Evaluation of the Emission Reduction Performance of a Hamworthy/Krystallon Exhaust Gas Cleaning Scrubber

Bluefield
HOLDINGS INC

FINAL REPORT

MV APL England

May, 2013

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DISCLAIMER

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Abstract

Using funding from the ports of Los Angeles and Long Beach and the other project participants, a successful demonstration project proved the efficacy of a sea water scrubbing system in removing SO2 and PM from the emissions produced by multiple auxiliary engines installed on a 5500 TEU container ship owned and operated by APL. Testing was conducted in April and May 2012 aboard the vessel while in transit between Taiwan and mainland China and at berth at the APL Global Gateway South Container Terminal in Los Angeles. The three auxiliary engines have a total rated capacity of 9.75 MW and are connected to a single scrubber that allows separate or simultaneous operation of the engines at any load. Emissions and discharges from the scrubber met all project expectations.

Acronyms

APL	APL Bermuda Ltd., a subsidiary of Singapore-based Neptune Orient Lines
ARB	California Air Resources Board
CEMS	Continuous Emissions Monitoring System
DMA	Marine Gas Oil (MGO) at or below 1.5% sulfur
DMB	Marine diesel oil at or below 0.1% sulfur
ECA	Emissions Control Area
EPA	US Environmental Protection Agency
GRE	Glass Reinforced Epoxy
HFO	Heavy Fuel Oil (Grades IFO 180 to 700 centistokes)
IMO	International Maritime Agency
LSFO	Low Sulfur Fuel Oil
NTU	National Turbidity Units
OGV	Ocean Going Vessel
PAH	Polycyclic Aromatic Hydrocarbons
ISO	International Standards Organization
TEU	Twenty-foot Equivalent Units
VGP	UA EPA Vessel General Permit
pH	Measure of the acid/base properties of water
mg/L	Milligrams Per Liter
µg/L	Micrograms Per Liter
ppm	Parts Per Million
ppb	Parts Per Billion
CO	Carbon Monoxide
CO_2	Carbon Dioxide
NO_2	Nitrogen Dioxide
NOx	Nitrogen Oxides (NO & NO_2)
PM	Particulate Matter
SOx	Sulfur Dioxide
THC	Total Hydrocarbon Content
VOC	Volatile Organic Compounds

Summary of Results

Emissions

Testing the emissions resulting from combusting HFO and MGO followed the ISO 8178-D2 marine engine certification cycles. Real-time gaseous emissions data (CO_2, CO, NOx, THC, SOx, and PM) were sampled before and after the scrubber and particulate matter filter samples were collected and analyzed in a laboratory to quantify the total (PM 2.5) emissions and reductions. The data support the design criteria established for the project and all regulatory requirements.

The scrubber reduced the SOx emission by up to 99% and PM up to 70% when running HFO fuel; on MGO, SOx was reduced up to 97% and PM up to 78%. The data are fully detailed in Tables 1A & 1B. SOx and PM reductions were generally consistent for both fuels across all engine loads. The variation in PM reductions for both fuels is consistent with the engine loads prescribed in the test cycles; lower engine loads produce higher concentrations of PM because the engines turn less of the fuel into work than at higher loads. There were no variations in emission levels for similar loads during the testing period. Removal efficiencies will remain constant for the operating life of the scrubber as long as the volume and pressure of the washwater is maintained.

NOx reductions for HFO of 2% to 5%; MGO 2% to 8% are identified in Tables 1A & B. The solubility of NO_2 is the only mechanism for decreasing NOx in the scrubber (maximum theoretical reduction of less than 10%). This data was recorded by the Chemiluminescence technology included in the RAVEM portable particulate/gaseous measurement system.

See Appendix A for additional discussion.

Discharges

Washwater discharged from the treatment system complies with MARPOL IV and the NPDES General permit issued for Exhaust Gas Cleaning Devices by EPA.

Standard:	Test Result:
• pH: 6.5 measured at the overboard discharge point	6.5 pH
• PAH: 50 µg/L above inlet water upstream of reaction water	6.96 PAH
• Turbidity: 25 NTU above inlet water	22.7 NTU

The high turbidity and TSS of the discharge sample (22.7) compared to its field duplicate (7.54) indicate that excess sediment was likely present in the sampling pipes at the time of sample collection. It is likely that the sampling port plumbing was not thoroughly flushed prior to the collection of the samples. The high solids content of these samples is responsible for the elevated metals levels reported such as Copper (Cu) and Zinc (Zn). This does not reflect metals discharges from the scrubber system which contains no Cu or Zn materials or a concentration of these metals in the harbor water above approved levels.

Additional discharge samples taken from the scrubber in February, 2013 show Cu as not detected above the reporting limit and Zn at 16.7, was far below the water quality criteria of 90 µg/L.

INTRODUCTION

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Purpose statement:
The primary focus of this project was to reduce the emission of SOx from an Ocean Going Vessel using an Exhaust Gas Cleaning Device to meet the IMO Fuel Sulfur Limits in Emission Control Areas and further to reduce PM, and VOC emissions. The project demonstrated that a single low maintenance seawater scrubbing device installed on three auxiliary engines successfully treated the emissions from high-sulfur and low-sulfur marine diesel fuels, reduced the targeted contaminants in the exhaust stream, removed the waste from the washwater prior to discharge overboard and maintained the pH of the discharged water within the IMO guidelines. This same device can be scaled up to be used on main engines achieving the same technical results.

Technology:
The Exhaust Gas Cleaning System is a multi-stage device that uses seawater to “scrub” pollutants from marine diesel engine exhaust. Built from high quality alloy steels and glass reinforced epoxy compounds this device can be used to treat the emissions from a wide variety of marine engines and fuels. The natural buffering effect of the alkalinity in water is exploited to remove sulfur dioxide in the emission; the high turbulence within the scrubber agglomerates unburned hydrocarbon compounds with particulate matter around minute air bubbles allowing them to be removed in a multi-stage washwater treatment plant. Total Hydrocarbon Content is used to describe the quantity of the measured hydrocarbon impurities present in the gas stream. All recovered solids are disposed ashore as hazardous waste and the treated washwater is discharged overboard.

The fuels used during the testing were a Heavy Fuel Oil, IFO580 between 2.3-2.5% sulfur content and ARB compliant Marine Gas Oil at 0.5% sulfur. Both emissions and discharges from the scrubber were tested using EPA standard test methods and equipment as well as by an on-board Continuous Electronic Monitoring System (CEMS). With the scrubber running HFO fuel, the reductions in sulfur were all in the range of 98-99% and fine particulate matter (PM 2.5) reductions from 56-70%. MGO fuel sulfur reductions range from 95-98% and PM from 68-75%.

Note:
This program followed MEPC 59/24/Add.1ANNEX 9 RESOLUTION MEPC.184(59), adopted on 17 July 2009 titled “2009 GUIDELINES FOR EXHAUST GAS CLEANING SYSTEMS” and included additional requirements as specified by ARB.

1.0: Vessel, Engines and Scrubber
APL England IMO: 9218650 a 65,000mt 5510 TEU container ship owned and operated by **APL Bermuda Ltd. ("APL")**. This ship was built in 2001 by Samsung Heavy Industries Co. Ltd. Auxiliary engines three (3) MAN B&W 7L32/40, 4-cycle, 720 RPM 3,270 kW.

Figure 1-1: August 2012 shows the operating scrubber to right of the funnel

Specific Emission Control Technology Used:

Hamworthy/Krystallon Scrubber: Model 1#8M3, 48,000 Nm3/h with capacity for three 3,270 kW engines operating at 90% MCR simultaneously
Date of manufacture: 2010
Hours of Service: New; designed for the specific vessel
Service Designation: Continuous
Operation/Maintenance Manual: Approved by the vessels' Classification Society
Commissioned in November 2011

Figure 1-2: Scrubber to right of funnel and de-aeration tank to the left viewed from stern

Figure 1-3: On the day of commissioning with two B&W 7L32/40's running the scrubber exhaust is clear and has no plume

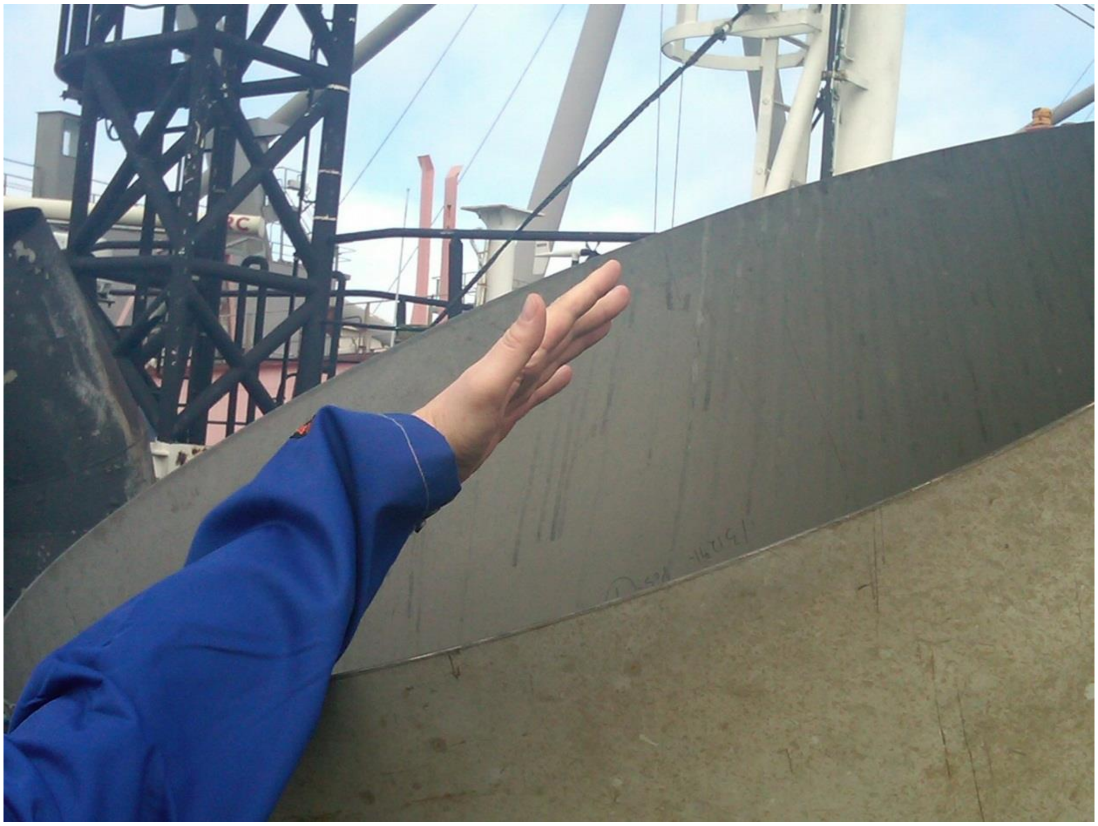
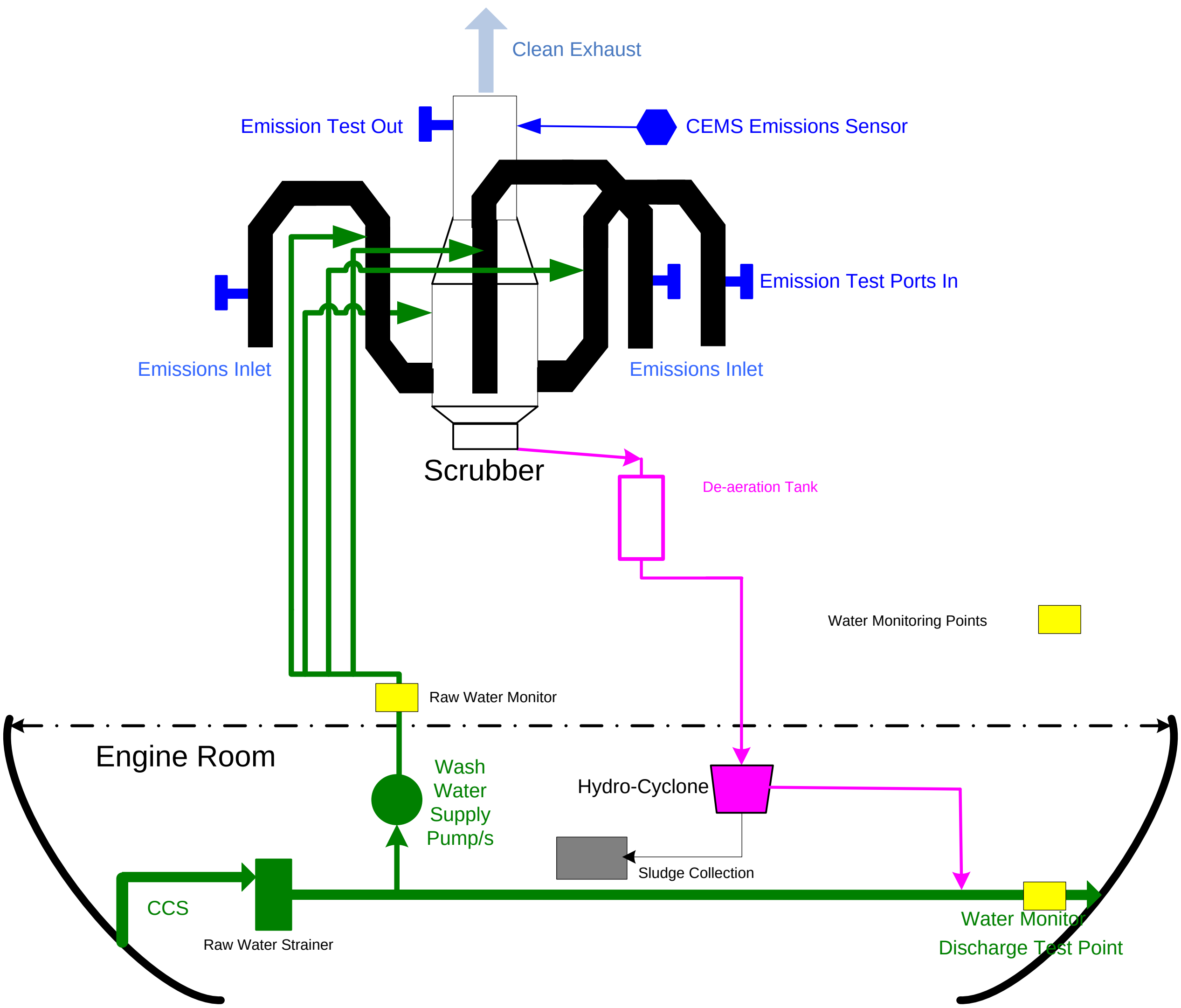


Figure 1-4: One of three (3) MAN B&W 7L32/40, 4-cycle, 720 RPM 3,270 kW Auxiliary Engines connected to the scrubber

Figure 1-5: Scrubber Layout and Monitoring Points



2.0: Parties involved in the project

Ports of LA/LB, project funding
APL Bermuda Ltd., APL England crews, Los Angeles and Singapore Office
Hamworthy/Krystallon Ltd., Design and fabrication of scrubber, supervision of installation, commissioning and training
Yiu Lian Dockyards (Shekou) Limited, dry-dock services, procurement of mechanical and electrical equipment, installation of the scrubber and supporting structure
infoWedge and EF&EE, El Dorado Hills, CA emissions testing and reporting
EarthCon, Seattle, WA washwater sampling and data management
Columbia Analytical Laboratories, Kelso, WA washwater testing
Bluefield Holdings, Seattle, WA overall project management

3.0: Port Calls and Testing

3.1 Scrubber operation in the Port of LA

The APL England operated two auxiliary engines while running the scrubber in LA during four port calls with an actual load of 1.2 MW on each engine during calls averaging 72 hours. The scrubber was brought on-line approximately 25 nm offshore and was operated continuously until the vessel exited state waters.

Scrubber Test Dates
November 30, 2011
January 11, 2012
May 23, 2012 (testing conducted at berth)

> **Note**: Emissions were not tested during maneuvering in LA due to the large amount of equipment that would have to be removed from the ship at sea. These tests were conducted on April 23-24 during transit between Kaohsiung, Taiwan and Chiwan, China.

August 4, 2012

3.1.1 Fuel used on the APL England

3.1.2 Fuel

During emissions testing, IFO 580 and Marine Gas Oil were burned in the auxiliary engines. Fuel blending during switchover of fuels is responsible for slight variations in sulfur content from those listed in the Bunker Delivery Notes conveyed by fuel suppliers.

All fuel used in this test program was provided from on-board stores. Under IMO regulation, on January 1, 2012, the global limit for Heavy Fuel Oil used in OGV's could not contain more than 3.5% sulfur therefore, APL started bunkering with fuel below 3.5% in October, 2011. This fuel is segregated from other fuels on the vessel to allow APL to certify that by January 1, 2012 there are no fuels above the IMO limit. On or before August 1, 2012, to meet North American Emission Control Area limits, all OGV's had to burn fuel containing less than 1% Sulfur. APL uses distillate fuel to comply with this requirement in the ECA and California waters. Records from each bunkering event stored on the vessel were made available to the emissions test contractor. They confirmed the appropriate sulfur content of the fuel.

Whenever an engine is switched from one fuel to the other a blending of the two fuel types occurs in the system and continues until the former fuel is flushed by the latter fuel. When fuel switches had to occur during testing, up to 60 minutes was allowed for the new fuel to become the dominant component of the mixture. However, it was assumed that due to varying engine loads and the resulting fluctuating fuel usage some mixing could persist for a longer period, so fuel samples were taken during testing to allow the determination of the fuel mixing ratio during the test.

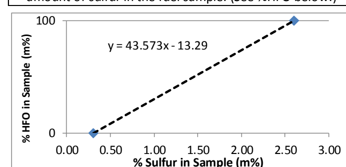
Fuel Blending Calculation

Fuel Sample Analysis Results (Inspectorate)

Sample Description	Pure HFO	MGO	MGO	Pure MGO	HFO	HFO
Sample Date-ID	20120425-01	20120425-02	20120425-03A/B	20120523-01/02	20120523-03	20120523-04
Lower Heating Value (MJ/kg)	40.237			42.599		
Mass%C (g C/100 g fuel)	85.5			86.8		
Mass%H (g H/100 g fuel)	9.7			13.2		
Mass%S (g S/100 g fuel)	2.60	0.860	0.659	0.305	1.89	2.36
Mass%N (g N/100 g fuel)	0.4					
Notes:	per BDN: HFO S = 2.51%, MGO S = 0.5%			per BDN: HFO S = 2.23%, MGO S = same (0.5%)		
	BDN = Bunker Delivery Note					

Calculation of Fuel Blending based upon sulfur content

- We have one sample of pure HFO and one of pure MGO.
- For a period of time after switching from one fuel to the other, the fuel to the engine is a blend (HFO/MGO)
- We can calculate the blend of HFO/MGO from the amount of sulfur in the fuel sample. (See %HFO below.)



% Sulfur	% HFO
2.60	100
0.305	0

Values Calculated from Analysis Results

Convert mass percent values to molar ratios, normalized to carbon content of fuel.

Mol%C (mol C/100 mol fuel)	7.125			7.233		
Mol%H (mol H/100 mol fuel)	9.604			13.07		
Mol%S (mol S/100 mol fuel)	0.08100	0.02679	0.02053	0.00950	0.05888	0.07352
Mol%N (mol N/100 mol fuel)	0.02857					
MolRatioC (mol C/mol C)	1			1		
MolRatioH (mol H/mol C)	1.348			1.807		
MolRatioS (mol S/mol C)	0.011			0.001		
MolRatioN (mol N/mol C)	0.004					

Determine important values for other calculations from each sample based upon blending between fuels (via sulfur content).

% HFO in fuel	100.0	24.2	15.4	0.0	69.1	89.5	<== from equation developed above
Lower Heating Value (kJ/kg)	40237	42027.8	42234.7	42599	40967.7	40484.0	<== ratio between measured HFO & MGO values
MassRateCO2 (g CO2/g fuel)	3.14	3.171	3.175	3.18	3.150	3.140	<== ratio between measured HFO & MGO values
MassFracS (g S/g fuel)	0.0260	0.00860	0.00659	0.00305	0.0189	0.0236	<== all are measured values
MassFracSO2 (g SO2/g fuel)	0.0519	0.01717	0.01316	0.00609	0.0377	0.0471	<== all are measured values (assumes all S becomes SO2)
Notes:	meas'd	calc'd	calc'd	meas'd	calc'd	calc'd	

Last edited on 26 Sep 2012 by Andrew Burnette, infoWedge.

Atomic Masses

AtmMassCarbon	12.0	g/mol
AtmMassHydrogen	1.01	g/mol
AtmMassSulfur	32.1	g/mol
AtmMassNitrogen	14.0	g/mol
AtmMassOxygen	16.0	g/mol

A Temporary Experimental or Research Exemption (Executive Order G-11-092) issued under California Code of Regulations, title 13, section 2299.2(c)(6) and title 17, section 93118.2(c)(6) was signed by the Executive Officer of the State of California Air Resources Board, allowing the APL England to burn non-compliant fuels in California during this research program.

3.1.3 Equipment durability

The scrubber design life is 25-years. All components exposed to seawater and treated exhaust gas are made of high alloy stainless steel. Water piping is made of Coast Guard and class approved Glass Reinforced Epoxy (GRE). There are no internal moving parts, no catalysts or components that required degreening.

There are no additives used in the washwater and no parts that require replacement after a fixed period of use. All pumps, valves, piping, electrical components etc. are commodity items in regular commercial use on large marine vessels. They are replaced on an as needed basis.

3.1.4 Periodic maintenance of the scrubber

- Inspect emissions and discharge monitoring data and sensors, daily
- Every 3-months service pH probes, inspect pumps & drives, piping
- Inspect exhaust ducting for emissions and water leaks, daily
- Inspect volume of solid waste in the disposal container weekly
- Switch the waste container at 90% maximum capacity (about every 4 months)
- Replace pump seals yearly or every 10,000 hours
- Replace demisters in scrubber every 5-years
- Replace, pumps, drives and electrical components as needed
- The scrubber is made of high chromium stainless steel; all the water piping and valves are made of epoxy resin and do not require maintenance unless there is a failure; there are no moving parts inside the scrubber and nothing requiring maintenance

3.1.5 Operator feedback

After the scrubber was commissioned in December 2011 various improvements were made based on input from the operator. As an example, the high pressure water spray nozzle attachment mechanisms were modified to reduce maintenance. Also the air operated motorized isolation valves in the exhaust duct from each of the three auxiliary engines were upgraded to overcome operating problems caused by soot build up on the valves which caused them to stick. Finally, various upgrades to the automation software were made to improve operator oversight.

3.1.6 Observations and lessons learned

The captains and crew come and go on ships of this type. It is important to initiate a company training program for new crew members to instruct them in the operation and maintenance of new environmental equipment of this type. APL has a longstanding and vital environmental management program which now contains a section on the scrubber operation and fuel switching in California.

4.0: Baseline Engine Testing

The APL England is equipped with a “shaft generator” driven off the propulsion engine when it operates at 71 RPM. It is normally the only source of electrical power when the ship is under way. There are three auxiliary engines installed, any one of the three can be “out of service” and the remaining two can safely satisfy the full electrical load of the ship under all conditions. Since instituting a "slow steaming" program in early 2012 the main engine operates at less than 71 RPM so the vessel no longer operates the shaft generator and relies exclusively on the auxiliary diesel electric generators for AC power.

4.1 Fuel Standards for OGV's in California and the North American Emission Control Area

		Heavy Oil	DMA	ppm	DMB	ppm
8/1/2012	IMO*	1%				10,000
	CA		1%	10,000		
	CA				0.50%	5,000
1/1/2014	CA		0.10%	1,000	0.10%	1,000
1/1/2015	IMO*				0.10%	1,000
	CA*		0.10%	1,000	0.10%	1,000
* Or use of an emissin control device such as a Scrubber						

Hamworthy/Krystallon Seawater Scrubber						
		Heavy Oil	DMA	ppm		**ppm
5/23/2012		2.60%		26,000		8
Calculated		3.50%		35,000		11
5/23/2012			0.305%	3,050		3
** SO2 concentrations measured after the scrubber						

4.1.1 Description of auxiliary generator electrical loads

"Hotelling" or house load is the sum of the electrical load from all pumps, lighting, ventilation and refrigerated containers. This load is fairly stable and on this vessel requires one or two auxiliary generators producing 1.2 to 2.4 MW of electrical load. The only variations are caused by the offloading/loading of refrigerated units (8 kW each).

"Maneuvering" load includes house load and the load attributed to the electric bow thruster used when the ship is entering or leaving port. Electrical output of up to 2,000 Kw is required when the thruster is activated during the arrival and departure sequence each of which takes approximately three hours. Large load changes are frequent. The maximum electrical load generated during maneuvering was 4.9 MW.

"Underway' load, describes the electrical load when the ship is moving under the power of the main engine and the electrical demand is the house load plus cooling water pumping for the main engine. This load can be met by the shaft generator, if it is being used or alternatively by one or two auxiliary generators. This load is up to 2.4 MW.

Although there are three (3) equally sized auxiliary engines installed on the vessel only two engines are typically operated simultaneously. The scrubber design will accommodate the simultaneous operation all three engines.

4.1.2 Emission test cycle

To test the performance of the scrubber under high load conditions, emissions were tested as the vessel maneuvered from the berth in Kaohsiung, Taiwan and while underway to the port of Chiwan on mainland China on April 25-26, 2012. The highest loads on the scrubber during this test program were recorded during this overnight transit. Hotelling loads were tested at berth at the APL Global Gateway South Container Terminal in Los Angeles, CA on May 23, 2012. During all scrubber testing events for each fuel, measurements were taken upstream and downstream of the scrubber.

Three successive test runs were conducted at each load setting to establish a baseline emission from the engines using each fuel type. Exhaust gasses were extracted from the emission ductwork immediately before and after the scrubber. See the infoWedge test plan in Appendix B, for photos and a schematic of the of sample port locations. The before and after scrubber sample ports on all three auxiliaries are conducive to short sampling lines of approximately a meter.

Each auxiliary generator operates at a fixed RPM and has a kW meter which reports electrical output. During each emission test the auxiliary engines were operated under a steady load. Engine power output was calculated using the brake power output of the engine (i.e., power at the flywheel/output shaft) using the brake-specific fuel consumption for the engine, then the engine power output was determined by dividing the fuel rate (g/hr) by its brake-specific fuel consumption (g/kW-hr). The fuel rate was calculated from the manufacturers' power output curve and recorded in the test data log.

The emissions were measured following the ISO certification cycle both before and after the scrubber. The protocol requires the following:

- Allowing the gaseous emissions to stabilize before measurement. Recording fuel flow rate and measuring air/fuel ratio in the "engine out" exhaust to calculate mass flow rate. The engine RPM, displacement, boost pressure and intake manifold temperature were recorded and the exhaust flow velocity was spot measured to independently validate the mass flow rate of the exhaust.
- Measuring PM concentrations for a time sufficient to acquire measurable filter mass.

Due to the operating conditions outlined above, the actual engine loads differed slightly from the target loads due to the number of refrigerated cargo containers on the ship and weather conditions on the day of the high load tests. Loads varied by 100 to 200 kW on certain tests; all load data are listed on Tables 1A and 1B. The range of the load changes were small and had no significant impact on the final emission reduction levels.

4.1.3 Emission testing instrumentation

4.1.3.1 SEMTECH-DS in use emissions analyzer. This emissions analyzer is a self-contained, extractive flue gas monitoring system utilizing various sensors with an internal sample pump. The DS measures CO_2, CO, O2, NO, NO2 and THC complying with EPA CFR 1065. A separate SO2 sensor system, supplied by another manufacturer was integrated into the DS sample train. See the infoWedge test plan in Appendix A, for a detailed description of the gaseous pollutant measurement systems and quality assurance procedures.

Measurements were taken from the exhaust ductwork before and after the scrubber to establish a baseline as described in 4.3 above. infoWedge technicians installed and operated the test apparatus.

Both average and instantaneous measurements of gas concentrations were used to determine the concentrations of:

- Carbon dioxide (CO_2)
- Carbon monoxide (CO)
- Total Hydrocarbons (THC)
- Nitrogen dioxide (NOx)
- Sulfur dioxide (SO_2)

4.1.3.2 RAVEM portable particulate/gaseous measurement system: This is a unit containing a dilution system, PM filter media holder, and gaseous pollutant measurement instruments. It was used primarily to measure PM emissions in accordance with applicable guidelines in 40 CFR 86 and also to measure several gaseous pollutants in parallel to the SEMTECH-DS system such as CO2 and NO by Chemiluminescence.

All PM samples were analyzed for salt crystals using a non-destructive technique called Proton Induced X-ray Emission (PIXE). The “net” increase in chlorine across the scrubber (calculated by comparing the mass rate of particulate form Cl entering to that of Cl exiting) would be assumed to be attributable to the sodium chloride (NaCl) particles that result from evaporation of seawater in the scrubber. No salt crystals were detected on any of the PM filters.

4.1.3.3 Continuous Emission Monitor (CEMS): The exhaust gas after the scrubber is monitored continuously, using the latest Procal 2000 IR in-situ exhaust gas analyzer for CO_2, SO_2. Over one hundred measurements per second are recorded and stored in a data logger. This information was correlated with the measured data collected on-board.

Gases measured:

- CO 0 - 200ppm / 250mg/Nm3
- CO_2 0 - 15%
- SO2 0 - 100ppm / 280mg/Nm3
- NO 0 - 300ppm / 400mg/Nm3
- H2O 0 - 12%

Data from the Procal Continuous Emissions Monitoring System located after the scrubber were recorded on the on-board data logger and manually entered into a spread sheet during the testing on May 23, 2012. The data compare favorably with measured emissions.

5.0: Washwater treatment and testing

A multi-stage washwater treatment system is employed to remove contaminants from the seawater used in the scrubber prior to discharge overboard. The first stage of treatment is a de-aeration tank used to remove entrained air from the washwater to facilitate settling of particulates, a combination of unburned fuel and carbon removed from the engine exhaust. Also, the seawater used in the scrubber, particularly in port, may be turbid which introduces various mineral solids in the water. Stage two treatments consist of a hydro-cyclone that centrifuges the washwater to remove these solids from the waste stream along with the diesel particulates. In the final stage, seawater is mixed with the treated washwater to insure that pH meets the IMO and the EPA vessel general permit for discharges incidental to the normal operation of vessels (VGP).

Section 2.2.26 VGP Exhaust Gas Scrubber Washwater Discharge

"Exhaust gas scrubber washwater discharge must not contain oil, including oily mixtures, in quantities that may be harmful as determined in accordance with 40 CFR Part 110. Sludge generated from exhaust gas scrubber washwater discharge must not be discharged in waters subject to this permit. In addition, EPA recommends that owner/operators of vessels with exhaust gas cleaning systems that result in washwater discharges follow the guidelines set out in section 10 for Exhaust Gas Cleaning Systems (IMO Resolution MEPC.170(57))."

IMO washwater discharge standards:

- pH: 6.5 measured at the overboard discharge point
- PAH: 50 µg/L above inlet water measured upstream of reaction water
- Turbidity: 25 NTU above inlet water

The washwater monitoring system installed on the APL England contains sensors on the intake and discharge lines to measure the following:

- Temperature, Turbidity, PAH and at the washwater inlet
- Washwater supply pressure to the scrubber
- Temperature, PAH, pH and Turbidity downstream of the treatment plant

- Temperature at washwater discharge
- Differential pressure across the water treatment plant
- Exhaust gas pressure at the scrubber inlet
- Exhaust gas temperature at the scrubber outlet

In addition to the continuous monitoring data discrete washwater samples were collected on May 23, 2012 from various points in the washwater treatment system; the raw water intake monitoring point, at the discharge monitor and at the overboard discharge. Samples were collected and tested for chemical oxygen demand (COD), dissolved metals, pH, total suspended solids (TSS), and hydrocarbons as PAHs.

Samples were also collected during the emissions testing conducted on April 25, 2012 while the ship was underway between Taiwan and mainland China. However, Chinese customs refused to allow the samples to be offloaded in Chaiwan for transshipment to the US even though all the appropriate paperwork had been executed by the ships port agent and FedEx. The holding times prescribed in the Test Methods would have been exceeded by many weeks if the samples were offloaded in Singapore and flown to the US therefore, these samples were discarded.

A second discharge sampling event was conducted on February 23, 2013 due to elevated TSS and Turbidity identified in the samples collected on May 23, 2012. These samples were tested for Copper (Cu) which was not detected above the reporting limit in µg/L and Zinc (Zn) at 16.7 µg/L, well below the water quality criteria of 90 µg/L.

All samples and field blanks collected in LA were shipped under Chain-of-Custody to Columbia Analytical Services in Kelso, Washington. EPA methods were used to test each sample and field blank. Sample collection and preservation techniques specified in the analytical methods were followed. The analytical methods and water quality criteria are listed below.

Laboratory quality control (QC) results (method blanks, laboratory control samples, matrix spikes, and matrix duplicates) were evaluated by a qualified water chemist at EarthCon under contract to Bluefield Holdings. A comparison of the intake and discharge results was used to determine if concentration changes are occurring during operation. It should be noted that analytical methods specifically for testing saline waters are not currently available. Matrix interferences caused by naturally occurring marine water components may elevate detection limits, especially for metals.

EarthCon chemistry quality assurance department managed the data from the testing program.

References for Water Quality Testing

USEPA 2009: National Recommended Water Quality Criteria, United States Environmental Protection Agency Office of Water, Office of Science and Technology.

USEPA 2006: National Primary Drinking Water Standards. United States Environmental Protection Agency Office of Water. http://www.epa.gov/safewater/contaminants/index.html

5.1: Data handling and reporting

infoWedge analyzed and interpreted the emissions data collected during the testing events on April 25 and May 23. Test results were presented in tabular form (including, fuel data, and engine parameters). EarthCon assembled the discharge samples and managed the QA/QC for the washwater data. Bluefield Holdings assembled all the data in a single document and prepared the final report.

Table 1A: HFO Fuel Summary of Emission Test Results

Summary of results -- HFO fuel (updated 2012.10.24) **Scrubber Inlet/Outlet Concentrations and Removals use NOx/CO2 ratios from chemiluminescence**

Low Scrubber Load			Target Load =	1.2	MW	% Load	Date:	23-May-12									
Aux Engine 3			Actual Load =	1.4	MW	50%	**HFO**	Fuel %S =	2.4	g S/100 g Fuel							
Inlet						Outlet						Reduction across Scrubber					
CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2	CO	NOx	THC	SO2	PM
kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	%	%	%	%	%	%
1.00	1.87	12.93	0.35	15.31	2.51	1.00	2.15	12.70	0.30	0.22	0.79	0%	-14%	2%	15%	99%	68%

Med Scrubber Load			Target Load =	2.4	MW	% Load	Date:	23-May-12									
Aux Engine 1			Actual Load =	2.4	MW	83%	**HFO**	Fuel %S =	1.9	g S/100 g Fuel							
Inlet						Outlet						Reduction across Scrubber					
CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2	CO	NOx	THC	SO2	PM
kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	%	%	%	%	%	%
1.00	0.71	17.37	0.33	12.56	1.83	1.00	0.72	16.63	0.29	0.17	0.80	0%	-1%	4%	12%	99%	56%

Med Scrubber Load			Target Load =	2.4	MW	% Load	Date:	23-May-12									
Aux Engine 3			Actual Load =	2.4	MW	83%	**HFO**	Fuel %S =	2.1	g S/100 g Fuel							
Inlet						Outlet						Reduction across Scrubber					
CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2	CO	NOx	THC	SO2	PM
kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	%	%	%	%	%	%
1.00	0.82	15.37	0.30	14.88	1.99	1.00	0.84	14.86	0.27	0.23	0.86	0%	-3%	3%	11%	98%	57%

High Scrubber Load			Target Load =	4.7	MW	% Load	Date:	25-Apr-12									
Aux Engines 1 & 3			Actual Load =	4.9	MW	88.5%	**HFO**	Fuel %S =	2.6	g S/100 g Fuel							
Inlet						Outlet						Reduction across Scrubber					
CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2	CO	NOx	THC	SO2	PM
kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	%	%	%	%	%	%
1.00	1.37	13.52	0.28	16.03	2.28	1.00	1.38	12.88	0.17	0.3	0.69	0%	-1%	5%	39%	98%	70%

Scrubber Outlet Exhaust Pollutant Emission Factors

Low Scrubber Load			Target Load =	1.2	MW		Date:	23-May-12					
Aux Engine 3			Actual Load =	1.4	MW		**HFO**	Fuel %S =	2.4	g S/100 g Fuel			
Fuel Flow	Flow rates from Scrubber						Engine Bra	Pollutant Emission Factors					
Rate	CO2	CO	NOx	THC	SO2	PM	Output	CO2	CO	NOx	THC	SO2	PM
kg/hr	kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kW	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
300	943.4	2024.3	11982.55	283.0317	205.6802	746.4728	1428	0.661	1.418	8.392	0.198	0.144	0.523

Med Scrubber Load			Target Load =	2.4	MW		Date:	23-May-12					
Aux Engine 1			Actual Load =	2.4	MW		**HFO**	Fuel %S =	1.9	g S/100 g Fuel			
Fuel Flow	Flow rates from Scrubber						Engine Bra	Pollutant Emission Factors					
Rate	CO2	CO	NOx	THC	SO2	PM	Output	CO2	CO	NOx	THC	SO2	PM
kg/hr	kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kW	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
486	1530.0	1096.32	25439.82	438.7431	261.153	1222.846	2429	0.630	0.451	10.475	0.181	0.108	0.504

Med Scrubber Load			Target Load =	2.4	MW		Date:	23-May-12					
Aux Engine 3			Actual Load =	2.4	MW		**HFO**	Fuel %S =	2.1	g S/100 g Fuel			
Fuel Flow	Flow rates from Scrubber						Engine Bra	Pollutant Emission Factors					
Rate	CO2	CO	NOx	THC	SO2	PM	Output	CO2	CO	NOx	THC	SO2	PM
kg/hr	kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kW	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
489	1536.7	1298.20	22836.53	408.5841	347.6426	1323.173	2429	0.633	0.535	9.403	0.168	0.143	0.545

High Scrubber Load			Target Load =	4.7	MW		Date:	25-Apr-12					
Aux Engines 1 & 3			Actual Load =	4.9	MW		**HFO**	Fuel %S =	2.6	g S/100 g Fuel			
Fuel Flow	Flow rates from Scrubber						Engine Bra	Pollutant Emission Factors					
Rate	CO2	CO	NOx	THC	SO2	PM	Output	CO2	CO	NOx	THC	SO2	PM
kg/hr	kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kW	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
993	3113.8	4303.063	40091.68	525.6987	820.9146	2135.281	4865	0.640	0.884	9.403	0.108	0.169	0.439

Scrubber Inlet (Engine-Out) Exhaust Pollutant Levels

Low Scrubber Load			Target Load =	1.2	MW		Date:	23-May-12				
Aux Engine 3			Actual Load =	1.4	MW		**HFO**	Fuel %S =	2.4	g S/100 g Fuel		
Flow rates from Scrubber							Pollutant Emission Factors					
CO2	CO	NOx	THC	SO2	PM		CO2	CO	NOx	THC	SO2	PM
kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr		kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
943.4	1768.9	10606.8	333.9	14445.8	2367.3		0.661	1.239	8.543	0.234	10.117	1.658

Med Scrubber Load			Target Load =	2.4	MW		Date:	23-May-12				
Aux Engine 1			Actual Load =	2.4	MW		**HFO**	Fuel %S =	1.9	g S/100 g Fuel		
Flow rates from Scrubber							Pollutant Emission Factors					
CO2	CO	NOx	THC	SO2	PM		CO2	CO	NOx	THC	SO2	PM
kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr		kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
1530.0	1081.1	23341.1	501.4	19216.2	2794.0		0.630	0.445	10.944	0.206	7.913	1.150

Med Scrubber Load			Target Load =	2.4	MW		Date:	23-May-12				
Aux Engine 3			Actual Load =	2.4	MW		**HFO**	Fuel %S =	2.1	g S/100 g Fuel		
Flow rates from Scrubber							Pollutant Emission Factors					
CO2	CO	NOx	THC	SO2	PM		CO2	CO	NOx	THC	SO2	PM
kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr		kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
1536.7	1260.3	20561.3	460.6	22872.0	3054.9		0.633	0.519	9.724	0.190	9.418	1.258

High Scrubber Load			Target Load =	4.7	MW		Date:	25-Apr-12				
Aux Engines 1 & 3			Actual Load =	4.9	MW		**HFO**	Fuel %S =	2.6	g S/100 g Fuel		
Flow rates from Scrubber							Pollutant Emission Factors					
CO2	CO	NOx	THC	SO2	PM		CO2	CO	NOx	THC	SO2	PM
kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr		kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
3113.8	4266.1	43178.8	859.3	49908.9	7102.0		0.640	0.877	8.654	0.177	10.258	1.460

Table 1B: MGO Fuel Summary of Emission Test Results

Summary of Results -- MGO fuel (updated 2012.12.12)

Scrubber Inlet/Outlet Concentrations and Removals use NOx/CO2 ratios from chemiluminescences

Low Scrubber Load — Target Load = 1.2 MW, % Load, Date: 23-May-12
Aux Engine 3 — Actual Load = 1.4 MW, 50%, **MGO** Fuel % S = 0.31 g S/100 g Fuel (calculation)

Inlet						Outlet						Reduction across Scrubber					
CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2	CO	NOx	THC	SO2	PM
kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	%	%	%	%	%	%
1.00	1.32	12.0	0.41	2.01	0.60	1.00	1.40	11.7	0.33	0.08	0.19	0%	-6%	2%	19%	96%	68%

Med Scrubber Load — Target Load = 2.4 MW, % Load, Date: 23-May-12
Aux Engine 3 — Actual Load = 2.3 MW, 83%, **MGO** Fuel % S = 0.31 g S/100 g Fuel

Inlet						Outlet						Reduction across Scrubber					
CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2	CO	NOx	THC	SO2	PM
kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	%	%	%	%	%	%
1.00	0.73	12.1	0.34	1.93	0.50	1.00	0.74	11.8	0.29	0.08	0.11	0%	-1%	2%	14%	96%	78%

Med Scrubber Load — Target Load = 2.4 MW, % Load, Date: 23-May-12
Aux Engine 1, MGO — Actual Load = 2.3 MW, 83%, **MGO** Fuel %S = 0.31 g S/100 g Fuel

Inlet						Outlet						Reduction across Scrubber					
CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2	CO	NOx	THC	SO2	PM
kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	%	%	%	%	%	%
1.00	0.76	13.6	0.40	1.92	0.52	1.00	0.77	13.3	0.32	0.10	0.15	0%	-1%	2%	19%	95%	71%

High Scrubber Load — Target Load = 4.7 MW, % Load, Date: 25-Apr-12
Aux Engines 1 & 3 — Actual Load = 4.8 MW, 89%, **MGO** Fuel %S = 0.76 g S/100 g Fuel

Inlet						Outlet						Reduction across Scrubber					
CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2/CO2	CO/CO2	NOx/CO2	THC/CO2	SO2/CO2	PM/CO2	CO2	CO	NOx	THC	SO2	PM
kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	kg/kg	g/kg	g/kg	g/kg	g/kg	g/kg	%	%	%	%	%	%
1.00	1.15	11.02	0.43	4.52	1.29	1.00	1.67	10.11	0.30	0.13	0.33	0%	-45%	8%	31%	97%	75%

CO result appears to be an outlier. Drift correction does not account for large difference from other CO results.

Scrubber Outlet Exhaust Pollutant Emission Factors

Low Scrubber Load — Target Load = 1.2 MW, Date: 23-May-12
Aux Engine 3 — Actual Load = 1.4 MW, **MGO** Fuel % S = 0.31 g S/100 g Fuel

Fuel Flow	Flow rates from Scrubber						Engine Bra	Pollutant Emission Factors					
Rate	CO2	CO	NOx	THC	SO2	PM	Output	CO2	CO	NOx	THC	SO2	PM
kg/hr	kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kW	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
286	908.8	1268.50	10613.7	299.91	72.48	177.01	1428	0.636	0.888	7.433	0.210	0.051	0.124

Med Scrubber Load — Target Load = 2.4 MW, Date: 23-May-12
Aux Engine 3 — Actual Load = 2.3 MW, **MGO** Fuel % S = 0.305 g S/100 g Fuel

Fuel Flow	Flow rates from Scrubber						Engine Bra	Pollutant Emission Factors					
Rate	CO2	CO	NOx	THC	SO2	PM	Output	CO2	CO	NOx	THC	SO2	PM
kg/hr	kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kW	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
450	1431.7	1056.94	16950.95	418.31	111.98	153.71	2316	0.618	0.456	7.320	0.181	0.048	0.066

Med Scrubber Load — Target Load = 2.4 MW, Date: 23-May-12
Aux Engine 1 — Actual Load = 2.3 MW, **MGO** Fuel % S = 0.305 g S/100 g Fuel

Fuel Flow	Flow rates from Scrubber						Engine Bra	Pollutant Emission Factors					
Rate	CO2	CO	NOx	THC	SO2	PM	Output	CO2	CO	NOx	THC	SO2	PM
kg/hr	kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kW	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
448	1424.7	1096.52	18971.7	460.24	145.23	215.56	2316	0.615	0.474	8.193	0.199	0.063	0.093

High Scrubber Load — Target Load = 4.7 MW, Date: 25-Apr-12
Aux Engines 1 & 3 — Actual Load = 4.8 MW, **MGO** Fuel % S = 0.760 g S/100 g Fuel

Fuel Flow	Flow rates from Scrubber						Engine Bra	Pollutant Emission Factors					
Rate	CO2	CO	NOx	THC	SO2	PM	Output	CO2	CO	NOx	THC	SO2	PM
kg/hr	kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kW	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
934	2965.2	4956.37	29987.72	886.53	378.59	966.22	4769	0.622	1.039	6.288	0.186	0.079	0.203

Scrubber Inlet (Engine-Out) Exhaust Pollutant Levels

Low Scrubber Load — Target Load = 1.2 MW, Date: 23-May-12
Aux Engine 3 — Actual Load = 1.4 MW, **MGO** Fuel % S = 0.31 g S/100 g Fuel

Flow rates from Scrubber						Pollutant Emission Factors					
CO2	CO	NOx	THC	SO2	PM	CO2	CO	NOx	THC	SO2	PM
kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
908.8	1195.1	11090.7	370.6	1822.8	548.9	0.636	0.837	7.615	0.260	1.277	0.384

Med Scrubber Load — Target Load = 2.4 MW, Date: 23-May-12
Aux Engine 3 — Actual Load = 2.3 MW, **MGO** Fuel % S = 0.31 g S/100 g Fuel

Flow rates from Scrubber						Pollutant Emission Factors					
CO2	CO	NOx	THC	SO2	PM	CO2	CO	NOx	THC	SO2	PM
kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
1431.7	1049.9	17659.5	486.9	2756.4	711.5	0.618	0.453	7.459	0.210	1.190	0.307

Med Scrubber Load — Target Load = 2.4 MW, Date: 23-May-12
Aux Engine 1, MGO — Actual Load = 2.3 MW, **MGO** Fuel % S = 0.31 g S/100 g Fuel

Flow rates from Scrubber						Pollutant Emission Factors					
CO2	CO	NOx	THC	SO2	PM	CO2	CO	NOx	THC	SO2	PM
kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
1424.7	1087.7	18589.3	568.2	2738.6	747.5	0.615	0.470	8.350	0.245	1.183	0.323

High Scrubber Load — Target Load = 4.7 MW, Date: 25-Apr-12
Aux Engines 1 & 3, MGO — Actual Load = 4.8 MW, **MGO** Fuel % S = 0.76 g S/100 g Fuel

Flow rates from Scrubber						Pollutant Emission Factors					
CO2	CO	NOx	THC	SO2	PM	CO2	CO	NOx	THC	SO2	PM
kg/hr	g/hr	g/hr	g/hr	g/hr	g/hr	kg/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr	g/kW-hr
2965.2	3406.759	37021.8	1282.3	13393.6	3828.6	0.622	0.714	6.849	0.269	2.808	0.803

PM result is higher than expected and appears to be an outlier

Table 2: CEMS LOG Auxiliary Engines 1 & 3 May 23, 2012 SPQ

Continuous Electronic Monitoring System (CEMS) sensors located at the scrubber outlet

	Eng	kW LOAD	SO_2 / CO_2 ratio	SO_2 ppm	CO_2%	S/W Temp	S/W Turbidity	Wash Water Turbidity	Type of Fuel	Fuel Sulfur % by mass
Stage 1										
TEST 1	#3	1220	2	11.7	6.01	26	1.7	2.8	MGO	0.31
TEST 2		1209	2.1	12.9	5.99	26	1.75	2.7	MGO	0.31
TEST 3		1210	1.8	10.8	6.21	26	1.84	2.9	MGO	0.31
Stage 2										
TEST 1	#3	1840	2.3	14.1	6.11	26.7	1.91	10.8	MGO	0.31
TEST 2		1850	1.9	11.6	6.02	26.7	1.9	7.5	MGO	0.31
TEST 3		1810	2.5	15	5.98	26.6	1.85	4.5	MGO	0.31
Stage 3										
TEST 1	#1	1840	2.4	14.6	6.01	26.4	2.6	3.9	MGO	0.31
TEST 2		1820	2.2	13.2	6.15	26.4	2.27	4.8	MGO	0.31
TEST 3		1860	2.5	15.2	6.22	26.4	2.7	6.3	MGO	0.31
Stage 4										
TEST 1	#1	1900	1.7	10.4	5.99	26.7	2.29	3.9	HFO	2.40
TEST 2		1915	1.4	8.7	6.22	26.7	2.35	2.91	HFO	2.40
TEST 3		1901	3.4	21.8	6.4	26.7	2.2	5.05	HFO	2.40
Stage 5										
TEST 1	#3	1898	3	18.5	6.21	26.2	2.32	4.19	HFO	1.90
TEST 2		1901	3.1	20.7	6.71	26.2	2.19	4.28	HFO	1.90
TEST 3		1920	3	19.4	6.62	26.2	2.2	2.72	HFO	1.90
Stage 6										
TEST 1	#3	1169	3.4	21.5	6.31	26.5	2.29	4.06	HFO	2.10
TEST 2		1156	2.9	18.9	6.52	26.5	2.11	4.21	HFO	2.10
TEST 3		1187	3.6	22.3	6.25	26.5	2.31	3.58	HFO	2.10
REMARKS		Three identical tests for each stage								
		pH was not taken due to defective sensor								

Table 3: Scrubber Discharge Testing Results
Polycyclic Aromatic Hydrocarbons (PAHs)
Samples Collected May 23, 2012

Constituent	Analytical Method	Units	Scrubber Discharge		Scrubber Discharge Field Duplicate		Intake		Overboard	
2-Methylnaphthalene	8270D SIM	ug/L	2.6		2.4		0.022	ND	1.3	
Acenaphthene	8270D SIM	ug/L	0.15		0.13		0.022	ND	0.075	
Acenaphthylene	8270D SIM	ug/L	0.041	ND	0.033	ND	0.022	ND	0.019	ND
Anthracene	8270D SIM	ug/L	0.13	ND	0.071	ND	0.022	ND	0.039	ND
Benz(a)anthracene	8270D SIM	ug/L	0.17	J	0.072	J	0.022	ND	0.049	
Benzo(a)pyrene	8270D SIM	ug/L	0.054	J	0.028	J	0.022	ND	0.019	ND
Benzo(b)fluoranthene	8270D SIM	ug/L	0.063	J	0.033	J	0.022	ND	0.019	ND
Benzo(g,h,i)perylene	8270D SIM	ug/L	0.038		0.021	ND	0.022	ND	0.019	ND
Benzo(k)fluoranthene	8270D SIM	ug/L	0.019	ND	0.021	ND	0.022	ND	0.019	ND
Chrysene	8270D SIM	ug/L	0.33		0.22	J	0.022	ND	0.12	
Dibenz(a,h)anthracene	8270D SIM	ug/L	0.02		0.021	ND	0.022	ND	0.019	ND
Dibenzofuran	8270D SIM	ug/L	0.16		0.13		0.022	ND	0.066	
Fluoranthene	8270D SIM	ug/L	0.13	J	0.086	J	0.022	ND	0.05	
Fluorene	8270D SIM	ug/L	0.33		0.29		0.022	ND	0.15	
Indeno(1,2,3-cd)pyrene	8270D SIM	ug/L	0.019	ND	0.021	ND	0.022	ND	0.019	ND
Naphthalene	8270D SIM	ug/L	1.2		1.1		0.033		0.58	
Phenanthrene	8270D SIM	ug/L	1.3		1.1		0.022	ND	0.56	
Pyrene	8270D SIM	ug/L	0.45	J	0.21	J	0.022	ND	0.15	
Total PAH	Calculated	ug/L	**6.995**		**5.799**		**0.033**		**3.100**	

ND - Not detected above the listed reporting limit
J - Estimated value
Results are validated.

Intake is raw water entering the scrubber
Scrubber Discharge (and Duplicate) is treated washwater
The overboard results are for treated water discharged from the vessel
1 µg/L = 1 PPB

Table 4: Scrubber Discharge Testing Results
Metals and Water Quality Parameters
Samples Collected May 23, 2012

Parameter	Analysis Method	Units	Water Quality Criteria	Scrubber Discharge		Scrubber Discharge Field Duplicate		Scubber Intake		Overboard	
Mercury, Total	245.1	ug/L	1.8	0.2	ND	0.2	ND	0.2	ND	0.2	ND
Antimony, Total	200.7	ug/L	640	10	ND	10	ND	10	ND	10	ND
Arsenic, Total	200.7	ug/L	69	10	ND	10	ND	10	ND	10	ND
Beryllium, Total	200.7	ug/L	4.0	0.2	ND	0.2	ND	0.2	ND	0.2	ND
Cadmium, Total	200.7	ug/L	40	0.5	ND	0.5	ND	0.5	ND	0.5	ND
Chromium, Total	200.7	ug/L	1100	205		7	ND	7	ND	7	ND
Copper, Total	200.7	ug/L	4.8	**72.8**	J	**10.3**	J	**6.2**		**16.8**	
Lead, Total	200.7	ug/L	210	10	ND	10	ND	10	ND	30	
Nickel, Total	200.7	ug/L	74	60.7	J	23	J	2	ND	12.8	
Selenium, Total	200.7	ug/L	290	20	ND	20	ND	20	ND	20	ND
Silver, Total	200.7	ug/L	1.9	1.9	ND	1.9	ND	1.9	ND	1.9	ND
Thallium, Total	200.7	ug/L	--	10	ND	10	ND	10	ND	10	ND
Zinc, Total	200.7	ug/L	90	48.9	J	17.6	J	18		**179**	
Turbidity	180.1	NTU	--	22.7	J	7.54	J	4.17		4.27	
Chemical Oxygen Demand (COD)	SM 5220 C	mg/L	--	406		426		398		347	
pH	SM 4500-H+ B	pH units	6.5 - 8.5	**6.07**	J	**5.95**	J	7.91	J	6.51	J
Solids, Total Suspended (TSS)	SM 2540 D	mg/L	--	49.3	J	8.4	J	13		4.3	
Nitrate as Nitrogen	353.2	mg/L	--	0.05	ND	0.05	ND	0.066		0.095	
Nitrate+Nitrite as Nitrogen	353.2	mg/L	--	0.113		0.127		0.066		0.095	
Nitrite as Nitrogen	353.2	mg/L	--	0.096		0.097		0.05	ND	0.05	ND
Sulfate	300.0	mg/L	250	**2520**		**2550**		**2480**		**2480**	

ND - Not detected above the listed reporting limit
J - Estimated value
Results are validated.
Intake is raw water entering the scrubber
Scrubber Discharge (and Duplicate) is treated washwater
The overboard results are for treated water discharged from the vessel
1 µg/L = 1 PPB

Note: The high turbidity and total suspended solids of the discharge sample compared to its field duplicate indicate that excess sediment was present in the sampling system pipes at the time of sample collection. It is likely that this plumbing was inadequately flushed prior to the collection of the samples. The high solids content of the sample is responsible for the elevated metals levels reported such as copper and zinc. The results do not reflect metals discharges from the scrubber or a concentration of these metals in the incoming water above approved levels.

The data below is from the scrubber water instrumentation system installed on the APL England. Incoming and outgoing seawater is measured for Turbidity whenever the scrubber is operated. Between 5/15 and 5/24, 2012 the scrubber operated continuously and some 4,447 discrete measurements were taken.

Parameter	Average of all measurements	Lab Data
Turbidity, Intake	5.3	4.17
Turbidity, Discharge	10.2	7.54 field duplicate
Intake minus Discharge	4.9	3.37

This certified instrument was calibrated just prior to the test program. The data indicates that the samples collected on 5/23/2012 contained significantly more turbidity than was measured by the on-board instrumentation and isolates the sampling error.

Table 4A. Scrubber Discharge Testing Results - Metals and Water Quality Parameters
Samples Collected February 23, 2013

Parameter	Analysis Method	Units	Water Quality Criteria	Discharge		Discharge Field Duplicate	Inlet		Overboard		Difference between Overboard & Inlet
Copper, Dissolved	200.7	ug/L	4.8	2.0	ND	3.2	2.0	ND	2.0	ND	0
Zinc, Dissolved	200.7	ug/L	90	18.4		25.5	13.4		30.1		16.7
Turbidity	180.1	NTU	--	13.7		12.3	4.01		4.34		0.33
Solids, Total Suspended (TSS)	SM 2540 D	mg/L	--	34.0		38.2	8.8		5.6		-3.2

ND - Not detected above the listed reporting limit

6.0 Business case for scrubber technology

The use of exhaust gas cleaning devices, such as seawater scrubbers, on OGV's allows an operator to continue to use low cost, high sulfur fuels and meet all IMO, EPA and ARB fuel sulfur regulations projected over the next 20-years. Currently, low sulfur fuel containing no more than 1.0% sulfur is required in emission control areas (ECA) throughout the world. In 2015 the sulfur content allowed in these areas drops to 0.1% and within a decade to 0.5% globally.

Scrubbing technology can reliably reduce sulfur emissions from any fuel oil to less than 20 parts per million easily meeting the most stringent international and ARB regulatory requirements shown in Section 5.1. And as an additional benefit particulate matter emissions from all fuels are reduced by over 60%.

According to Bunkerworld current premiums in the spring of 2013 for 1.0% LSFO average $80.00 per metric ton over IFO 380 containing 3.5% sulfur and fuels containing less than 0.1% range between $240 to over $350.00 more. In effect, use of a scrubber allows the vessel owner to capitalize a portion of its fuel cost and pay it over the life of the vessel. Using today's fuel prices, in 2020 an owner of an average 8000 TEU vessel could save almost $20-million annually in fuel cost; significantly more than the initial installed cost of a scrubber.

A USDOT study published in 2011, estimated equipment cost for open loop scrubbers like the unit installed on the APL England.

Capacity	Estimated Cost
36MW	$3,100,000
16MW	$2,900,000
12MW	$2,000,000
10MW	$1,800,000
3MW	$1,300,000
1MW	$1,000,000

The equipment necessary for all fuel burning devices on a transpacific containership was estimated at approximately $5,260,000. Installation and commissioning was assumed to be 50% of the equipment cost, engineering/design 7%, and training and documentation 2%. Maintenance and repair expenses were assumed to be 4% annually of the equipment costs.

Exhaust Gas Cleaning Systems Selection Guide
US Department of Transportation
Ship Operations Cooperative Program (SOCP)
Ellicott City, MD
File No. 10047.01
22 February 2011