	0.131	0.932	0.005	1.068	1.119	1.255
8/20/2016	ME	3	19:30	48%	63.78	2.26	3118	-0.49	4977	1.193	0.165	0.900	0.005	1.070	1.080	1.250
8/20/2016	ME	3	19:45	48%	64.08	2.30	3117	-0.50	5026	1.137	0.160	0.900	0.005	1.066	1.081	1.246
8/20/2016	ME	4	14:40	19%	61.93	2.77	3122	-0.46	4519	0.827	0.195	0.590	0.003	0.788	0.708	0.906
8/20/2016	ME	4	14:55	19%	63.81	2.84	3122	-0.46	4518	0.837	0.197	0.610	0.003	0.811	0.732	0.933
8/20/2016	ME	4	15:10	19%	64.35	2.90	3121	-0.47	4560	0.845	0.209	0.652	0.003	0.864	0.783	0.995
8/18/2016	AE	1	10:00	77%	25.48	10.66	3119	-0.06	4822	1.804	0.809	0.703	0.002	1.515	0.844	1.656
8/18/2016	AE	1	10:15	84%	25.49	10.96	3119	-0.27	4805	1.885	0.861	0.761	0.002	1.625	0.913	1.777
8/18/2016	AE	1	10:30	78%	25.40	10.44	3119	-0.27	4793	2.571	0.920	0.723	0.002	1.645	0.867	1.790
8/18/2016	AE	2	11:15	73%	25.10	9.52	3118	-0.44	4915	1.673	0.853	0.664	0.003	1.521	0.797	1.654
8/18/2016	AE	2	11:30	73%	25.07	9.35	3118	-0.38	4879	1.554	0.827	0.649	0.003	1.479	0.779	1.609
8/18/2016	AE	2	11:45	76%	25.05	9.40	3118	-0.44	4904	1.512	0.833	0.630	0.003	1.466	0.756	1.592
8/18/2016	AE	3	13:00	50%	33.75	6.21	3122	-0.51	5167	0.830	0.450	0.441	0.005	0.895	0.529	0.984
8/18/2016	AE	3	13:15	50%	34.04	6.24	3122	-0.45	5197	0.831	0.465	0.466	0.005	0.936	0.559	1.029
8/18/2016	AE	3	13:30	50%	33.28	6.11	3123	-0.45	5114	0.812	0.462	0.439	0.005	0.905	0.526	0.993
8/18/2016	AE	4	14:00	22%	46.08	12.66	3135	-0.54	6698	1.332	0.653	0.616	0.004	1.272	0.739	1.396
8/18/2016	AE	4	14:15	25%	44.03	13.03	3136	-0.53	6580	1.352	0.646	0.676	0.004	1.326	0.812	1.461
8/18/2016	AE	4	14:30	23%	44.66	12.28	3137	-0.52	6461	1.323	0.605	0.680	0.004	1.288	0.816	1.424

[1] SO_2 emissions were at the detection limit of the analyzer (1-2 ppm) thus the values presented are representative of a non-detectable value (nd)

Table F-4 Summary of each test point emission factors (g/kWhr)

Date	Source	Mode	Time	Load	Emission Factors (g/kWh)											
mm/dd/yyyy	n/a	n/a	hh:mm	% MCR	NOx	CO	CO2	SO2	O2	PM2.5	PM_EC	PM_OC	PM_S	PM_t	PM_OCcor	PM_TCcor
8/20/2016	ME	1	10:45	97%	14.74	0.61	628	-0.09	781	0.113	0.019	0.083	0.000	0.103	0.100	0.120
8/20/2016	ME	1	11:00	97%	14.63	0.60	623	-0.07	773	0.124	0.019	0.090	0.000	0.109	0.108	0.127
8/20/2016	ME	1	11:15	97%	14.57	0.58	623	-0.07	773	0.128	0.020	0.097	0.000	0.118	0.117	0.137
8/20/2016	ME	2	18:10	77%	14.85	0.60	632	-0.07	866	0.133	0.024	0.106	0.001	0.130	0.127	0.151
8/20/2016	ME	2	18:25	76%	14.75	0.60	635	-0.07	860	0.137	0.024	0.113	0.001	0.137	0.136	0.160
8/20/2016	ME	2	18:40	78%	14.08	0.57	610	-0.07	823	0.126	0.022	0.107	0.001	0.130	0.129	0.152
8/20/2016	ME	3	19:15	49%	13.75	0.48	661	-0.11	1063	0.224	0.028	0.198	0.001	0.227	0.237	0.266
8/20/2016	ME	3	19:30	48%	13.11	0.46	641	-0.10	1023	0.245	0.034	0.185	0.001	0.220	0.222	0.257
8/20/2016	ME	3	19:45	48%	13.82	0.50	672	-0.11	1084	0.245	0.035	0.194	0.001	0.230	0.233	0.269
8/20/2016	ME	4	14:40	19%	13.92	0.62	701	-0.10	1015	0.186	0.044	0.133	0.001	0.177	0.159	0.204
8/20/2016	ME	4	14:55	19%	15.29	0.68	748	-0.11	1083	0.200	0.047	0.146	0.001	0.194	0.175	0.223
8/20/2016	ME	4	15:10	19%	14.37	0.65	697	-0.10	1018	0.189	0.047	0.146	0.001	0.193	0.175	0.222
8/18/2016	AE	1	10:00	77%	5.68	2.38	696	-0.01	1075	0.402	0.181	0.157	0.001	0.338	0.188	0.369
8/18/2016	AE	1	10:15	84%	5.69	2.44	696	-0.06	1072	0.420	0.192	0.170	0.001	0.362	0.204	0.396
8/18/2016	AE	1	10:30	78%	5.66	2.33	696	-0.06	1069	0.573	0.205	0.161	0.001	0.367	0.193	0.399
8/18/2016	AE	2	11:15	73%	5.60	2.12	695	-0.10	1096	0.373	0.190	0.148	0.001	0.339	0.178	0.369
8/18/2016	AE	2	11:30	73%	5.59	2.08	695	-0.08	1088	0.347	0.184	0.145	0.001	0.330	0.174	0.359
8/18/2016	AE	2	11:45	76%	5.59	2.10	695	-0.10	1094	0.337	0.186	0.140	0.001	0.327	0.169	0.355
8/18/2016	AE	3	13:00	50%	7.53	1.38	696	-0.11	1152	0.185	0.100	0.098	0.001	0.200	0.118	0.219
8/18/2016	AE	3	13:15	50%	7.59	1.39	696	-0.10	1159	0.185	0.104	0.104	0.001	0.209	0.125	0.230
8/18/2016	AE	3	13:30	50%	7.42	1.36	696	-0.10	1140	0.181	0.103	0.098	0.001	0.202	0.117	0.221
8/18/2016	AE	4	14:00	22%	10.28	2.82	699	-0.12	1494	0.297	0.146	0.137	0.001	0.284	0.165	0.311
8/18/2016	AE	4	14:15	25%	9.82	2.91	699	-0.12	1467	0.301	0.144	0.151	0.001	0.296	0.181	0.326
8/18/2016	AE	4	14:30	23%	9.96	2.74	700	-0.12	1441	0.295	0.135	0.152	0.001	0.287	0.182	0.318

[1] SO_2 emissions were at the detection limit of the analyzer (1-2 ppm) thus the values presented are representative of a non-detectable value (nd)

Table F-5 Summary of the triplicate average for the sample, engine, and vessel conditions

Date	Project Name	Fuel	Source	Mode	Start Time	Engine Load		cor. Fuel Rate	bsFC FuelRate	Fuel Rate Carb.	bsFC Carb.	Sample Duration	DR	Exhaust Flow		H20 Fraction	O2 Conc
mm/dd/yyyy	name				hh:mm	MW	% MCR	kg/hr	g/kWhr	(kg/hr)	(g/kWh)	min	n/a	(scfm)	(m3/hr)	%	%
8/20/2016	CMA Golden Bear	MGO	ME	1	10:45	9.01	97%	1801	200	1,773	197	10	6.0	20,895	44,273	5.83	12.2
8/20/2016	CMA Golden Bear	MGO	ME	2	18:10	7.18	77%	1438	200	1,414	197	10	8.0	17,916	37,963	5.40	12.4
8/20/2016	CMA Golden Bear	MGO	ME	3	19:15	4.52	49%	955	211	937	207	10	12.0	13,080	27,715	4.87	13.3
8/20/2016	CMA Golden Bear	MGO	ME	4	14:40	1.79	19%	411	229	404	225	10	8.0	5,259	11,143	5.24	12.9
8/18/2016	CMA Golden Bear	MGO	AE	1	10:00	0.72	80%	160	223	158	220	10	6.0	2132	4516	5.02	13.2
8/18/2016	CMA Golden Bear	MGO	AE	2	11:15	0.67	74%	149	223	147	220	10	8.0	2011	4261	4.95	13.2
8/18/2016	CMA Golden Bear	MGO	AE	3	13:00	0.45	50%	100	223	99	220	10	12.0	1400	2967	4.78	13.5
8/18/2016	CMA Golden Bear	MGO	AE	4	14:00	0.21	23%	47	225	47	221	10	8.0	775	1642	4.04	14.6

Table F-6 Summary of the triplicate average emission factors (g/hr)

Date	Source	Mode	Time	Load	Emission Factors (g/hr)											
mm/dd/yyyy	n/a	n/a	hh:mm	% MCR	NOx	CO	CO2	SO2	O2	PM2.5	PM_EC	PM_OC	PM_S	PM_t	PM_OCcor	totalPMcor
8/20/2016	ME	1	10:45	97%	132,054	5,381	5,632,969	-674	6,991,275	1,095	174	813	3.8	991.4	975.8	1,154.0
8/20/2016	ME	2	18:10	77%	104,515	4,247	4,489,812	-506	6,097,539	948	167	780	4.4	951.5	935.9	1,107.4
8/20/2016	ME	3	19:15	49%	61,339	2,169	2,977,044	-474	4,778,987	1,076	145	870	4.8	1,020.1	1,044.1	1,194.1
8/20/2016	ME	4	14:40	19%	26,047	1,166	1,283,017	-190	1,862,853	344	82	254	1.3	337.3	304.3	388.0
8/18/2016	AE	1	10:00	80%	4,073	1,710	499,058	-32	769,059	333	138	117	0.4	255.4	140.1	278.7
8/18/2016	AE	2	11:15	74%	3,732	1,403	464,149	-62	729,261	235	125	96	0.5	221.6	115.6	240.9
8/18/2016	AE	3	13:00	50%	3,374	620	312,748	-47	516,773	83	46	45	0.5	91.4	53.9	100.4
8/18/2016	AE	4	14:00	23%	2,110	596	147,449	-25	309,300	63	30	31	0.2	61.0	37.1	67.2

[1] SO_2 emissions were at the detection limit of the analyzer (1-2 ppm) thus the values presented are representative of a non-detectable value (nd)

Table F-7 Summary of the triplicate average emission factors (g/kWhr)

Date	Source	Mode	Time	Load	Emission Factors (g/kWh)											
mm/dd/yyyy	n/a	n/a	hh:mm	% MCR	NOx	CO	CO2	SO2	O2	PM2.5	PM_EC	PM_OC	PM_S	PM_t	PM_OCcor	PM_TCcor
8/20/2016	ME	1	10:45	97%	14.65	0.60	625	-0.07	776	0.122	0.019	0.090	0.000	0.110	0.108	0.128
8/20/2016	ME	2	18:10	77%	14.56	0.59	626	-0.07	850	0.132	0.023	0.109	0.001	0.133	0.130	0.154
8/20/2016	ME	3	19:15	49%	13.56	0.48	658	-0.10	1057	0.238	0.032	0.192	0.001	0.226	0.231	0.264
8/20/2016	ME	4	14:40	19%	14.52	0.65	715	-0.11	1039	0.192	0.046	0.141	0.001	0.188	0.170	0.216
8/18/2016	AE	1	10:00	80%	5.68	2.38	696	-0.04	1072	0.465	0.193	0.163	0.001	0.356	0.195	0.388
8/18/2016	AE	2	11:15	74%	5.59	2.10	695	-0.09	1093	0.352	0.187	0.144	0.001	0.332	0.173	0.361
8/18/2016	AE	3	13:00	50%	7.51	1.38	696	-0.10	1150	0.184	0.102	0.100	0.001	0.203	0.120	0.223
8/18/2016	AE	4	14:00	23%	10.02	2.82	699	-0.12	1467	0.298	0.141	0.147	0.001	0.289	0.176	0.318

[1] SO_2 emissions were at the detection limit of the analyzer (1-2 ppm) thus the values presented are representative of a non-detectable value (nd)

Table F- 8 Summary of the triplicate average emission factors (g/kgfuel)

Date	Source	Mode	Time	Load	Emission Factors (g/kg-fuel)											
mm/dd/yyyy	n/a	n/a	hh:mm	% MCR	NOx	CO	CO2	SO2	O2	PM2.5	PM_EC	PM_OC	PM_S	PM_t	PM_OCcor	PM_TCcor
8/20/2016	ME	1	10:45	97%	73.31	2.99	3127	-0.37	3881	0.608	0.097	0.452	0.002	0.551	0.542	0.641
8/20/2016	ME	2	18:10	77%	72.70	2.95	3123	-0.35	4241	0.659	0.116	0.543	0.003	0.662	0.651	0.770
8/20/2016	ME	3	19:15	49%	64.22	2.27	3117	-0.50	5004	1.128	0.152	0.911	0.005	1.068	1.093	1.250
8/20/2016	ME	4	14:40	19%	63.36	2.84	3122	-0.46	4533	0.836	0.201	0.617	0.003	0.821	0.741	0.945
8/18/2016	AE	1	10:00	80%	25.46	10.68	3119	-0.20	4807	2.087	0.864	0.729	0.002	1.595	0.875	1.741
8/18/2016	AE	2	11:15	74%	25.07	9.42	3118	-0.42	4899	1.580	0.838	0.648	0.003	1.489	0.777	1.618
8/18/2016	AE	3	13:00	50%	33.69	6.19	3122	-0.47	5159	0.824	0.459	0.448	0.005	0.912	0.538	1.002
8/18/2016	AE	4	14:00	23%	44.92	12.66	3136	-0.53	6580	1.335	0.634	0.657	0.004	1.296	0.789	1.427

[1] SO_2 emissions were at the detection limit of the analyzer (1-2 ppm) thus the values presented are representative of a non-detectable value (nd)

Table F-9 Summary of engine condition, vessel, and emissions sampling coefficient of variation (COV)

Date	Project Name	Fuel	Source	Mode	Start Time	Engine Load		cor. Fuel Rate	bsFC FuelRate	Fuel Rate Carb.	bsFC Carb.	Sample Duration	DR	Exhaust Flow		H20 Fraction	O2 Conc
mm/dd/yyyy	name				hh:mm	MW	% MCR	kg/hr	g/kWhr	(kg/hr)	(g/kWh)	min	n/a	(scfm)	(m3/hr)	%	%
8/20/2016	CMA Golden Bear	MGO	ME	4	15:10	1%	1%	5%	4%	5%	4%	0%	0%	5%	5%	1%	0%
8/20/2016	CMA Golden Bear	MGO	ME	3	19:30	0%	0%	3%	2%	3%	2%	0%	0%	3%	3%	1%	0%
8/20/2016	CMA Golden Bear	MGO	ME	2	18:25	1%	1%	1%	2%	1%	2%	0%	0%	1%	1%	1%	0%
8/20/2016	CMA Golden Bear	MGO	ME	1	11:00	0%	0%	1%	0%	1%	0%	0%	0%	1%	1%	0%	0%
8/18/2016	CMA Golden Bear	MGO	AE	4	14:00	6%	6%	6%	0%	6%	0%	0%	0%	6%	6%	2%	0%
8/18/2016	CMA Golden Bear	MGO	AE	3	13:30	0%	0%	0%	0%	0%	0%	0%	0%	1%	1%	1%	0%
8/18/2016	CMA Golden Bear	MGO	AE	2	11:30	3%	3%	3%	0%	3%	0%	0%	0%	3%	3%	0%	0%
8/18/2016	CMA Golden Bear	MGO	AE	1	10:00	4%	4%	4%	0%	4%	0%	0%	0%	4%	4%	0%	0%

Table F-10 Summary of emission factors coefficient of variation (COV) in g/hr units

Date	Source	Mode	Time	Load	Emission Factors (g/hr)										
mm/dd/yyyy	n/a	n/a	hh:mm	% MCR	NOx	CO	CO2	SO2	PM2.5	PM_EC	PM_OC	PM_S	PM_t	PM_OCcor	totalPMcor
8/20/2016	ME	4	15:10	19%	6%	6%	5%	-	5%	5%	6%	5%	5%	6%	6%
8/20/2016	ME	3	19:30	49%	3%	3%	3%	-	5%	11%	4%	3%	2%	4%	3%
8/20/2016	ME	2	18:25	77%	2%	2%	1%	-	3%	2%	3%	1%	3%	3%	3%
8/20/2016	ME	1	11:00	97%	1%	2%	1%	-	6%	3%	8%	1%	7%	8%	7%
8/18/2016	AE	4	14:00	23%	4%	8%	6%	-	7%	8%	11%	6%	8%	11%	8%
8/18/2016	AE	3	13:30	50%	1%	1%	0%	-	2%	2%	4%	1%	2%	4%	3%
8/18/2016	AE	2	11:30	74%	3%	3%	3%	-	4%	3%	2%	3%	2%	2%	2%
8/18/2016	AE	1	10:00	80%	4%	6%	4%	-	19%	8%	8%	4%	7%	8%	8%

Table F-11 Summary of emission factors coefficient of variation (COV) in g/kWhr units

Date	Source	Mode	Time	Load	Emission Factors (g/kWh)										
mm/dd/yyyy	n/a	n/a	hh:mm	% MCR	NOx	CO	CO2	SO2	PM2.5	PM_EC	PM_OC	PM_S	PM_t	PM_OCcor	PM_TCcor
8/20/2016	ME	4	15:10	19%	5%	5%	4%	-	4%	4%	5%	4%	5%	5%	5%
8/20/2016	ME	3	19:30	49%	3%	3%	2%	-	5%	12%	3%	3%	2%	3%	2%
8/20/2016	ME	2	18:25	77%	3%	3%	2%	-	4%	3%	3%	3%	3%	3%	3%
8/20/2016	ME	1	11:00	97%	1%	2%	0%	-	6%	3%	8%	1%	7%	8%	7%
					3%	3%	2%	-	5%	8%	4%	3%	3%	4%	3%
8/18/2016	AE	4	14:00	23%	2%	3%	0%	-	1%	4%	5%	1%	2%	5%	2%
8/18/2016	AE	3	13:30	50%	1%	1%	0%	-	1%	2%	3%	1%	2%	3%	2%
8/18/2016	AE	2	11:30	74%	0%	1%	0%	-	5%	2%	3%	0%	2%	3%	2%
8/18/2016	AE	1	10:00	80%	0%	2%	0%	-	20%	6%	4%	0%	4%	4%	4%
					1%	2%	0%	-	11%	4%	4%	0%	3%	4%	3%

Table F-12 Summary of emission factors coefficient of variation (COV) in g/kg-fuel units

Date	Source	Mode	Time	Load	Emission Factors (g/kg-fuel)										
mm/dd/yyyy	n/a	n/a	hh:mm	% MCR	NOx	CO	CO2	SO2	PM2.5	PM_EC	PM_OC	PM_S	PM_t	PM_OCcor	PM_TCcor
8/20/2016	ME	4	15:10	19%	2%	2%	0%	-	1%	4%	5%	1%	5%	5%	5%
8/20/2016	ME	3	19:30	49%	1%	1%	0%	-	6%	12%	2%	0%	0%	2%	0%
8/20/2016	ME	2	18:25	77%	1%	1%	0%	-	2%	1%	3%	1%	2%	3%	3%
8/20/2016	ME	1	11:00	97%	0%	2%	0%	-	7%	3%	8%	0%	7%	8%	7%
8/18/2016	AE	4	14:00	23%	2%	3%	0%	-	1%	4%	5%	1%	2%	5%	2%
8/18/2016	AE	3	13:30	50%	1%	1%	0%	-	1%	2%	3%	1%	2%	3%	2%
8/18/2016	AE	2	11:30	74%	0%	1%	0%	-	5%	2%	3%	0%	2%	3%	2%
8/18/2016	AE	1	10:00	80%	0%	2%	0%	-	20%	6%	4%	0%	4%	4%	4%