CIMAC

2012

EMISSION CALCULATION CHECK GUIDE – IMO NOx Technical Code 2008

Set of Sample Measurement Data for evaluation of correct calculation according to the algorithms provided by the Code

The International Council on Combustion Engines

Conseil International des Machines à Combustion

Contents

1 Introduction

On 10 October 2008, the IMO Marine Environment Protection Committee at its 58th session, by Resolution MEPC.177(58), has adopted amendments to the Technical Code on Control of Emission of Nitrogen Oxides (NOx) from Marine Diesel Engines, hereafter referred to as the Code.

The purpose of the Code is to specify the requirements for the testing, survey, and certification of marine Diesel engines to ensure they comply with the NOx emission limits as of Regulation 13 of Annex VI of the MARPOL Convention.

In order to achieve repeatable and comparable results for the assessment of an engine's emission behaviour, tests must be performed on the applicable test cycle under defined reference conditions and using standardised exhaust gas measurement methods as described in Appendix III of the Code.

Other engine parameters than exhaust gas components like engine power, temperatures, pressures etc. need to be measured with prescribed accuracy.

The measurement results need to be documented in a test report which shall include also the calculated specific emissions of all relevant individual exhaust gas components, as calculated as the weighted average emission value, using the weighting factors of the applicable test cycle.

The set of data provided in this document may be used to verify the proper calculation of any self programmed calculation software against the results listed and commented.

The set of data has been used by numerous members of the CIMAC Working Group 'Exhaust Emissions Control' (WG5) applying their individual calculation software in order to identify possible sources of errors. At the end, the presented results are considered to be representative for a correct application of the Code's algorithms.

2 Applicable Test Cycles

The following test cycles for different final engine applications shall be applied for verification of compliance with the applicable NOx limit for a marine Diesel engine, see also MARPOL Annex VI, Appendix II:

2.1 For constant-speed marine Diesel engines intended to be used for ship main propulsion, including Diesel-electric drive, test cycle E2 shall be applied.

2.2 For controllable-pitch propeller set test cycle E2 shall be applied.

2.3 For propeller-law-operated main and propeller-law-operated auxiliary engines test cycle E3 shall be applied.

2.4 For constant-speed auxiliary engines test cycle D2 shall be applied.

2.5 For variable-speed / variable-load auxiliary engines, not included above, test cycle C1 shall be applied.

The tables below contain the information necessary for running the test and for calculating the engine's actual NOx emission value to be compared with the applicable limit value, and entered in the engine's Engine International Air Pollution Prevention certificate.

Test cycle type E2	Speed	100%	100%	100%	100%
	Power	100%	75%	50%	25%
	Weighting factor	0.2	0.5	0.15	0.15

Test cycle type E3	Speed	100%	91%	80%	63%
	Power	100%	75%	50%	25%
	Weighting factor	0.2	0.5	0.15	0.15

Test cycle type D2	Speed	100%	100%	100%	100%	100%
	Power	100%	75%	50%	25%	10%
	Weighting factor	0.05	0.25	0.3	0.3	0.1

Figure 1:

3 Sample Data Sets

The following data may be used as sample for the verification of calculation programs, differentiated for test cycles E3, E2, and D2.

Sample Data Set Test Cycle E3

Cycle			**E3**			
Power			**100**	**75**	**50**	**25**
Speed			**100**	**91**	**80**	**63**
Power	P	kW	11000	8250	5500	2750
Speed	nd	rpm	120	110	96	76
Nitrogen Oxides (wet)	NOXw	ppm	1050	1100	1500	1641
Nitrogen Oxides (dry)	NOXd	ppm				
Carbon Monoxide (dry)	COd	ppm	48	51	34	22
Carbon Dioxide (dry)	CO2d	%	4,92	4,57	4,80	4,93
Oxigen (dry)	O2d	%	14,26	14,70	14,36	14,19
Hydro Carbons (wet)	HCw	ppm	153	166	155	132
Fuel Consumption	q_{mf}	kg/h	2000	1500	1000	500
Charge Air Pressure	pC	bar	3,0	2,6	1,1	0,5
Carge Air Temperature	TSC	°C	40	35	30	30
Charge Air Ref. Temperature	TSCRef	°C	41	35	30	32
Rel. humidity of the intake air	Ra	%	19	20	20	19
Total barometric pressure	pb	mbar	982	984	984	984
Inlet Air Temperature	Ta	°C	26	27	27	28
Air Temperatur at RH sensor	TRa	°C	26	27	27	28

Figure 2:

Fuel Data	Hydrogen **H**	ALF	%	13,00	13,00	13,00	13,00
Carbon **C**		BET	%	87,00	87,00	87,00	87,00
Sulfur **S**		GAM	%	0,00	0,00	0,00	0,00
Nitrogen **N**		DEL	%	0,00	0,00	0,00	0,00
Oxigen **O**		EPS	%	0,00	0,00	0,00	0,00

Sample Data Set Test Cycle E2

Cycle			**E2**			
Power			**100**	**75**	**50**	**25**
Speed			**100**	**100**	**100**	**100**
Power	P	kW	5000	3750	2500	1300
Speed	nd	rpm	1000	1000	1000	1000
Nitrogen Oxides (wet)	NOXw	ppm				
Nitrogen Oxides (dry)	NOXd	ppm	960	900	850	590
Carbon Monoxide (dry)	COd	ppm	64	49	63	161
Carbon Dioxide (dry)	CO2d	%	6,51	6,58	6,92	6,76
Oxigen (dry)	O2d	%	12,14	12,01	11,58	11,79
Hydro Carbons (wet)	HCw	ppm	218	271	292	288
Fuel Consumption	q_{mf}	kg/h	1000	750	570	350
Charge Air Pressure	pC	bar	3,0	1,5	1,5	0,4
Carge Air Temperature	TSC	°C	54	51	50	51
Charge Air Reference Temperature	TSCRef	°C	60	45	50	50
Relative humidity of the intake air	Ra	%	20	30	40	50
Total barometric pressure	pb	mbar	900	950	1000	1050
Inlet Air Temperature	Ta	°C	20	24	25	26
Air Temperatur at RH sensor	TRa	°C	25	25	25	25

Figure 3:

Fuel Data	Hydrogen **H**	ALF	%	13,70	13,70	13,70	13,70
Carbon **C**		BET	%	86,00	86,00	86,00	86,00
Sulfur **S**		GAM	%	0,30	0,30	0,30	0,30
Nitrogen **N**		DEL	%	0,00	0,00	0,00	0,00
Oxigen **O**		EPS	%	0,00	0,00	0,00	0,00

Sample Data Set Test Cycle D2

Cycle			**D2**				
Power			**100**	**75**	**50**	**25**	**10**
Speed			**100**	**100**	**100**	**100**	**100**
Power	P	kW	5000	3750	2500	1300	500
Speed	nd	rpm	1000	1000	1000	1000	1000
Nitrogen Oxides (wet)	NOXw	ppm	960	900	850	590	300
Nitrogen Oxides (dry)	NOXd	ppm					
Carbon Monoxide (dry)	COd	ppm	64	49	63	161	219
Carbon Dioxide (dry)	CO2d	%	6,51	6,58	6,92	6,76	5,20
Oxigen (dry)	O2d	%	12,14	12,01	11,58	11,79	13,90
Hydro Carbons (wet)	HCw	ppm	218	271	292	288	437
Fuel Consumption	q_{mf}	kg/h	950	750	570	350	200
Charge Air Pressure	pC	bar	3,0	1,5	1,5	0,4	0,1
Carge Air Temperature	TSC	°C	54	51	50	51	10
Charge Air Reference Temperature	TSCRef	°C	60	45	50	50	50
Relative humidity of the intake air	Ra	%	20	30	40	50	60
Total barometric pressure	pb	mbar	900	950	1000	1050	1050
Inlet Air Temperature	Ta	°C	20	24	25	26	26
Air Temperatur at RH sensor	TRa	°C	25	25	25	25	25

Figure 4:

Hydrogen **H**	ALF	%	13,00	13,00	13,00	13,00	13,00
Carbon **C**	BET	%	86,40	86,40	86,40	86,40	86,40
Sulfur **S**	GAM	%	0,30	0,30	0,30	0,30	0,30
Nitrogen **N**	DEL	%	0,20	0,20	0,20	0,20	0,20
Oxigen **O**	EPS	%	0,10	0,10	0,10	0,10	0,10

4 Calculation Results including Comments

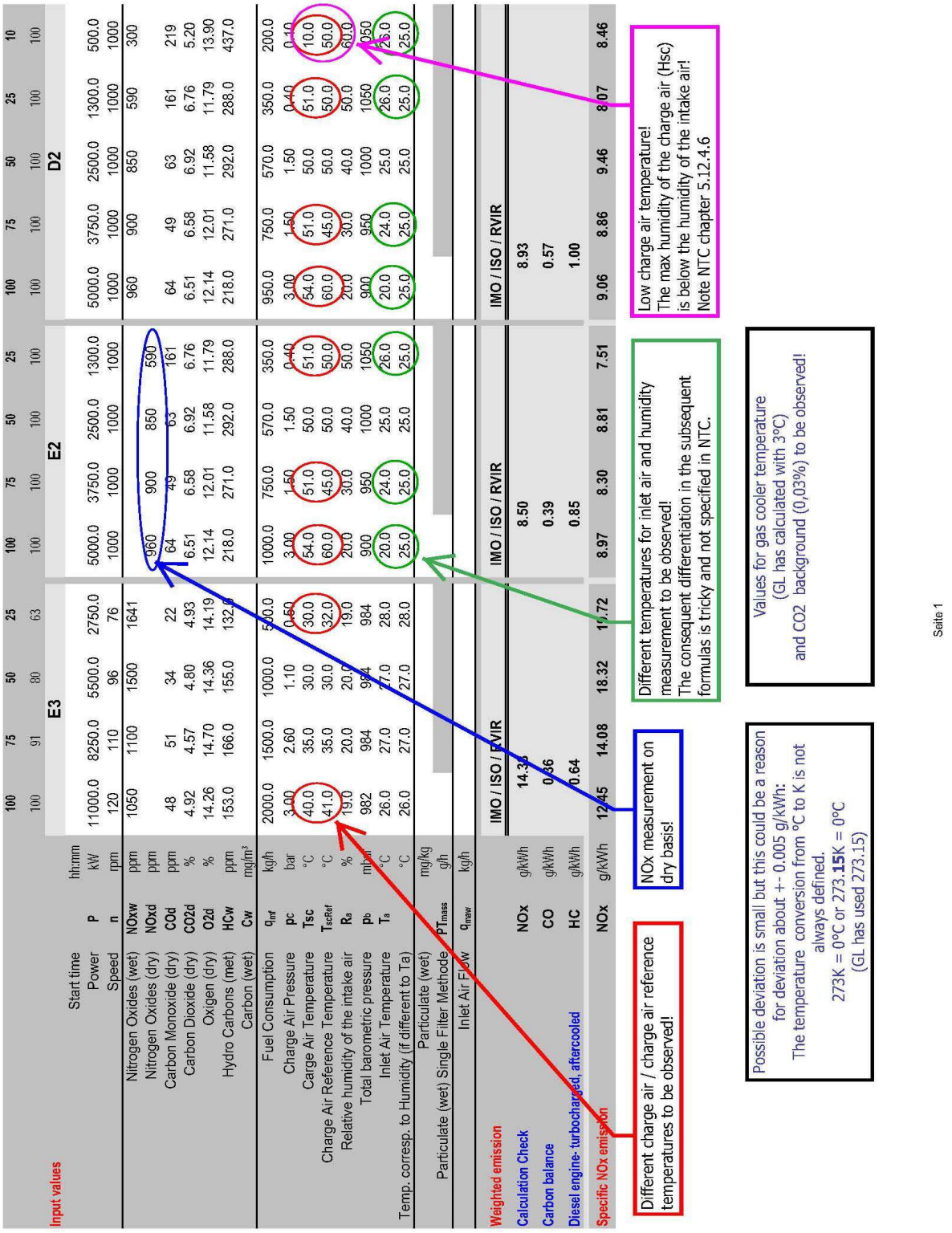

Figure 5:

5 Calculation Results including Intermediate Results

IMO Tier II Calculation check	Location											Version: Emission Calc II - 2009-09-08				
NA	Engine type															Inte
NA	Serial number															
NA	Date															
NA	Rated power [kW]															
NA	Rated speed [rpm]															
Calculation Check																
Carbon balance					100	75	50	25	100	75	50	25	100	75	50	25	10
Diesel engine- turbocharged, aftercooled					100	91	80	63	100	100	100	100	100	100	100	100	100
Input values			Ref. IMO	Ref. ISO	E3				E2				D2				
Start time		hh:mm															
Power	P	kW			11000.0	8250.0	5500.0	2750.0	5000.0	3750.0	2500.0	1300.0	5000.0	3750.0	2500.0	1300.0	500.0
Speed	n	rpm			120	110	96	76	1000	1000	1000	1000	1000	1000	1000	1000	1000
Nitrogen Oxides (wet)	NOxw	ppm			1050	1100	1500	1641					960	900	850	590	300
Nitrogen Oxides (dry)	NOxd	ppm							960	900	850	590					
Carbon Monoxide (dry)	COd	ppm			48	51	34	22	64	49	63	161	64	49	63	161	219
Carbon Dioxide (dry)	CO2d	%			4.92	4.57	4.80	4.93	6.51	6.58	6.92	6.76	6.51	6.58	6.92	6.76	5.20
Oxigen (dry)	O2d	%			14.26	14.70	14.36	14.19	12.14	12.01	11.58	11.79	12.14	12.01	11.58	11.79	13.90
Hydro Carbons (met)	HCw	ppm			153.0	166.0	155.0	132.0	218.0	271.0	292.0	288.0	218.0	271.0	292.0	288.0	437.0
Carbon (wet)	Cw	mg/m³															
Fuel Consumption	q_{mf}	kg/h			2000.0	1500.0	1000.0	500.0	1000.0	750.0	570.0	350.0	950.0	750.0	570.0	350.0	200.0
Charge Air Pressure	pc	bar			3.00	2.60	1.10	0.50	3.00	1.50	1.50	0.40	3.00	1.50	1.50	0.40	0.10
Carge Air Temperature	Tsc	°C			40.0	35.0	30.0	30.0	54.0	51.0	50.0	51.0	54.0	51.0	50.0	51.0	10.0
Charge Air Reference Temperature	T_{scRef}	°C			41.0	35.0	30.0	32.0	60.0	45.0	50.0	50.0	60.0	45.0	50.0	50.0	50.0
Relative humidity of the intake air	R_a	%			19.0	20.0	20.0	19.0	20.0	30.0	40.0	50.0	20.0	30.0	40.0	50.0	60.0
Total barometric pressure	pb	mbar			982	984	984	984	900	950	1000	1050	900	950	1000	1050	1050
Inlet Air Temperature	T_a	°C			26.0	27.0	27.0	28.0	20.0	24.0	25.0	26.0	20.0	24.0	25.0	26.0	26.0
Temp. corresp. to Humidity (if different to Ta)		°C			26.0	27.0	27.0	28.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0	25.0
Particulate (wet)		mg/kg															
Particulate (wet) Single Filter Methode	PT_{mass}	g/h															
Inlet Air Flow	q_{maw}	kg/h															
Weighted emission					IMO / ISO / RVIR				IMO / ISO / RVIR				IMO / ISO / RVIR				
Calculation Check	NOx	g/kWh			14.3771				8.5040				8.9318				
Carbon balance	CO	g/kWh			0.3637				0.3903				0.5655				
Diesel engine- turbocharged, aftercooled	HC	g/kWh			0.6394				0.8500				1.0011				
Specific NOx emission	NOx	g/kWh			12.454	14.079	18.325	19.718	8.970	8.298	8.811	7.508	9.061	8.857	9.460	8.072	8.455
Uncorrected specific fuel consumption		g/kWh			181.82	181.82	181.82	181.82	200.00	200.00	228.00	269.23	190.00	200.00	228.00	269.23	400.00
Atmospheric factor	fa	-			1.0162	1.0203	1.0203	1.0255	1.0482	1.0321	1.0026	0.9755	1.0482	1.0321	1.0026	0.9755	0.9776
NOx humidity correction factor	khd	-			0.9314	0.9362	0.9362	0.9440	0.9330	0.9324	0.9687	0.9863	0.9330	0.9324	0.9687	0.9863	1.0743
Dry to wet correction factor for the raw exhaust gas	k_{w2}	-			0.9591	0.9613	0.9594	0.9583	0.9430	0.9394	0.9339	0.9327	0.9460	0.9425	0.9370	0.9358	0.9522
Gas mass flow	NOx	kg/h			136.995	116.152	100.787	54.224	44.848	31.117	22.028	9.761	45.307	33.216	23.651	10.493	4.228
	CO	kg/h			3.928	3.368	1.426	0.449	1.952	1.107	1.027	1.645	1.866	1.113	1.033	1.655	1.666
	CO2	kg/h			6323	4739	3161	1582	3118	2334	1771	1085	2980	2348	1782	1091	621
	O2	kg/h			13324	11084	6876	3310	4228	3097	2155	1375	4040	3116	2168	1384	1207
	HC	kg/h			6.473	5.655	3.360	1.395	3.496	3.231	2.526	1.564	3.331	3.240	2.533	1.569	1.731
Specific emission	NOx	g/kWh			13.371	15.038	19.573	20.887	9.614	8.900	9.096	7.613	9.713	9.500	9.766	8.184	7.870
IMO/ISO	NOx	g/kWh			12.454	14.079	18.325	19.718	8.970	8.298	8.811	7.508	9.061	8.857	9.460	8.072	8.455
	CO	g/kWh			0.357	0.408	0.259	0.163	0.390	0.295	0.411	1.265	0.373	0.297	0.413	1.273	3.332
	CO2	g/kWh			574.781	574.454	574.775	575.160	623.595	622.365	708.307	834.310	595.984	626.116	712.617	839.353	1242.441
	O2	g/kWh			1211.286	1343.527	1250.261	1203.688	845.532	825.947	861.815	1057.997	808.095	830.925	867.059	1064.392	2414.778
	HC	g/kWh			0.588	0.685	0.611	0.507	0.699	0.862	1.011	1.203	0.666	0.864	1.013	1.207	3.462
Exhaust mass flow	q_{mew}	kg/h			88323.50	71114.34	45251.49	22069.31	33481.34	24889.84	18063.01	11339.46	31895.39	24958.30	18111.03	11370.06	8270.63
Fuel composition																	
Hydrogen H	ALF	%			13.00	13.00	13.00	13.00	13.70	13.70	13.70	13.70	13.00	13.00	13.00	13.00	13.00
Carbon C	BET	%			87.00	87.00	87.00	87.00	86.00	86.00	86.00	86.00	86.40	86.40	86.40	86.40	86.40
Sulfur S	GAM	%			0.0000	0.0000	0.0000	0.0000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000	0.3000
Nitrogen N	DEL	%			0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2000	0.2000	0.2000	0.2000	0.2000
Oxigen O	EPS	%			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10

Figure 6:

6 Appendix: Acknowledgement, Membership & Disclaimer

By endorsing this document, CIMAC acknowledges the work accomplished by the CIMAC Working Group "Exhaust Emissions Control" through its worldwide membership.

The document does not replace the recommendations of engine builders, equipment manufacturers and oil suppliers, which may vary with designs and applications and take precedence over any CIMAC guidance. Users must evaluate whether the guidance in this document is appropriate for their purpose. CIMAC and the authors of this document make no warranty and shall have no legal responsibility for any consequence of the application of these guidelines.

Availability of CIMAC Recommendations and Guides

Copies of this and other CIMAC publications are available via the CIMAC webpage:

http://www.cimac.com/services/Index1-publications.htm

Download of all files (pdf) is free for members, non-members have to use the 'guest' status for log-in and can purchase full paper pdf-files at the fees mentioned at each abstract by filling-in the electronic order-sheet (upon receipt of payment the respective pdf-files will be sent by e-mail).

For further information on CIMAC please visit our homepage on the internet:

http://www.cimac.com

CIMAC Working Group 'Exhaust Emissions Control' Members

(during the preparation of this document)

Firm/Organisation	Country
A.P. Møller - Mærsk A/S	Denmark
American Bureau of Shipping	UK
Aderco Europe S.A.	Belgium
AVL List	Austria
Caterpillar Motoren	Germany
Germanischer Lloyd	Germany
Guangxi Yuchai Machinery Co., Ltd.	China
HYUNDAI Heavy Industries Co. Ltd.	Korea
JICEF - Japan IC Engine Federation	Japan
Johnson Matthey Plc	UK
LEC - Large Engines Competence Center	Austria
Lloyds Register EMEA	UK
MAN Diesel & Turbo SE Denmark	Denmark
MAN Diesel & Turbo	Germany
Mitsubishi Power Systems	Germany
Ministry of Defence	Netherlands
MTI Holland	Netherlands
MTU Friedrichshafen	Germany
NAVSEA Warfare Centers	United States
Niigata Power Systems Co., Ltd.	Japan
Petróleo Brasileiro S.A.	Brazil
Ricardo Deutschland	Germany
Ricardo UK Ltd.	UK
Rolls-Royce Marine AS	Norway
Shanghai Marine Diesel Engine	China
Universität Rostock	Germany
National Technical University of Athens	Greece
Netherlands Defence Academy	Netherlands
Wärtsilä Italia S.p.A.	Italy
Wärtsilä Finland	Finland
Wärtsilä Switzerland	Switzerland

COUNTRIES OF THE NATIONAL MEMBER ASSOCIATIONS (NMA) per December 2012

Austria
Peoples Republic of China
Denmark
Finland
Germany
Greece
India
Japan
Korea
Norway
Sweden
Switzerland
United Kingdom
USA

CORPORATE MEMBERS OF CIMAC (CM) per December 2012

Belgium	Aderco Europe S.
	Anglo Belgian Corporation N.V.
	Chevron Texaco Technology Gent
Brazil	Petróleo Brasileiro **(**PETROBRAS)
Canada	Teekay Shipping (Canada) Ltd.
Czech Republic	PBS Turbo s.r.o.
Italy	O.M.T. Officine Meccaniche Torino S.p.A.
Namibia	Lubrication Specialists (PTY) Ltd.
Netherlands	Chevron Oronite Technology b.v.
	KEMA Nederland BV
	MTI Holland BV (on behalf of IHC Merwede BV)
	Royal Netherlands Naval College (RNNC)
	Stolt-Nielsen Transportation Group
	Techno Fysica B.V.
	VAF Instruments B.V.
	Van Oord Shipmanagement bv
	Woodward Governor Nederland B.V.
Poland	CELSA HUTA OSTROWIEC
Russia	LLK-INTERNATIONAL
	OAO Kolomensky Zavod
Singapore	Maritec Pte Ltd
Spain	Gerdau Sidenor I+D
	Guascor I+D
	O&M Energy, S.A., Gas Natural Fenosa
United Arab Emirates	VELA International Marine Ltd.
USA	Cummins Inc.
	Dresser Waukesha
	Representative located in Germany: ExxonMobil
	Hiltner Combustion Systems LLC
	Sealub Alliance America’s Inc.
	Transmontaigne