Measurement of Gaseous Emissions from the Boiler Operating on a PanaMax Class Container Vessel

Final Report (April, 2009)

Contract # 05-412

Prepared for:
California Air Resources Board
1001 I Street,
Sacramento, CA 95814

Authors:

Dr. J. W. Miller
Mr. Harshit Agrawal
Mr. Bill Welch

University of California, Riverside
College of Engineering-Center for Environmental Research and Technology
Riverside, CA 92521

Disclaimer

Acknowledgements

The authors express appreciation to the following associates who contributed much to the success of the project and the furtherance of knowledge of emissions from ocean going vessels operating in waters near California. We very much appreciated the financial support of the CARB throughout the project, their help in planning the test work and the assistance of the shipping company and the helping hands on the vessel for enabling these measurements to be integrated into their busy operating schedule.

California Air Resources Board

- Ms. Peggy Taricco
- Ms. Bonnie Soriano
- Mr. Paul Milkey

1 Introduction

The auxiliary boilers on diesel driven ships are used for supplying steam and hot water for non-propulsion uses such as fuel heating, galley, cabin space heating, and to drive steam turbines on tankers that offload petroleum crude oil in port. Boilers are a significant source of gaseous emissions, mostly at dockside or close to shore, and can be comparable to the SO_x emissions from auxiliary engines, as shown in Table 1[1]. There is a lack of existing in-use emissions data from the boilers on ocean going vessels. This study helps to address this by presenting the gaseous emissions from the boiler on a modern container vessel.

Table 1: Projected Emissions from Different Engines on an Ocean-going Vessel

2010 Uncontrolled Emissions (tons/day)		
Ship Emissions Source	NO_x	SO_x
Main Engines	130	76
Auxiliary Engines	55	35
Auxiliary Boilers	3.3	26

Source: ARB Emissions Inventory. Emissions within 24nm of coastline. Assumes all auxiliary boilers use heavy fuel oil at 2.5% sulfur and there are no boiler emissions during transiting.

2 Test Method

The boiler operation data is provided in Table 2. The boiler was SAACKE-ESV[2] type. The concentrations of gases in the raw exhaust were measured with a Horiba PG-250 portable multi-gas analyzer. The PG-250 can simultaneously measure up to five separate gas components using the measurement methods recommended by the EPA. The calibration sheets for the measurements are provided in Appendix A of this report.

Table 2: Boiler Operation Data

Steam p (Bar)	8.1
Steam T (ºC)	181.2
Engine Room T (ºC)	25.4
Outside T (ºC)	17.5
Engine Room p (Mbar)	2
Fuel Consumption (l/hr)	160

3 Results

The emission factors of the boiler on the PanaMax Class container vessel are presented in Table 3. The NO_x and CO emission factors were calculated based on the measured concentrations of the pollutants. The sulfur dioxide emission factor was calculated from the sulfur content in the fuel and the fuel consumption. The fuel analysis sheet is attached

[1] http://www.arb.ca.gov/ports/marinevess/presentations/092407/092407boilerpres.pdf
[2] http://www.saacke.de/downloads/land/en/SKV-A_m105_engl.pdf

in Appendix B of this report. The PM measurements were not done due to time constraints.

Table 3: Emission Factors for the Boiler (kg/tonne)

	NO_x	**Calculated SO_2**	**CO**
Run-1	7.27	50.46	0.12
Run-2	7.22	51.36	0.12
Run-3	7.15	51.81	0.11
Average	7.21 ± 0.06	51.21 ± 0.68	0.12 ± 0.01

4 Comparison of the emissions from the container vessel's boiler and the boiler on a crude oil tanker

The emissions from the boilers depend heavily on the size of the boiler and the extent of their use. On the container vessels, boilers are usually used for auxiliary hotel loads while on crude oil lightering vessels the boilers are used for discharging the crude oil. In Table 4, the gaseous emissions from a tanker boiler in a past study[3] are compared to the container vessel under consideration in this study. It is evident from Table 4 that the gaseous emissions from the boiler on a crude oil tanker are higher.

Table 4: Comparison of the Gaseous Emissions from a Crude Oil Tanker[3] and the Container Vessel (kg/tonne)

	Crude Oil Tanker[3]	Container Vessel
NO_x	9.24 ± 0.09	7.21 ± 0.06
Calculated SO_2	55.72	51.21 ± 0.68
CO	0.51 ± 0.04	0.12 ± 0.01

[3] Agrawal, H.; Welch W.A.;Miller J.W.; Cocker D.R.; Emission Measurement from a Crude Oil Tanker at Sea. Accepted for publication in Environmental Science and Technology (2008)

Appendix A: Gaseous Calibration

PRAXAIR

Praxair
5700 South Alameda Street
Los Angeles, CA 90058
Telephone: (323) 585-2154
Facsimile: (714) 542-6689

CERTIFICATE OF ANALYSIS / EPA PROTOCOL GAS

CUSTOMER UC RIVERSIDE   **P.O NUMBER** EZ149

REFERENCE STANDARD

COMPONENT	NIST SRM NO.	CYLINDER NO.	CONCENTRATION
NITRIC OXIDE GMIS	vs.SRM#1685	CC 140559	249.6 ppm
CARBON MONOXIDE GMIS	vs.SRM#1680	CC 95754	499 ppm
CARBON DIOXIDE GMIS	vs.SRM#2745	HA 8215	9.99 %

ANALYZER READINGS

R=REFERENCE STANDARD   *Z=ZERO GAS*   *C=GAS CANDIDATE*

1. COMPONENT NITRIC OXIDE GMIS   **ANALYZER MAKE-MODEL-S/N** Thermo Env. 42H S/N 42H-44979-273

ANALYTICAL PRINCIPLE Chemiluminescence   **LAST CALIBRATION DATE** 03/01/07

FIRST ANALYSIS DATE 02/22/07   **SECOND ANALYSIS DATE** 03/01/07

Z	0.0	R	246.3	C	143.0	CONC.	145	Z	0.0	R	243.4	C	144.4	CONC.	148
R	245.6	Z	0.0	C	143.3	CONC.	146	R	243.7	Z	0.0	C	143.7	CONC.	147
Z	0.0	C	144.4	R	246.8	CONC.	146	Z	0.0	C	143.1	R	243.9	CONC.	146
U/M	ppm					MEAN TEST ASSAY	146	U/M	ppm					MEAN TEST ASSAY	147

2. COMPONENT CARBON MONOXIDE GMIS   **ANALYZER MAKE-MODEL-S/N** HORIBA, VIA-510, S/N 576876015

ANALYTICAL PRINCIPLE NDIR   **LAST CALIBRATION DATE** 03/01/07

FIRST ANALYSIS DATE 02/22/07   **SECOND ANALYSIS DATE** 03/01/07

Z	0.0	R	498.9	C	449.8	CONC.	450	Z	0.0	R	499.0	C	449.9	CONC.	450
R	499.0	Z	0.0	C	450.0	CONC.	450	R	499.1	Z	0.0	C	450.0	CONC.	450
Z	0.0	C	449.7	R	499.4	CONC.	449	Z	0.0	C	450.1	R	499.1	CONC.	450
U/M	ppm					MEAN TEST ASSAY	450	U/M	ppm					MEAN TEST ASSAY	450

3. COMPONENT CARBON DIOXIDE GMIS   **ANALYZER MAKE-MODEL-S/N** Siemens Ultramat 5E S/N A12-730

ANALYTICAL PRINCIPLE NDIR   **LAST CALIBRATION DATE** 02/02/07

FIRST ANALYSIS DATE 02/22/07   **SECOND ANALYSIS DATE**

Z	0.00	R	10.00	C	9.21	CONC.	9.20	Z		R		C		CONC.	
R	10.00	Z	0.00	C	9.22	CONC.	9.21	R		Z		C		CONC.	
Z	0.00	C	9.22	R	10.00	CONC.	9.21	Z		C		R		CONC.	
U/M	%					MEAN TEST ASSAY	9.21	U/M	%					MEAN TEST ASSAY	

THIS CYLINDER NO. CC 159747
HAS BEEN CERTIFIED ACCORDING TO SECTION EPA-600/R97/121
OF TRACEABILITY PROTOCOL NO. REV.9/97
PROCEDURE G1
CERTIFIED ACCURACY ± 1 % NIST TRACEABLE
CYLINDER PRESSURE 2000 PSIG
CERTIFICATION DATE 03/01/07
EXPIRATION DATE 03/01/09 TERM 24 MONTHS

CERTIFIED CONCENTRATION

NITRIC OXIDE	146 ppm
CARBON MONOXIDE	450 ppm
CARBON DIOXIDE	9.21 %
NITROGEN	BALANCE

ALL VALUES NOT VALID BELOW 150 PSIG.
NOx VALUE FOR REFERENCE ONLY.

ANALYZED BY Henry Koung   *CERTIFIED BY* Jack Fu

Praxair
5700 South Alameda Street
Los Angeles, CA 90058
Telephone: (323) 585-2154
Facsimile: (714) 542-6689

CERTIFICATE OF ANALYSIS / EPA PROTOCOL GAS

CUSTOMER UC RIVERSIDE/EZ149

P.O NUMBER

REFERENCE STANDARD

COMPONENT	NIST SRM NO.	CYLINDER NO.	CONCENTRATION
NITRIC OXIDE GMIS	vs.SRM#2630	CC 240946	1517 ppm

ANALYZER READINGS

R=REFERENCE STANDARD   Z=ZERO GAS   C=GAS CANDIDATE

1. COMPONENT NITRIC OXIDE GMIS   ANALYZER MAKE-MODEL-S/N BECKMAN 951A S/N#0101354

ANALYTICAL PRINCIPLE CHEMILUMINESCENCE   LAST CALIBRATION DATE 01/16/07

FIRST ANALYSIS DATE 02/08/07   SECOND ANALYSIS DATE 02/15/07

Z 0	R 526	C 832	CONC. 2400		Z 0	R 601	C 953	CONC. 2405
R 527	Z 0	C 834	CONC. 2401		R 601	Z 0	C 953	CONC. 2405
Z 0	C 836	R 528	CONC. 2402		Z 0	C 952	R 600	CONC. 2407
U/M mV		MEAN TEST ASSAY	2401		U/M mV		MEAN TEST ASSAY	2406

NOx value for reference only.
All values not valid below 150 psig.

THIS CYLINDER NO.	SA 11914	CERTIFIED CONCENTRATION	
HAS BEEN CERTIFIED ACCORDING TO SECTION	EPA-600/R97/121	NITRIC OXIDE	2404 ppm
OF TRACEABILITY PROTOCOL NO.	Rev. 9/97	NITROGEN	BALANCE
PROCEDURE	G1	NOx	2423 ppm
CERTIFIED ACCURACY	± 1 % NIST TRACEABLE		
CYLINDER PRESSURE	2000 PSIG		
CERTIFICATION DATE	02/15/07		
EXPIRATION DATE	02/15/09 TERM 24 MONTHS		

ANALYZED BY GEORGE WAHBA   CERTIFIED BY Victor D. (G.F.) VICTOR DOTAN

Appendix B: Fuel Analysis

Intertek

Intertek Denmark
Branch of Dutch company: Intertek Caleb Brett Nederland B.V.
Dokhavnsvej 3, Postboks 67
DK-4400 Kalundborg
Telephone: (+45) 59 51 32 23
Telefax: (+45) 59 51 35 51
E-mail: opscbe.denmark@intertek.com
CVR nr.: VAT reg. no: 19 85 99 08

MAN B&W DIESEL A/S
TEGLHOLMSGADE 41
DK-2450 KØBENHAVN SV

Att.: Jens Bjerkvig

Deres ref. / Your ref.

Vor ref. / Our ref. LH

Dato / Date 28.11.2007

Certificate of Quality
31989

Sample received from: Yourselves

Sample submitted as: HFO 2

Description on label: Test 43

Seal on sample: -

The above sample was examined with following result:

Ash (20 g)	0,035	% mass	Method: ASTM D 482
Asphaltenes	11,9	% mass	Method: IP 143
Cetane Index	*		Method: ASTM D 4737
Conr. Carbon, direct	19,6	% mass	Method: ASTM D 4530
Density at 15°C	1,0042	g/ml	Method: ASTM D 4052
Flash Point P.M., c.c.	94	°C	Method: ASTM D 93/B
Heat of Comb. Nett Equal to	39,66 9473	MJ/kg Kcal/kg	Method: ASTM D 4868
Sulphur	2,98	% mass	Method: ASTM D 4294
Viscosity (50°C)	482,9	mm²/s	Method: ASTM D 445
Water	0,3	% mass	Method: ASTM D 95
C-content	86,3	% mass	Method: ASTM D 5291
H-content	9,6	% mass	Method: ASTM D 5291
N-content 0,35%	~~< 0,75~~ [illegible]	% mass	Method: ASTM D 5291
O-content	4,64	% mass	Method: E.A.
Al-content	5	mg/kg	Method: A.A.S.
Ca-content	11	mg/kg	Method: A.A.S.
Zn-content	2	mg/kg	Method: A.A.S.
P-contnet	< 1	mg/kg	Method: I.C.P.
Si-content	6	mg/kg	Method: A.A.S.
V-content	100	mg/kg	Method: A.A.S.

* Not possible to calculate

Intastet i perf database
værdier er skaleret
/ [illegible]