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CONFERENCE OF PARTIES TO THE INTERNATIONAL CONVENTION FOR THE PREVENTION OF POLLUTION FROM SHIPS, 1973, AS MODIFIED BY THE PROTOCOL OF 1978 RELATING THERETO

Agenda item 7

CONSIDERATION AND ADOPTION OF RESOLUTIONS AND RECOMMENDATIONS AND RELATED MATTERS

Texts of Conference Resolutions 1 to 8 and the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines

as adopted by the Conference

SUMMARY

Executive Summary:	This document provides texts of Conference Resolutions 1 to 8 and the NOx Technical Code adopted by the Conference
Action to be Taken:	For information
Related documents:	MP/CONF. 3/WP. 3, MP/CONF. 3/WP. 4/Add.1 and MP/CONF. 3/33/Rev.1

Attached at annex are texts of the following Conference resolutions:

Resolution 1 - Review of the 1997 Protocol;

Resolution 2 - Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines;

Resolution 3 - Review of Nitrogen Oxides Emission Limitations;

Resolution 4 - Monitoring the World-Wide Average Sulphur Content of Residual Fuel Oil Supplied for Use on board Ships;

Resolution 5 - Consideration of Measures to Address Sulphur Deposition in North West Europe;

Resolution 6- Introduction of the Harmonized System of Survey and Certification in Annex VI;

Resolution 7 - Restriction on the Use of Perfluorocarbons on board Ships; and

Resolution 8 - CO_2 Emissions from Ships

and the text of the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines which is annexed to Conference Resolution 2, as set out in attachment 2 to the Final Act of the Conference.

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ANNEX

CONFERENCE RESOLUTION 1

REVIEW OF THE 1997 PROTOCOL

THE CONFERENCE,

HAVING ADOPTED the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (the 1997 Protocol),

NOTING that Article 6(1) of the 1997 Protocol provides that it shall enter into force twelve months after the date on which not less than fifteen States, the combined merchant fleets of which constitute not less than 50 per cent of the gross tonnage of the world's merchant shipping, have become Parties to it in accordance with Article 5 of the same Protocol,

DESIRING that the conditions for entry into force of the 1997 Protocol be satisfied by 31 December 2002, enabling air pollution requirements to be implemented internationally as soon as possible,

BEING COGNIZANT that the unique characteristics of air pollution from ships and the provisions of the annex to the 1997 Protocol may require a timely review of the provisions of the instrument,

1 URGES Member States of the Organization to take the steps necessary to consent to be bound by the 1997 Protocol no later than 31 December 2002;

2 REQUESTS the Secretary-General to review the progress of Member States in consenting to become bound by the 1997 Protocol; and

3 INVITES, if the conditions for entry into force of the 1997 Protocol have not been met by 31 December 2002, the Marine Environment Protection Committee, at its first meeting thereafter, to initiate, as a matter of urgency, a review to identify the impediments to entry into force of the Protocol and any necessary measures to alleviate those impediments.

CONFERENCE RESOLUTION 2

TECHNICAL CODE ON CONTROL OF EMISSION OF NITROGEN OXIDES FROM MARINE DIESEL ENGINES

THE CONFERENCE,

RECALLING resolution A.719(17) adopted by the Assembly of the International Maritime Organization, which indicates that the objective of prevention of air pollution from ships would best be achieved by establishing a new annex to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78) to provide rules for restriction and control of emission of harmful substances from ships into the atmosphere,

RECOGNIZING that the emission of nitrogen oxides from marine diesel engines installed on board ships has an adverse effect on the environment causing acidification, formation of ozone, nutrient enrichment and contributes to adverse health effects globally,

BEING AWARE of the protocols and declarations to the 1979 Convention on Long-Range Transboundary Air Pollution concerning, inter alia, the reduction of emission of nitrogen oxides or its transboundary fluxes,

HAVING ADOPTED the Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (the 1997 Protocol),

NOTING regulation 13 of Annex VI of MARPOL 73/78 which makes the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines mandatory under that regulation,

HAVING CONSIDERED the recommendations made by the Marine Environment Protection Committee at its thirty-ninth session,

1 ADOPTS the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines (NOx Technical Code), the text of which is set out at annex to the present resolution;

2 RESOLVES that the provisions of the NOx Technical Code shall enter into force, as mandatory requirements, for all Parties to the 1997 Protocol on the same date as the entry into force date of that Protocol;

3 INVITES Parties to MARPOL 73/78 to implement the provisions of the NOx Technical Code in accordance with the provisions of regulation 13 of Annex VI; and

4 URGES Parties to MARPOL 73/78 to bring the NOx Technical Code to the immediate attention of shipowners, ship operators, ship builders, marine diesel engine manufacturers and any other interested groups.

TECHNICAL CODE

ON CONTROL OF EMISSION OF NITROGEN OXIDES

FROM

MARINE DIESEL ENGINES

Foreword

On 26 September 1997, the Conference of Parties to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78), adopted, by Conference resolution 2, the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines. Under the provisions of Annex VI - Regulations for the Prevention of Air Pollution from Ships, of MARPOL 73/78, and subsequent to the entry into force of Annex VI, each marine diesel engine to which regulation 13 of that annex applies, must comply with the provisions of this Code.

As general background information, the precursors to the formation of nitrogen oxides during the combustion process are nitrogen and oxygen. Together these compounds comprise 99% of the engine intake air. Oxygen will be consumed during the combustion process, with the amount of excess oxygen available being a function of the air/fuel ratio which the engine is operating under. The nitrogen remains largely unreacted in the combustion process, however a small percentage will be oxidized to form various oxides of nitrogen. The nitrogen oxides (NO_x) which can be formed include NO and NO_2, while the amounts are primarily a function of flame or combustion temperature and, if present, the amount of organic nitrogen available from the fuel. It is also a function of the time the nitrogen and the excess oxygen are exposed to the high temperatures associated with the diesel engine's combustion process. In other words, the higher the combustion temperature (e.g., high peak pressure, high compression ratio, high rate of fuel delivery, etc.), the greater the amount of NO_x formation. A slow speed diesel engine, in general, tends to have more NO_x formation than a high speed engine. NO_x has an adverse effect on the environment causing acidification, formation of ozone, nutrient enrichment and contributes to adverse health effects globally.

The purpose of this Code is to establish mandatory procedures for the testing, survey and certification of marine diesel engines which will enable engine manufacturers, shipowners and Administrations to ensure that all applicable marine diesel engines comply with the relevant limiting emission values of NO_x as specified within regulation 13 of Annex VI to MARPOL 73/78. The difficulties of establishing with precision, the actual weighted average NO_x emission of marine diesel engines in service on vessels have been recognised in formulating a simple, practical set of requirements in which the means to ensure compliance with the allowable NO_x emissions, are defined.

Administrations are encouraged to assess the emissions performance of propulsion and auxiliary diesel engines on a test bed where accurate tests can be carried out under properly controlled conditions. Establishing compliance with regulation 13 of Annex VI at this initial stage is an essential feature of this Code. Subsequent testing on board the ship may inevitably be limited in scope and accuracy and its purpose should be to infer or deduce the emission performance and to confirm that engines are installed, operated and maintained in accordance with the manufacturer´s specifications and that any adjustments or modifications do not detract from the emissions performance established by initial testing and certification by the manufacturer.

CONTENTS

APPENDICES

ABBREVIATIONS, SUBSCRIPTS AND SYMBOLS

Tables 1, 2, 3 and 4 below summarize the abbreviations, subscripts and symbols used throughout this Code, including specifications for the analytical instruments in appendix 3, calibration requirements for the analytic instruments contained in appendix 4 and the formulae for calculation of gas mass flow as contained in chapter 5 and appendix 6 of this Code.

.1 Table 1: symbols used to represent the chemical components of diesel engine gas emissions addressed throughout this Code;

.2 Table 2: abbreviations for the analysers used in the measurement of gas emissions from diesel engines, as specified in appendix 3 of this Code;

.3 Table 3: symbols and subscripts of terms and variables used in all formulae for the calculation of exhaust gas mass flow for the test bed measurement methods, as specified in chapter 5 of this Code; and

.4 Table 4: subscripts and descriptions of terms and variables used in all formulae for the calculation of exhaust gas mass flow following the carbon balance method, as specified in appendix 6 of this Code.

Table 1. Symbols for the chemical components of diesel engine emissions

Symbol	Chemical Component	Symbol	Chemical Component
C_3H_8	Propane	NO	Nitric Oxide
CO	Carbon monoxide	NO_2	Nitrogen Dioxide
CO_2	Carbon dioxide	NO_x	Oxides of nitrogen
HC	Hydrocarbons	O_2	Oxygen
H_2O	Water		

Table 2. Abbreviations for analysers in measurement of diesel engine gaseous emissions (refer to appendix 3 of this Code)

Abbreviation	Term	Abbreviation	Term
CFV	Critical flow venturi	HFID	Heated flame ionization detector
CLD	Chemiluminescent detector	NDIR	Non-dispersive infrared analyser
ECS	Electrochemical sensor	PDP	Positive displacement pump
FID	Flame ionization detector	PMD	Paramagnetic detector
FTIR	Fourier transform infrared analyser	UVD	Ultraviolet detector
HCLD	Heated chemiluminescent detector	ZRDO	Zirconiumdioxide sensor

Table 3. Symbols and subscripts for terms and variables used in the formulae for the test bed measurement methods (refer to chapter 5 of this Code)

Symbol	Term	Dimension
A_T	Cross sectional area of the exhaust pipe	m^2
C1	Carbon 1 equivalent hydrocarbon	-
conc	Concentration	ppm or Vol%
$conc_c$	Background corrected concentration	ppm or Vol%
EAF	Excess Air Factor (kg dry air per kg fuel)	kg/kg
EAF_{Ref}	Excess Air Factor (kg dry air per kg fuel) at reference conditions	kg/kg
f_a	Laboratory atmospheric factor (applicable only to an engine family)	-
F_{FCB}	Fuel specific factor for the carbon balance calculation	-
F_{FD}	Fuel specific factor for exhaust flow calculation on dry basis	-
F_{FH}	Fuel specific factor used for the calculations of wet concentrations from dry concentrations	-
F_{FW}	Fuel specific factor for exhaust flow calculation on wet basis	-
G_{AIRW}	Intake air mass flow rate on wet basis	kg/h
G_{AIRD}	Intake air mass flow rate on dry basis	kg/h
G_{EXHW}	Exhaust gas mass flow rate on wet basis	kg/h
G_{FUEL}	Fuel mass flow rate	kg/h
GAS_x	Average weighted NO_x emission value	g/kWh
H_{REF}	Reference value of absolute humidity (10.71 g/kg; for calculation of NO_x and particulate humidity correction factors)	g/kg
H_a	Absolute humidity of the intake air	g/kg
HTCRAT	Hydrogen-to-Carbon ratio	mol/mol
i	Subscript denoting an individual mode	-
K_{HDIES}	Humidity correction factor for NO_x for diesel engines	-

Symbol	Term	Dimension
$K_{W,a}$	Dry to wet correction factor for intake air	-
$K_{W,r}$	Dry to wet correction factor for the raw exhaust gas	-
L	Percent torque related to the maximum torque for the test engine speed	%
mass	Emissions mass flow rate	g/h
p_a	Saturation vapour pressure of the engine intake air (in ISO 3046-1, 1995: p_{sy} = PSY, test ambient vapour pressure)	kPa
p_B	Total barometric pressure (in ISO 3046-1, 1995: p_x = PX, site ambient total pressure; p_y = PY, test ambient total pressure)	kPa
p_s	Dry Atmospheric pressure	kPa
P	Power, brake uncorrected	kW
P_{AUX}	Declared total power absorbed by auxiliaries fitted for the test only, but not required on board the ship	kW
P_m	Maximum measured or declared power at the test engine speed under test conditions	kW
r	Ratio of cross sectional areas of isokinetic probe and exhaust pipe	-
R_a	Relative humidity of the intake air	%
R_f	FID response factor	-
R_{fM}	FID response factor for methanol	-
S	Dynamometer setting	kW
T_a	Absolute temperature of the intake air	K
T_{Dd}	Absolute dewpoint temperature	K
T_{SC}	Temperature of the intercooled air	K
$T_{ref.}$	Reference temperature (of combustion air: 298 K)	K
T_{SCRef}	Intercooled air reference temperature	K
V_{AIRD}	Intake air volume flow rate on dry basis	m^3/h
V_{AIRW}	Intake air volume flow rate on wet basis	m^3/h
	Exhaust gas volume flow rate on dry basis	

Symbol	Term	Dimension
V_{EXHD} V_{EXHW}	Exhaust gas volume flow rate on wet basis	m^3/h m^3/h
W_F	Weighting factor	-

Table 4. Symbols and descriptions of terms and variables used in the formulae for the carbon balance measurement method (refer to appendix 6 of this Code)

Symbol	Description	Dimension	Remark
ALF	H content of fuel	% m/m	
AWC	Atomic weight of C		
AWH	Atomic weight of H		
AWN	Atomic weight of N		
AWO	Atomic weight of O		
AWS	Atomic weight of S		
BET	C content of fuel	% m/m	
CO2D	Concentration of CO_2	% V/V	in dry exhaust
CO2W	Concentration of CO_2	% V/V (wet)	in wet exhaust
COD	Concentration of CO	ppm	in dry exhaust
COW	Concentration of CO	ppm	in wet exhaust
CW	Soot	mg/m^3	in wet exhaust
DEL	N content of fuel	% m/m	
EAFCDO	Excess-air-factor based on the complete combustion and the CO_2-concentration, $l_{V,CO2}$	kg/kg	
EAFEXH	Excess-air-factor based on the exhaust gas concentration of carbon containing components, l_V	kg/kg	
EPS	O content of fuel	% m/m	
ETA	Nitrogen content of wet combustion air	% m/m	
EXHCPN	Exhaust gas ratio of components with carbon, c	V/V	
EXHDE NS	Density of wet exhaust	kg/m^3	
FFCB	Fuel specific factor for the carbon balance calculation		
FFD	Fuel specific factor for exhaust flow calculation on dry basis		dry basis
FFH	Fuel specific factor used for calculation of wet concentration from dry concentration		
FFW	Fuel specific factor for exhaust flow calculation on wet basis		wet basis
GAIRD	Combustion air mass flow	kg/h	dry combustion air
GAIRW	Combustion air mass flow	kg/h	wet combustion air
GAM	S content of fuel	% m/m	
GCO	Emission of CO	g/h	
GCO2	Emission of CO_2	g/h	
GEXHD	Exhaust mass flow	kg/h	dry exhaust
gexhw	Exhaust mass flow, calculated by the carbon balance method, G_{EXHW}	kg/h	
GEXHW	Exhaust mass flow	kg/h	wet exhaust
GFUEL	Fuel mass flow	kg/h	
GHC	Emission of HC	g/h	hydrocarbons
GH2O	Emission of H_2O	g/h	

Symbol	Description	Dimension	Remark
GN2	Emission of N_2	g/h	
GNO	Emission of NO	g/h	
GNO2	Emission of NO_2	g/h	
GO2	Emission of O_2	g/h	
GSO2	Emission of SO_2	g/h	
HCD	Hydrocarbons	ppm C1	in dry exhaust
HCW	Hydrocarbons	ppm C1	in wet exhaust
HTCRAT	Hydrogen-to-Carbon ratio of the fuel, a	mol /mol	
MV...	Molecular volume of ...	l/mol	individual gas
MW...	Molecular weight of ...	g/mole	individual gas
NO2W	Concentration of NO_2	ppm	in wet exhaust
NOW	Concentration of NO	ppm	in wet exhaust
NUE	Water content of combustion air	% m/m	
O2D	Concentration of O_2	% V/V	in dry exhaust
O2W	Concentration of O_2	% V/V (wet)	in wet exhaust
STOIAR	Stoichiometric air demand for the combustion of 1 kg fuel	kg /kg	
TAU	Oxygen content of wet combustion air	% m/m	wet air
TAU1	Oxygen content of wet combustion air that is emitted	% m/m	wet air
TAU2	Oxygen content of wet combustion air that is combusted	% m/m	wet air
VCO	Volume flow of CO	m^3/h	(exhaust content)
VCO2	Volume flow of CO_2	m^3/h	(exhaust content)
VH2O	Volume flow of H_2O	m^3/h	(exhaust content)
VHC	Volume flow of HC	m^3/h	(exhaust content)
VN2	Volume flow of N_2	m^3/h	(exhaust content)
VNO	Volume flow of NO	m^3/h	(exhaust content)
VNO2	Volume flow of NO_2	m^3/h	(exhaust content)
VO2	Volume flow of O_2	m^3/h	(exhaust content)
VSO2	Volume flow of SO_2	m^3/h	(exhaust content)

Notes: - For STANDARD m^3, or STANDARD Litre, the dimensions std. m^3 and std. l are used. The STANDARD m^3 of a gas is related to 273.15 K and 101.3 kPa
- Water gas equilibrium constant = 3.5

TECHNICAL CODE ON CONTROL OF EMISSION OF NITROGEN OXIDES FROM MARINE DIESEL ENGINES

Chapter 1 - GENERAL

1.1 PURPOSE

The purpose of this Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines, hereunder referred to as the Code, is to specify the requirements for the testing, survey and certification of marine diesel engines to ensure they comply with the nitrogen oxides (NO_x) emission limits of regulation 13 of Annex VI of MARPOL 73/78.

1.2 APPLICATION

1.2.1 This Code applies to all diesel engines with a power output of more than 130 kW which are installed, or are designed and intended for installation, on board any ship subject to Annex VI, with the exception of those engines described in paragraph 1(b) of regulation 13. Regarding the requirements for survey and certification under regulation 5 of Annex VI, this Code addresses only those requirements applicable to an engine's compliance with the NO_x emission limits.

1.2.2 For the purpose of the application of this Code, Administrations are entitled to delegate all functions required of an Administration by this Code to an organization authorized to act on behalf of the Administration.[1] In every case, the Administration assumes full responsibility for the survey and certificate.

1.2.3 For the purpose of this Code, an engine shall be considered to be operated in compliance with the NO_x limits of regulation 13 of Annex VI if it can be demonstrated that the weighted NO_x emissions from the engine are within those limits at the initial certification, intermediate surveys and such other surveys as are required

1.3 DEFINITIONS

1.3.1 *Nitrogen Oxide (NO_x) Emissions* means the total emission of nitrogen oxides, calculated as the total weighted emission of NO_2 and determined using the relevant test cycles and measurement methods as specified in this Code.

1.3.2 *Substantial modification* of a marine diesel engine means:

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[1] Refer to the Guidelines for the Authorization of Organizations Acting on Behalf of Administrations adopted by the Organization by resolution A.739(18) and to the Specifications on the Survey and Certification Functions of Recognized Organizations Acting on Behalf of the Administration adopted by the Organization by resolution A.789(19).

.1 For engines installed on ships constructed on or after 1 January 2000, *substantial modification* means any modification to an engine that could potentially cause the engine to exceed the emission standards set out in regulation 13 of Annex VI. Routine replacement of engine components by parts specified in the Technical File that do not alter emission characteristics shall not be considered a "substantial modification" regardless of whether one part or many parts are replaced.

.2 For engines installed on ships constructed before 1 January 2000, *substantial modification* means any modification made to an engine which increases its existing emission characteristics established by the simplified measurement method as described in 6.3 in excess of the allowances set out in 6.3.11. These changes include, but are not limited to, changes in its operations or in its technical parameters (e.g., changing camshafts, fuel injection systems, air systems, combustion chamber configuration, or timing calibration of the engine).

1.3.3 *Components* are those interchangeable parts which influence the NO_x emissions performance, identified by their design/parts number.

1.3.4 *Setting* means adjustment of an adjustable feature influencing the NO_x emissions performance of an engine.

1.3.5 *Operating values* are engine data, like cylinder peak pressure, exhaust gas temperature, etc., from the engine log which are related to the NO_x emission performance. These data are load-dependent.

1.3.6 The *EIAPP Certificate* is the Engine International Air Pollution Prevention Certificate which relates to NO_x emissions.

1.3.7 The *IAPP Certificate* is the International Air Pollution Prevention Certificate.

1.3.8 *Administration* has the same meaning as Article 2, sub-paragraph (5) of MARPOL 73/78.

1.3.9 *On-board NOx verification procedures* mean a procedure, which may include an equipment requirement, to be used on board at initial certification survey or at the periodical and intermediate surveys, as required, to verify compliance with any of the requirements of this Code, as specified by the engine manufacturer and approved by the Administration.

1.3.10 *Marine diesel engine* means any reciprocating internal combustion engine operating on liquid or dual fuel, to which regulations 5, 6 and 13 of Annex VI apply, including booster/compound systems if applied.

1.3.11 *Rated power* means the maximum continuous rated power output as specified on the nameplate and in the Technical File of the marine diesel engine to which regulation 13 of Annex VI and the NO_x Technical Code apply.

1.3.12 *Rated speed* is the crankshaft revolutions per minute at which the rated power occurs as specified on the nameplate and in the Technical File of the marine diesel engine.

1.3.13 *Brake power* is the observed power measured at the crankshaft or its equivalent, the engine being equipped only with the standard auxiliaries necessary for its operation on the test bed.

1.3.14 *On-board conditions* mean that an engine is:

.1 installed on board and coupled with the actual equipment which is driven by the engine; and

.2 under operation to perform the purpose of the equipment.

1.3.15 A *technical file* is a record containing all details of parameters, including components and settings of an engine, which may influence the NO_x emission of the engine, in accordance with 2.4 of this Code.

1.3.16 A *record book of engine parameters* is the document for recording all parameter changes, including components and engine settings, which may influence NO_x emission of the engine.

Chapter 2 - SURVEYS AND CERTIFICATION

2.1 GENERAL

2.1.1 Each marine diesel engine specified in 1.2, except as otherwise permitted by this Code, shall be subject to the following surveys:

.1 A pre-certification survey which shall be such as to ensure that the engine, as designed and equipped, complies with the NO_x emission limits contained in regulation 13 of Annex VI. If this survey confirms compliance, the Administration shall issue an Engine International Air Pollution Prevention (EIAPP) Certificate.

.2 An initial certification survey which shall be conducted on board a ship after the engine is installed but before it is placed in service. This survey shall be such as to ensure that the engine, as installed on board the ship, including any modifications and/or adjustments since the pre-certification, if applicable, complies with the NO_x emission limits contained in regulation 13 of Annex VI. This survey, as part of the ship's initial survey, may lead to either the issuance of a ship's initial International Air Pollution Prevention (IAPP) Certificate or an amendment of a ship's valid IAPP Certificate reflecting the installation of a new engine.

.3 Periodical and intermediate surveys, which shall be conducted as part of a ship's surveys required by regulation 5 of Annex VI, to ensure the engine continues to fully comply with the provisions of this Code.

.4 An initial engine's certification survey which shall be conducted on board a ship every time a substantial modification is made to an engine to ensure that the modified engine complies with the NO_x emission limits contained in regulation 13 of Annex VI.

2.1.2 To comply with the survey and certification requirements described in 2.1.1, there are five alternative methods included in this Code from which the engine manufacturer, ship builder or ship-owner, as applicable, can choose to measure, calculate or test an engine for its NO_x emissions, as follows:

.1 test bed testing for the pre-certification survey in accordance with chapter 5;

.2 on-board testing for an engine not pre-certificated for a combined pre-certification and initial certification survey in accordance with the full test bed requirements of chapter 5;

.3 on-board engine parameter check method for confirmation of compliance at initial, periodical and intermediate surveys for pre-certified engines or engines that have undergone modifications or adjustments to the designated components and adjustable features since they were last surveyed, in accordance with 6.2;

.4 on-board simplified measurement method for confirmation of compliance at periodical and intermediate surveys or confirmation of pre-certified engines for initial certification surveys, in accordance with 6.3 when required; or

.5 on-board direct measurement and monitoring for confirmation of compliance at periodical and intermediate surveys only, in accordance with 2.3.4, 2.3.5. 2.3.7, 2.3.8, 2.3.11, 2.4.4 and 5.5.

2.2 PROCEDURES FOR PRE-CERTIFICATION OF AN ENGINE

2.2.1 Prior to installation on board, every marine diesel engine, except as allowed by 2.2.2 and 2.2.4, shall:

.1 be adjusted to meet the applicable NO_x emission limits,

.2 have its NO_x emissions measured on a test bed in accordance with the procedures specified in chapter 5 of this Code, and

.3 be pre-certified by the Administration, as documented by issuance of an EIAPP Certificate.

2.2.2 For the pre-certification of serially manufactured engines, depending on the approval of the Administration, the engine family or the engine group concept may be applied (see chapter 4). In such a case, the testing specified in 2.2.1.2 is required only for the parent engine(s) of an engine group or engine family.

2.2.3 The method of obtaining pre-certification for an engine is for the Administration to:

.1 certify a test of the engine on a test bed;

.2 verify that all engines tested, including, if applicable, those to be delivered within an engine family or group, meet the NO_x limits; and

.3 if applicable, verify that the selected parent engine(s) is representative of an engine family or engine group.

2.2.4 There are engines which, due to their size, construction and delivery schedule, cannot be pre-certified on a test bed. In such cases, the engine manufacturer, shipowner or ship builder shall make application to the Administration requesting an on-board test (see 2.1.2.2). The applicant must demonstrate to the Administration that the on-board test fully meets all of the requirements of a test bed procedure as specified in chapter 5 of this Code. Such a survey may be accepted for one engine or for an engine group represented by the parent engine only, but it shall not be accepted for an engine family certification. In no case shall an allowance be granted for possible deviations of measurements if an initial survey is carried out on board a ship without any valid pre-certification test.

2.2.5 If the pre-certification test results show that an engine fails to meet the NO_x emission limits as required by regulation 13 of Annex VI, a NO_x reducing device may be installed. This device, when installed on the engine, must be recognized as an essential component of the engine and its presence will be recorded in the engine's Technical File. To receive an EIAPP Certificate for this assembly, the engine, including the reducing device, as installed, must be re-tested to show compliance with the NO_X emission limits. However, in this case, the assembly may be re-tested in accordance with the simplified measurement method addressed in 6.3. The NO_x reducing device shall be included on the EIAPP Certificate together with all other records requested by the Administration. The engine's Technical File shall also contain on-board NO_x verification procedures for the device to ensure it is operating correctly.

2.2.6 For pre-certification of engines within an engine family or engine group, an EIAPP Certificate shall be issued in accordance with procedures established by the Administration to the parent engine(s) and to every member engine produced under this certification to accompany the engines throughout their life whilst installed on ships under the authority of that Administration.

2.2.7.1 When an engine is manufactured outside the country of the Administration of the ship on which it will be installed, the Administration of the ship may request the Administration of the country in which the engine is manufactured to survey the engine. Upon satisfaction that the requirements of regulation 13 of Annex VI are complied with pursuant to this NO_x Technical Code, the Administration of the country in which the engine is manufactured shall issue or authorize the issuance of the EIAPP Certificate.

2.2.7.2 A copy of the certificate(s) and a copy of the survey report shall be transmitted as soon as possible to the requesting Administration.

2.2.7.3 A certificate so issued shall contain a statement to the effect that it has been issued at the request of the Administration.

2.2.8 A flow chart providing guidance for compliance with the requirements of a pre-certification survey for marine diesel engines intended for installation on board of ships is provided in figure 1 of appendix 2 of this Code.

2.2.9 A model form of an EIAPP Certificate is attached as appendix 1 to this Code.

2.3 PROCEDURES FOR CERTIFICATION OF AN ENGINE

2.3.1 For those engines which have not been adjusted or modified relative to the original specification of the manufacturer, the provision of a valid EIAPP Certificate should suffice to demonstrate compliance with the applicable NO_x limits.

2.3.2 After installation on board, it shall be determined to what extent an engine has been subjected to further adjustments and/or modifications which could affect the NO_x emission. Therefore, the engine, after installation on board, but prior to issuance of the IAPP Certificate, shall be inspected for modifications and be approved using the on-board NO_x verification procedures and one of the methods described in 2.1.2.

2.3.3 There are engines which, after pre-certification, need final adjustment or modification for performance optimization. In such a case, the engine group concept could be used to ensure that the engine still complies with the limits.

2.3.4 The shipowner shall have the option of direct measurement of NO_x emissions during engine operation. Such data may take the form of spot checks logged with other engine operating data on a regular basis and over the full range of engine operation or may result from continuous monitoring and data storage. Data must be current (taken within the last 30 days) and must have been acquired using the test procedures cited in this NO_x Technical Code. These monitoring records shall be kept on board for three months for verification purposes by the Parties to the Protocol of 1997. Data shall also be corrected for ambient conditions and fuel specification, and measuring equipment must be checked for correct calibration and operation, in accordance with the procedures specified by the measurement equipment manufacturer in the engine's Technical File. Where exhaust gas after-treatment devices are fitted which influence the NO_x emissions, the measuring point(s) must be located downstream of such devices.

2.3.5 To demonstrate compliance by the direct measurement method, sufficient data shall be collected to calculate the weighted average NO_x emissions in accordance with this Code.

2.3.6 Every marine diesel engine installed on board a ship shall be provided with a Technical File. The Technical File shall be prepared by the engine manufacturer and approved by the Administration, and required to accompany an engine throughout its life on board ships. The Technical File shall contain information as specified in 2.4.1.

2.3.7 Where an after-treatment device is installed and needed to comply with the NO_x limits, one of the options providing a ready means for verifying compliance with regulation 13 of Annex VI is direct NO_x measurement and monitoring in accordance with 2.3.4. However, depending on the technical possibilities of the device used, subject to the approval of the Administration, other relevant parameters could be monitored.

2.3.8 Where, for the purpose of achieving NO_x compliance, an additional substance is introduced, such as ammonia, urea, steam, water, fuel additives, etc., a means of monitoring the consumption of such substance shall be provided. The Technical File shall provide sufficient information to allow a ready means of demonstrating that the consumption of such additional substances is consistent with achieving compliance with the applicable NO_x limit.

2.3.9 If any adjustments or modifications are made to any engine after its pre-certification, a full record of such adjustments or modifications shall be recorded in the engine's record book of engine parameters.

2.3.10 If all of the engines installed on board are verified to remain within the parameters, components, and adjustable features recorded in the Technical File, the engines should be accepted as performing within the NO_x limits specified in regulation 13 of Annex VI. In this case, with respect to this Code, an IAPP Certificate should then be issued to the ship.

2.3.11 If any adjustment or modification is made which is outside the approved limits documented in the Technical File, the IAPP Certificate may be issued only if the overall NO_x emission performance is verified to be within the required limits by: a direct on-board NO_x monitoring, as approved by the Administration; a simplified on-board NO_x measurement; or, reference to the test bed testing for the relevant engine group approval showing that the adjustments or modifications do not exceed the NO_x emissions limits.

2.3.12 The Administration may, at its own discretion, abbreviate or reduce all parts of the survey on board, in accordance with this Code, to an engine which has been issued an EIAPP Certificate. However, the entire survey on board must be completed for at least one cylinder and/or one engine in an engine family or engine group, or spare part, if applicable, and the abbreviation may be made only if all the other cylinders and/or engines or spare parts are expected to perform in the same manner as the surveyed engine and/or cylinder or spare part.

2.3.13 Flow charts providing guidance for compliance with the requirements of an initial, periodical and intermediate surveys for certification of marine diesel engines installed on board of ships are provided in figures 2 and 3 of appendix 2 of this Code.

2.4 TECHNICAL FILE AND ON-BOARD NO_x VERIFICATION PROCEDURES

2.4.1 To enable an Administration to perform the engine surveys described in 2.1, the Technical File required by 2.3.6 shall, at a minimum, contain the following information:

.1 identification of those components, settings and operating values of the engine which influence its NO_x emissions;

.2 identification of the full range of allowable adjustments or alternatives for the components of the engine;

.3 full record of the relevant engine's performance, including the engine's rated speed and rated power;

.4 a system of on-board NO_x verification procedures to verify compliance with the NO_x emission limits during on-board verification surveys in accordance with chapter 6;

.5 a copy of the test report required in 5.10;

.6 if applicable, the designation and restrictions for an engine which is a member of an engine group or engine family;

.7 specifications of those spare parts/components which, when used in the engine, according to those specifications, will result in continued compliance of the engine with the NOx emission limits; and

.8 the EIAPP Certificate, as applicable.

2.4.2 To ensure that engines are in compliance with regulation 13 of Annex VI after installation, each engine with an EIAPP Certificate shall be checked at least once prior to issuance of the IAPP Certificate. Such check can be done using the on-board NO_x verification procedures specified in the engine's Technical File or one of the other methods if the owner's representative does not wish to check using the on-board NO_x verification procedures.

2.4.3 As a general principle, on-board NO_x verification procedures shall enable a surveyor to easily determine if an engine has remained in compliance with regulation 13 of Annex VI. At the same time, it shall not be so burdensome as to unduly delay the ship or to require in-depth knowledge of the characteristics of a particular engine or specialist measuring devices not available on board.

2.4.4 On-board NO_x verification procedures shall be determined by using one of the following methods:

.1 engine parameter check in accordance with 6.2 to verify that an engine's component, setting and operating values have not deviated from the specifications in the engine's Technical File;

.2 simplified measurement method in accordance with 6.3, or

.3 the direct measurement and monitoring method in accordance with 2.3.4, 2.3.5, 2.3.7, 2.3.8, 2.3.11, and 5.5.

2.4.5 When a NO_x monitoring and recording device is specified as on-board NO_x verification procedures, such device shall be approved by the Administration based on guidelines to be developed by the Organization. These guidelines shall include, but are not limited to, the following items:

.1 a definition of continuous NO_x monitoring, taking into account both steady state and transitional operations of the engine;

.2 data recording, processing and retention;

.3 a specification for the equipment to ensure that its reliability is maintained during service;

.4 a specification for environmental testing of the device;

.5 a specification for the testing of the equipment to demonstrate that it has a suitable accuracy, repeatability and cross sensitivity compared with the applicable sections of this Code; and

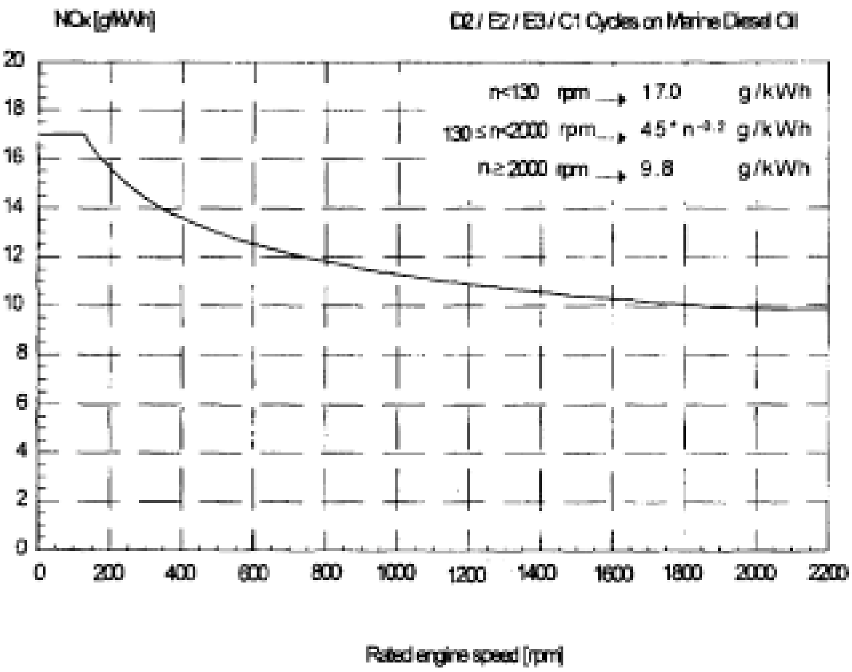
.6 the form of the approval certificate to be issued by the Administration.

2.4.6 When considering what on-board NO_x verification procedures should be included in an engine's Technical File to verify whether an engine complies with the NO_x emission limits during any of the required on-board verification surveys, subsequent to the issuance of an IAPP Certificate, an engine manufacturer or the shipowner may choose any of the three methods for on board NO_x verification procedures specified in 6.1.

Chapter 3 - NITROGEN OXIDES EMISSION STANDARDS

3.1 MAXIMUM ALLOWABLE NO_X EMISSION LIMITS FOR MARINE DIESEL ENGINES

3.1.1 The graph in figure 1 represents the maximum allowable NO_x emission limit values based on the formulae included in paragraph 3(a) of regulation 13 of Annex VI. The total weighted NO_x emissions, as measured and calculated in accordance with the procedures in this Code, shall be equal to or less than the applicable value from the graph corresponding to the rated speed of the engine.



where n = rated engine speed (crankshaft revolutions per minute)

Figure 1. Maximum Allowable NO_x Emissions for Marine Diesel Engines

3.1.2 When the engine operates on marine diesel oil in accordance with 5.3, the total emission of nitrogen oxides (calculated as the total weighted emission of NO_2) shall be determined using the relevant test cycles and measurement methods as specified in this Code.

3.1.3 An engine's applicable exhaust emissions limit value from figure 1 and the actual calculated exhaust emissions value for the engine shall be stated on the engine's EIAPP Certificate.

3.2 TEST CYCLES AND WEIGHTING FACTORS TO BE APPLIED

3.2.1 For every individual engine or parent engine of an engine group or family, one of the test cycles specified in 3.2.2 to 3.2.6 shall be applied for verification of compliance with the NO_x emission limits in accordance with regulation 13 of Annex VI.

3.2.2 For constant speed marine engines for ship main propulsion, including diesel electric drive, test cycle **E2** shall be applied in accordance with table 1.

3.2.3 For variable pitch propeller sets, test cycle **E2** shall be applied in accordance with table 1.

Table 1. Test cycle for "Constant Speed Main Propulsion" Application (including Diesel Electric Drive and Variable Pitch Propeller Installations)

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

3.2.4 For propeller law operated main and propeller law operated auxiliary engines, test cycle **E3** shall be applied in accordance with table 2.

Table 2. Test cycle for "Propeller Law operated Main and Propeller Law operated Auxiliary Engine" Application

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

3.2.5 For constant speed auxiliary engines, test cycle **D2** shall be applied in accordance with table 3.

Table 3. Test cycle for "Constant Speed Auxiliary Engine" Application

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

	Factor					

3.2.6 For variable speed, variable load auxiliary engines, not included above, test cycle **C1** shall be applied in accordance with table 4.

Table 4. Test cycle for "Variable Speed, Variable Load Auxiliary Engine" Application

	Speed	Rated				Inter mediate			Idle
Test cycle type C1	Torque %	100 %	75 %	50 %	10 %	100 %	75 %	50 %	0 %
	Weighting Factor	0.15	0.15	0.15	0.1	0.1	0.1	0.1	0.15

3.2.7 The torque figures given in test cycle C1 are percentage values which represent for a given test mode the ratio of the required torque to the maximum possible torque at this given speed.

3.2.8 The intermediate speed for test cycle C1 shall be declared by the manufacturer, taking into account the following requirements:

.1 For engines which are designed to operate over a speed range on a full load torque curve, the intermediate speed shall be the declared maximum torque speed if it occurs between 60% and 75% of rated speed.

.2 If the declared maximum torque speed is less than 60% of rated speed, then the intermediate speed shall be 60% of the rated speed.

.3 If the declared maximum torque speed is greater than 75% of the rated speed, then the intermediate speed shall be 75% of rated speed.

.4 For engines which are not designed to operate over a speed range on the full load torque curve at steady state conditions, the intermediate speed will typically be between 60% and 70% of the maximum rated speed.

3.2.9 If an engine manufacturer applies for a new test cycle application on an engine already certified under a different test cycle specified in 3.2.2 to 3.2.6, then it may not be necessary for that engine to undergo the full certification process for the new application. In this case, the engine manufacturer may demonstrate compliance by recalculation, by applying the measurement results from the specific modes of the first certification test to the calculation of the total weighted emissions for the new test cycle application, using the corresponding weighting factors from the new test cycle.

Chapter 4 - APPROVAL FOR SERIALLY MANUFACTURED ENGINES: ENGINE FAMILY AND ENGINE GROUP CONCEPTS

4.1 GENERAL

4.1.1 To avoid certification testing of every engine for compliance with the NO_x emission limits, one of two approval concepts may be adopted, namely the engine family or the engine group concept.

4.1.2 The engine family concept may be applied to any series produced engines which, through their design are proven to have similar NO_x emission characteristics, are used as produced, and, during installation on board, require no adjustments or modifications which could adversely affect the NO_x emissions.

4.1.3 The engine group concept may be applied to a smaller series of engines produced for similar engine application and which require minor adjustments and modifications during installation or in service on board. These engines are normally large power engines for main propulsion.

4.1.4 Initially the engine manufacturer may, at its discretion, determine whether engines should be covered by the engine family or engine group concept. In general, the type of application shall be based on whether the engines will be modified, and to what extent, after testing on a test bed.

4.2 DOCUMENTATION

4.2.1 All documentation for certification must be completed and suitably stamped by the duly authorized Authority as appropriate. This documentation shall also include all terms and conditions, including replacement of spare parts, to ensure that the engines maintain compliance with the required emission standards.

4.2.2 For an engine within an engine group, the required documentation necessary for the engine parameter check method is specified in 6.2.3.6.

4.3 APPLICATION OF THE ENGINE FAMILY CONCEPT

4.3.1 The engine family concept provides the possibility of reducing the number of engines which must be submitted for approval testing, while providing safeguards that all engines within the family comply with the approval requirements. In the engine family concept, engines with similar emission characteristics and design are represented by a parent engine within the family.

4.3.2 Engines that are series produced and not intended to be modified may be covered by the engine family concept.

4.3.3 The selection procedure for the parent engine is such that the selected engine incorporates those features which will most adversely affect the NO_x emission level. This engine, in general, shall have the highest NO_x emission level among all of the engines in the family.

4.3.4 On the basis of tests and engineering judgement, the manufacturer shall propose which engines belong to an engine family, which engine(s) produce the highest NO_x emissions, and which engine(s) should be selected for certification testing.

4.3.5 The Administration shall review for certification approval the selection of the parent engine within the family and shall have the option of selecting a different engine, either for approval or production conformity testing, in order to have confidence that the complete family of engines complies with the NO_x emission limits.

4.3.6 The engine family concept does allow minor adjustments to the engines through adjustable features. Marine engines equipped with adjustable features must comply with all requirements for any adjustment within the physically available range. A feature is not considered adjustable if it is permanently sealed or otherwise not normally accessible. The Administration may require that adjustable features be set to any specification within its adjustable range for certification or in-use testing to determine compliance with the requirements.

4.3.7 Before granting an engine family approval, the Administration shall take the necessary measures to verify that adequate arrangements have been made to ensure effective control of the conformity of production.

4.3.8 Guidelines for the Selection of an Engine Family

4.3.8.1 The engine family shall be defined by basic characteristics which must be common to all engines within the family. In some cases there may be interaction of parameters; these effects must also be taken into consideration to ensure that only engines with similar exhaust emission characteristics are included within an engine family, e.g., the number of cylinders may become a relevant parameter on some engines due to the aspiration or fuel system used, but with other designs, exhaust emissions characteristics may be independent of the number of cylinders or configuration.

4.3.8.2 The engine manufacturer is responsible for selecting those engines from their different models of engines that are to be included in a family. The following basic characteristics, but not specifications, must be common among all engines within an engine family:

.1 combustion cycle
- 2 stroke cycle
- 4 stroke cycle

.2 cooling medium
- air
- water
- oil

.3 individual cylinder displacement
- to be within a total spread of 15%

.4 number of cylinders and cylinder configuration
- applicable in certain cases only, e.g., in combination with exhaust gas cleaning devices

.5 method of air aspiration
- naturally aspirated
- pressure charged

.6 fuel type
- distillate/heavy fuel oil

- dual fuel

.7 combustion chamber
- open chamber
- divided chamber

.8 valve and porting, configuration, size and number
- cylinder head
- cylinder wall

.9 fuel system type
- pump-line-injector
- in-line
- distributor
- single element
- unit injector
- gas valve

.10 miscellaneous features
- exhaust gas re-circulation
- water / emulsion injection
- air injection
- charge cooling system
- exhaust after-treatment
    - reduction catalyst
    - oxidation catalyst
    - thermal reactor
    - particulates trap

4.3.8.3 If there are engines which incorporate other features which could be considered to affect NO_x exhaust emissions, these features must be identified and taken into account in the selection of the engines to be included in the family.

4.3.9 Guidelines for Selecting the Parent Engine of an Engine Family

4.3.9.1 The method of selection of the parent engine for NO_x measurement shall be agreed to and approved by the Administration. The method shall be based upon selecting an engine which incorporates engine features and characteristics which, from experience, are known to produce the highest NO_x emissions expressed in grammes per kilowatt hour (g/kWh). This requires detailed knowledge of the engines within the family. Under certain circumstances, the Administration may conclude that the worst case NO_x emission rate of the family can best be characterised by testing a second engine. Thus, the Administration may select an additional engine for test based upon features which indicate that it may have the highest NO_x emission levels of the engines within that family. If engines within the family incorporate other variable features which could be considered to affect NO_x emissions, these features must also be identified and taken into account in the selection of the parent engine.

4.3.9.2 The following criteria for selecting the parent engine for NO_x emission control shall be considered, but the selection process must take into account the combination of basic characteristics in the engine specification:

.1 main selection criteria

- higher fuel delivery rate

.2 supplementary selection criteria
- higher mean effective pressure
- higher maximum cylinder peak pressure
- higher charge air/ignition pressure ratio
- dp/dα, the lower slope of the combustion curve
- higher charge air pressure
- higher charge air temperature

4.3.9.3 If engines within the family incorporate other variable features which may affect the NO_x emissions, these features must also be identified and taken into account in the selection of the parent engine.

4.3.10 Certification of an Engine Family

4.3.10.1 The certification shall include a list, to be prepared and maintained by the engine manufacturer and approved by the Administration, of all engines and their specifications accepted under the same engine family, the limits of their operating conditions and the details and limits of engine adjustments that may be permitted.

4.3.10.2 A pre-certificate, or EIAPP Certificate, should be issued for a member engine of an entire family in accordance with this Code which certifies that the parent engine meets the NO_X levels specified in regulation 13 of Annex VI.

4.3.10.3 When the parent engine of an engine family is tested/measured under the most adverse conditions specified within this Code and confirmed as complying with the maximum allowable emission limits (see 3.1), the results of the test and NO_x measurement shall be recorded in the EIAPP Certificate issued for the particular parent engine and for all member engines of the engine family.

4.3.10.4 If two or more Administrations agree to accept each other's EIAPP's, then an entire engine family, certified by one of these Administrations, shall be accepted by the other Administrations which entered into that agreement with the original certifying Administration, unless the agreement specified otherwise. Certificates issued under such agreements shall be acceptable as prima facie evidence that all engines included in the certification of the engine family comply with the specific NO_x emission requirements. There is no need for further evidence of compliance with regulation 13 of Annex VI if it is verified that the installed engine has not been modified and the engine adjustment is within the range permitted in the engine family certification.

4.3.10.5 If the parent engine of an engine family is to be certified in accordance with an alternative standard or a different test cycle than allowed by this Code, the manufacturer must prove to the Administration that the weighted average NO_x emissions for the appropriate test cycles fall within the relevant limit values under regulation 13 of Annex VI and this Code before the Administration may issue an EIAPP Certificate.

4.3.10.6 Before granting an engine group approval for new, serially produced engines, the Administration shall take the necessary measures to verify that adequate arrangements have been made to ensure effective control of the conformity of production. This requirement may not be necessary for groups established for the purpose of engine modifications on board after an EIAPP Certificate has been issued.

4.4 APPLICATION OF THE ENGINE GROUP CONCEPT

4.4.1 These are engines used primarily for main propulsion. They normally require adjustment or modification to suit the on-board operating conditions but which should not result in NO_x emissions exceeding the limits in 3.1 of this Code.

4.4.2 The engine group concept also provides the possibility for a reduction in approval testing for modifications to engines in production or in service.

4.4.3 In general, the engine group concept may be applied to any engine type having the same design features as specified in 4.4.5, but individual engine adjustment or modification after test bed measurement is allowed. The range of engines in an engine group and choice of parent engine shall be agreed to and approved by the Administration.

4.4.4 The application for the engine group concept, if requested by the engine manufacturer or another party, shall be considered for certification approval by the Administration. If the engine owner, with or without technical support from the engine manufacturer, decides to perform modifications on a number of similar engines in the owner's fleet, the owner may apply for an engine group certification. The engine group may include a test engine on the test bench. Typical applications are similar modifications of similar engines in service or similar engines in similar operational conditions.

4.4.5 Guidelines for the Selection of an Engine Group

4.4.5.1 The engine group may be defined by basic characteristics and specifications in addition to the parameters defined in 4.3.8 for an engine family.

4.4.5.2 The following parameters and specifications must be common to engines within an engine group:

.1 bore and stroke dimensions,

.2 method and design features of pressure charging and exhaust gas system,
- constant pressure
- pulsating system

.3 method of charge air cooling system,
- with/without charge air cooler

.4 design features of the combustion chamber that effect NO_x emission,

.5 design features of the fuel injection system, plunger and injection cam which may profile basic characteristics that effect NO_x emission, and

.6 maximum rated power per cylinder at maximum rated speed. The permitted range of derating within the engine group shall be declared by the manufacturer and approved by the Administration.

4.4.5.3 Generally, if the parameters required by 4.4.5.2 are not common to all engines within a prospective engine group, then those engines may not be considered as an engine group. However, an engine group may be accepted if only one of those parameters or specifications is not common for all of the engines within a prospective engine group provided the engine manufacturer or the shipowner can, within the Technical File, prove to the Administration that such a transgression of that one parameter or specification would still result in all engines within the engine group complying with the NO_x emission limits.

4.4.6 Guidelines for Allowable Adjustment or Modification within an Engine Group

4.4.6.1 Minor adjustments and modifications in accordance with the engine group concept are allowed after pre-certification or final test bed measurement within an engine group upon agreement of the parties concerned and approval of the Administration, if:

.1 an inspection of emission-relevant engine parameters and/or provisions of the on-board NO_x verification procedures of the engine and/or data provided by the engine manufacturer confirm that the adjusted or modified engine complies with the applicable NO_x emission limits. The engine test bed results on NO_x emissions should be accepted as an option for verifying on-board adjustments or modifications to an engine within an engine group, or

.2 on-board measurement confirms that the adjusted or modified engine complies with the applicable NO_x emission limits.

4.4.6.2 Examples of adjustments and modifications within an engine group that may be permitted, but are not limited to those described below:

.1 For on-board conditions, adjustment of:
- injection timing for compensation of fuel property differences,
- injection timing for optimization of maximum cylinder pressure,
- fuel delivery differences between cylinders.

.2 For performance optimization, modification of:
- turbocharger,
- injection pump components,
    - plunger specification
    - delivery valve specification
- injection nozzles,
- cam profiles,
    - intake and/or exhaust valve
    - injection cam
- combustion chamber.

4.4.6.3 The above examples of modifications after a test-bed trial concern essential improvements of components or engine performance during the life of an engine. This is one of the main reasons for the existence of the engine group concept. The Administration, upon application, may accept the results from a demonstration test carried out on one engine, possibly a test engine, indicating the effects of the modifications on the NO_x level which may be accepted for all engines within that engine group without requiring certification measurements on each engine of the group.

4.4.7 Guidelines for the Selection of the Parent Engine of an Engine Group

The selection of the parent engine shall be in accordance with the criteria in 4.3.9, as applicable. It is not always possible to select a parent engine from small volume production engines in the same way as the mass produced engines (engine family). The first engine ordered may be registered as the parent engine. The method used to select the parent engine to represent the engine group shall be agreed to and approved by the Administration.

4.4.8 Before granting an initial engine group approval for serially produce engines, the Administration shall take the necessary measures to verify that adequate arrangements have been made to ensure effective control of the conformity of production. This requirement may not be necessary for groups established for the purpose of engine modification on board after an EIAPP Certificate has been issued.

Chapter 5 - PROCEDURES FOR NO_X EMISSION MEASUREMENTS ON A TEST BED

5.1 GENERAL

5.1.1 This procedure shall be applied to every initial approval testing of a marine engine regardless of the location of that testing (the methods described in 2.1.2.1 and 2.1.2.2).

5.1.2 This chapter specifies the measurement and calculation methods for gaseous exhaust emissions from reciprocating internal combustion engines (RIC engines) under steady-state conditions, necessary for determining the average weighted value for the NO_x exhaust gas emission.

5.1.3 Many of the procedures described below are detailed accounts of laboratory methods, since determining an emissions value requires performing a complex set of individual measurements, rather than obtaining a single measured value. Thus, the results obtained depend as much on the process of performing the measurements as they depend on the engine and test method.

5.1.4 This chapter includes the test and measurement methods, test run and test report as a procedure for a test bed measurement.

5.1.5 In principle, during emission tests, an engine shall be equipped with its auxiliaries in the same manner as it would be used on board.

5.1.6 For many engine types within the scope of this Code, the auxiliaries which may be fitted to the engine in service may not be known at the time of manufacture or certification. It is for this reason that the emissions are expressed on the basis of brake power as defined in 1.3.13.

5.1.7 When it is not appropriate to test the engine under the conditions as defined in 5.2.3, e.g., if the engine and transmission form a single integral unit, the engine may only be tested with other auxiliaries fitted. In this case the dynamometer settings shall be determined in accordance with 5.2.3 and 5.9. The auxiliary losses shall not exceed 5% of the maximum observed power. Losses exceeding 5% shall be approved by the Administration involved prior to the test.

5.1.8 All volumes and volumetric flow rates shall be related to 273 K (0°C) and 101.3 kPa.

5.1.9 Except as otherwise specified, all results of measurements, test data or calculations required by this chapter shall be recorded in the engine's test report in accordance with 5.10.

5.2 TEST CONDITIONS

5.2.1 Test condition parameter and test validity for engine family approval

Parameter f_a shall be determined according to the following provisions:

.1 naturally aspirated and mechanically supercharged engines:

$$f_a = \left(\frac{99}{p_s}\right) \bullet \left(\frac{T_a}{298}\right)^{0.7}$$

.2 turbocharged engine with or without cooling of the intake air:

$$f_a = \left(\frac{99}{p_s}\right)^{0.7} \bullet \left(\frac{T_a}{298}\right)^{1.5}$$

and, for a test to be recognized as valid, parameter f_a shall be such that:

$$0.98 \leq f_a \leq 1.02 \qquad (3)$$

5.2.2 Engines with charge air cooling

5.2.2.1 The temperature of the cooling medium and the temperature of the charge air shall be recorded. The cooling system shall be set with the engine operating at the reference speed and load. The charge air temperature and cooler pressure drop shall be set to within ± 4 K and ± 2 kPa, respectively, of the manufacturer's specification.

5.2.2.2 All engines when equipped as intended for installation on board ships must be capable of operating within the allowable NO_x emission levels of regulation 13(3) of Annex VI at an ambient seawater temperature of 25°C.[2]

5.2.3 Power

5.2.3.1 The basis for the measurement of specific emissions is uncorrected brake power.

5.2.3.2 Auxiliaries not necessary for the operation of the engine and which may be mounted on the engine may be removed for the test. See also 5.1.5 and 5.1.6.

5.2.3.3 Where non-essential auxiliaries have not been removed, the power absorbed by them at the test speeds shall be determined in order to calculate the uncorrected brake power in accordance with formula (18). See also 5.12.5.1.

5.2.4 Engine air inlet system

The test engine shall be equipped with an air inlet system which provides an air inlet restriction, specified by the manufacturer, to represent an unfouled air cleaner at the engine operating conditions, as specified by the manufacturer, and which results in maximum air flow in the respective engine application.

5.2.5 Engine exhaust system

2 25°C seawater temperature is the reference ambient condition to comply with the NOx limits. An additional temperature increase due to heat exchangers installed on board, e.g., for the low temperature cooling water system, shall be taken into consideration.

The test engine shall be equipped with an exhaust system which provides an exhaust back pressure as specified by the manufacturer at the engine operating conditions and which results in the maximum declared power in the respective engine application.

5.2.6 Cooling system

An engine cooling system with sufficient capacity to maintain the engine at normal operating temperatures as specified by the manufacturer shall be used.

5.2.7 Lubricating oil

Specifications of the lubricating oil used for the test shall be recorded.

5.3 TEST FUELS

5.3.1 Fuel characteristics may influence the engine exhaust gas emission. Therefore, the characteristics of the fuel used for the test shall be determined and recorded. Where reference fuels are used, the reference code or specifications and the analysis of the fuel shall be provided.

5.3.2 The selection of the fuel for the test depends on the purpose of the test. Unless otherwise agreed by the Administration and when a suitable reference fuel is not available, a DM-grade marine fuel specified in ISO 8217, 1996, with properties suitable for the engine type, shall be used.

5.3.3 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 temperature and location of measurement recorded.

5.4 MEASUREMENT EQUIPMENT

5.4.1 The emission of gaseous components by the engine submitted for testing shall be measured by methods as analysers, whose specifications are set out in appendix 3 of this Code.

5.4.2 Other systems or analysers may, subject to the approval of the Administration, be accepted if they yield equivalent results to that of the equipment referenced in 5.4.1.

5.4.3 This Code does not contain details of flow, pressure, and temperature measuring equipment. Instead, only the accuracy requirements of such equipment necessary for conducting an emissions test are given in 1.3.1 of appendix 4 of this Code.

5.4.4 Dynamometer specification

5.4.4.1 An engine dynamometer with adequate characteristics to perform the appropriate test cycle described in 3.2 shall be used.

5.4.4.2 The instrumentation for torque and speed measurement shall allow the measurement of the shaft power over the range of the test bed operations as specified by the manufacturer. If this is not the case, then additional calculations shall be required and recorded.

5.4.4.3 The accuracy of the measuring equipment shall be such that the maximum tolerances of the values given in 1.3.1 of appendix 4 of this Code are not exceeded.

5.5 DETERMINATION OF EXHAUST GAS FLOW

The exhaust gas flow shall be determined by one of the methods specified in 5.5.1, 5.5.2, or 5.5.3.

5.5.1 Direct measurement method

This method involves the direct measurement of the exhaust flow by flow nozzle or equivalent metering system and shall be in accordance with a recognized international standard.

Note: Direct gaseous flow measurement is a difficult task. Precautions should be taken to avoid measurement errors which will impact emission value errors.

5.5.2 Air and fuel measurement method

5.5.2.1 The method for determining exhaust emission flow using the air and fuel measurement method shall be conducted in accordance with a recognized international standard.

5.5.2.2 Air flowmeters and fuel flowmeters with an accuracy defined in 1.3.1 of appendix 4 of this Code shall be used.

5.5.2.3 The exhaust gas flow shall be calculated as follows:

.1 $G_{EXHW} = G_{AIRW} + G_{FUEL}$ (for wet exhaust mass) (4)

or

.2 $V_{EXHD} = V_{AIRD} + F_{FD} \bullet G_{FUEL}$ (for dry exhaust volume) (5)

or

.3 $V_{EXHW} = V_{AIRW} + F_{FW} \bullet G_{FUEL}$ (for wet exhaust volume) (6)

Note: Values for F_{FD} and F_{FW} vary with the fuel type (see table 1 of appendix 6 of this Code)

5.5.3 Carbon balance method

This method involves exhaust gas mass flow calculation from fuel consumption and exhaust gas concentrations using the carbon and oxygen balance method as specified in appendix 6 of this Code.

5.6 PERMISSIBLE DEVIATIONS OF INSTRUMENTS FOR ENGINE RELATED PARAMETERS AND OTHER ESSENTIAL PARAMETERS

The calibration of all measuring instruments shall be traceable to recognized international standards and shall comply with the requirements as set out in 1.3.1 of appendix 4 of this Code.

5.7 ANALYSERS FOR DETERMINATION OF THE GASEOUS COMPONENTS

The analysers to determine the gaseous components shall meet the specifications as set out in appendix 3 of this Code.

5.8 CALIBRATION OF THE ANALYTICAL INSTRUMENTS

Each analyser used for the measurement of an engine's parameters, as discussed in appendix 3 of this Code, shall be calibrated as often as necessary as set out in appendix 4 of this Code.

5.9 TEST RUN

5.9.1 General

5.9.1.1 Detailed descriptions of the recommended sampling and analysing systems are contained in 5.9.2 to 5.9.4. Since various configurations may produce equivalent results, exact conformance with these figures is not required. Additional components, such as instruments, valves, solenoids, pumps, and switches, may be used to provide additional information and coordinate the functions of the component systems. Other components which are not needed to maintain the accuracy on some systems, may be excluded if their exclusion is based upon good engineering judgement.

5.9.1.2 The settings of inlet restriction and exhaust back pressure shall be adjusted to the upper limits as specified by the manufacturer in accordance with 5.2.4 and 5.2.5, respectively.

5.9.2 Main exhaust components to be analysed

5.9.2.1 An analytical system for the determination of the gaseous emissions (CO, CO_2, HC, NO_x, O_2) in the raw exhaust gas shall be based on the use of the following analysers:

.1 HFID analyser for the measurement of hydrocarbons;

.2 NDIR analyser for the measurement of carbon monoxide and carbon dioxide;

.3 HCLD or equivalent analyser for the measurement of nitrogen oxides; and

.4 PMD, ECS or ZRDO for the measurement of oxygen.

5.9.2.2 For the raw exhaust gas, the sample for all components may be taken with one sampling probe or with two sampling probes located in close proximity and internally split to the different analysers. Care must be taken that no condensation of the exhaust components (including water and sulphuric acid) occurs at any point of the analytic system.

5.9.2.3 Specifications and calibration of these analysers shall be as set out in appendices 5 and 6 of this Code, respectively.

5.9.3 Sampling for gaseous emissions

5.9.3.1 The sampling probes for the gaseous emissions shall be fitted at least 0.5m or 3 times the diameter of the exhaust pipe - whichever is the larger - upstream of the exit of the exhaust gas system, as far as practicable, but sufficiently close to the engine so as to ensure an exhaust gas temperature of at least 343 K (70°C) at the probe.

5.9.3.2 In the case of a multi-cylinder engine with a branched exhaust manifold, the inlet of the probe shall be located sufficiently far downstream so as to ensure that the sample is representative of the average exhaust emission from all cylinders. In multi-cylinder engines having distinct groups of manifolds, such as in a "Vee" engine configuration, it is permissible to acquire a sample from each group individually and calculate an average exhaust emission. Other methods which have been shown to correlate with the above methods may be used. For exhaust emission calculation, the total exhaust mass flow must be used.

5.9.3.3 If the composition of the exhaust gas is influenced by any exhaust after-treatment system, the exhaust sample must be taken downstream of this device.

5.9.4 Checking of the analysers

The emission analysers shall be set at zero and spanned.

5.9.5 Test cycles

All engines shall be tested in accordance with the test cycles as defined in 3.2. This takes into account the variations in engine application.

5.9.6 Test sequence

5.9.6.1 After the procedures in 5.9.1 to 5.9.5 have been completed, the test sequence shall be started. The engine shall be operated in each mode in accordance with the appropriate test cycles defined in 3.2.

5.9.6.2 During each mode of the test cycle after the initial transition period, the specified speed shall be held to within ± 1% of rated speed or ± 3 min^{-1}, whichever is greater, except for low idle which shall be within the tolerances declared by the manufacturer. The specific torque shall be held so that the average, over the period during which the measurements are to be taken, is within ± 2% of the maximum torque at the test speed.

5.9.7 Analyser response

The output of the analysers shall be recorded, both during the test and during all response checks (zero and span), on a strip chart recorder or measured with an equivalent data acquisition system with the exhaust gas flowing through the analysers at least during the last ten minutes of each mode.

5.9.8 Engine conditions

The engine speed and load, intake air temperature and fuel flow shall be measured at each mode once the engine has been stabilised. The exhaust gas flow shall be measured or calculated and recorded.

5.9.9 Re-checking the analysers

After the emission test, the calibration of the analysers shall be re-checked using a zero gas and the same span gas as used prior to the measurements. The test shall be considered acceptable if the difference between the two calibration results is less than 2%.

5.10 TEST REPORT

5.10.1 For every engine tested for pre-certification or for initial certification on board without pre-certification, the engine manufacturer shall prepare a test report which shall contain, as a minimum, the data as set out in appendix 5 of this Code. The original of the test report shall be maintained on file with the engine manufacturer and a certified true copy shall be maintained on file by the Administration.

5.10.2 The test report, either an original or certified true copy, shall be attached as a permanent part of an engine's Technical File.

5.11 DATA EVALUATION FOR GASEOUS EMISSIONS

For the evaluation of the gaseous emissions, the chart reading of the last 60 seconds of each mode shall be averaged, and the average concentrations (conc) of CO, CO_2, HC, NO_x and O_2 during each mode shall be determined from the average chart readings and the corresponding calibration data.

5.12 CALCULATION OF THE GASEOUS EMISSIONS

The final results for the test report shall be determined by following the steps in 5.12.1 to 5.12.4.

5.12.1 Determination of the exhaust gas flow

The exhaust gas flow rate (G_{EXHW}, V_{EXHW}, or V_{EXHD}) shall be determined for each mode in accordance with one of the methods described in 5.5.1 to 5.5.3.

5.12.2 Dry/wet correction

When applying G_{EXHW} or V_{EXHW}, the measured concentration, if not already measured on a wet basis, shall be converted to a wet basis according to the following formulae.

$$conc\,(wet) = K_W \bullet conc\,(dry) \tag{7}$$

5.12.2.1 For the raw exhaust gas:

$$K_{w,r} = \left(1 - F_{FH} \bullet \frac{G_{FUEL}}{G_{AIRD}}\right) - K_{W2} \tag{8}$$

$$K_{W2} = \frac{1.608 \bullet H_a}{1000 + (1.608 \bullet H_a)} \tag{9}$$

$$H_a = \frac{6.220 \bullet R_a \bullet p_a}{p_B \quad p_a \bullet R_a \bullet 10^{2}} \tag{10}$$

with:

H_a, H_d = g water per kg dry air

R_a = relative humidity of the intake air, %

p_a = saturation vapour pressure of the intake air, kPa

p_B = total barometric pressure, kPa

Note: Formulae using F_{FH} are simplified versions of those quoted in section 3.7 of appendix 6 of this Code (formulae (2-44) & (2-45)) which when applied give comparable results to those expected from the full formulae.

5.12.2.2 Alternatively:

$$K_{W,r} = \frac{1}{1 + H_{TCRAT} \bullet 0.005 \bullet (\%\ CO\ \ (dry) + \%\ COSUB2\,(dry))}\ K_{W2} \tag{11}$$

5.12.2.3 For the intake air:

$$K_{W,a} = 1\ \ K_{W2} \tag{12}$$

5.12.2.4 Formula (8) shall be accepted as the definition of the fuel specific factor F_{FH}. Defined this way, F_{FH} is a value for the water content of the exhaust in relationship to the fuel to air ratio.

5.12.2.5 Typical values for F_{FH} may be found in table 1 of appendix 6 of this Code. Table 1 of appendix 6 of this Code contains a list of F_{FH} values for different fuels. F_{FH} does not only depend on the fuel specifications, but also, to a lesser degree, on the fuel to air ratio of the engine.

5.12.2.6 Section 3.9 of appendix 6 of this Code contains formulae for calculating F_{FH} from the hydrogen content of the fuel and the fuel to air ratio.

5.12.2.7 Formula (8) considers the water from the combustion and from the intake air to be independent from each other and to be additive. Formula (2-45) in section 3.7 of appendix 6 of this Code shows that the two water terms are not additive. Formula (2-45) is the correct version but it is very complicated and, therefore, the more practical formulae (8) & (11) shall be used.

5.12.3 NO_x correction for humidity and temperature

5.12.3.1 As the NO_x emission depends on ambient air conditions, the NO_x concentration shall be corrected for ambient air temperature and humidity by multiplying with the factors given in formulae (13) and (14).

5.12.3.2 The standard value of 10.71 g/kg at the standard reference temperature of 25°C shall be used for all calculations involving humidity correction throughout this Code. Other reference values for humidity instead of 10.71 g/kg must not be used.

5.12.3.3 Other correction formulae may be used if they can be justified or validated upon agreement of the parties involved and if approved by the Administration.

5.12.3.4 Water or steam injected into the air charger (air humidification) is considered an emission control device and shall therefore not be taken into account for humidity correction. Water that condensates in the charge cooler may change the humidity of the charge air and shall therefore be taken into account for humidity correction.

5.12.3.5 Diesel engines in general

For diesel engines in general, the following formula for calculating K_{HDIES} shall be used:

$$K_{HDIES} = \frac{1}{1 + A \bullet (H_a \; 10.71) + B \bullet (T_a \; 298)} \tag{13}$$

where:

A = 0.309 G_{FUEL} / G_{AIRD} - 0.0266

B = -0.209 G_{FUEL} / G_{AIRD} - 0.00954

T_a = temperature of the air in K

H_a = humidity of the intake air, g water per kg dry air (as determined by formula (10))

5.12.3.6 Diesel engines with intermediate air coolers

For diesel engines with intermediate air coolers, the following alternative formula (14) shall be used:

.1 To take the humidity in the charge air into account, the following consideration is added.

Hsc = humidity of the charging air, g water per kg dry air in which:

Hsc = 6.220 · Psc · 100 / (PC - Psc)

where:

Psc = saturation vapour pressure of the charging air, kPa

PC = charging air pressure, kPa

.2 If Ha ≥ Hsc, then Hsc shall be used in place of Ha in formula (14). In this case, G_{EXHW} in 5.5.2.3 shall be corrected as follows:

$G_{EXHW\ Corrected}$= $G_{EXHW\ (5.5.2.3)}$ · (1 - (Ha - Hsc) / 1000))

.3 If Ha < Hsc, then Ha in formula (14) shall be used as it is.

$$K_{HDIES} = \frac{1}{1 \; 0.012 \bullet (H_a \; 10.71) \; 0.00275 \bullet (T_a \; 298) + 0.00285 \bullet (T_{SC} \; T_{SC\,Ref})} \tag{14}$$

where:

T_{SC} = Temperature of the intercooled air
$T_{SC\ Ref}$ = Reference temperature of the intercooled air corresponding to a seawater temperature of 25°C. The $T_{SC\ Ref}$ to be specified by the manufacturer

Note: For an explanation of the other variables, see formula (13).

5.12.4 Calculation of the emission mass flow rates

5.12.4.1 The emission mass flow rates for each mode shall be calculated as follows (for the raw exhaust gas):

$$Gas\ mass = u \bullet conc \bullet G_{EXHW} \quad (15)$$

or

$$Gas\ mass = v \bullet conc \bullet V_{EXHD} \quad (16)$$

or

$$Gas\ mass = w \bullet conc \bullet V_{EXHW} \quad (17)$$

5.12.4.2 The coefficients u-wet, v-dry and w-wet shall be used as specified in table 5.

Table 5. Coefficients u, v, w

Gas	u	v	w	conc
NO_x	0.001587	0.002053	0.002053	ppm
CO	0.000966	0.00125	0.00125	ppm
HC	0.000479	-	0.000619	ppm
CO_2	15.19	19.64	19.64	percent
O_2	11.05	14.29	14.29	percent

Note: The coefficients for u given in table 5 are correct values for an exhaust density of 1.293 only; for exhaust density ≠ 1.293, u = w / density.

5.12.5 Calculation of the specific emissions

5.12.5.1 The emission shall be calculated for all individual components in the following way:

$$GAS_x = \frac{\sum_{i=1}^{i=n} M_{GAS_i} \bullet W_{F_i}}{\sum_{i=1}^{i=n} P_i \bullet W_{F_i}} \qquad (18)$$

where:

$$P_i = P_{M,i} + P_{AUX,i}$$

5.12.5.2 The weighting factors and the number of modes (n) used in the above calculation are according to the provisions of 3.2.

5.12.5.3 The resulting average weighted NO_x emission value for the engine as determined by formula (18) shall then be compared to figure 1 in 3.1 to determine if the engine is in compliance with regulation 13 of Annex VI.

Chapter 6 - PROCEDURES FOR DEMONSTRATING COMPLIANCE WITH NO_X EMISSION LIMITS ON BOARD

6.1 GENERAL

After installation of a pre-certificated engine on board a ship, every marine diesel engine shall have on-board verification surveys conducted as specified in 2.1.1.2 to 2.1.1.4 to verify that the engines continue to comply with the NO_x emission limits contained in regulation 13 of Annex VI. Such verification of compliance shall be determined by using one of the following methods:

.1 engine parameter check method in accordance with 6.2 to verify that an engine's component, settings and operating values have not deviated from the specifications in the engine's Technical File;

.2 simplified measurement method in accordance with 6.3; or

.3 the direct measurement and monitoring method in accordance with 2.3.4, 2.3.5, 2.3.7, 2.3.8, 2.3.11, 2.4.4, and 5.5.

6.2 ENGINE PARAMETER CHECK METHOD

6.2.1 General

6.2.1.1 Engines that meet the following conditions shall be eligible for an engine parameter check method:

.1 engines that have received a pre-certificate (EIAPP Certificate) on the test bed and those that received a certificate (IAPP Certificate) following an initial certification survey; and

.2 engines that have undergone modifications or adjustments to the designated engine components and adjustable features since they were last surveyed.

6.2.1.2 An engine parameter check method shall be conducted on engines, subject to 6.2.1.1, whenever there is a change of components and/or adjustable features of the engine that affect NO_x emission levels. This method shall be used to confirm compliance with the NO_x emission limits. Engines installed in ships shall be designed in advance for an easy check of components, adjustable features and engine parameters that affect NO_x emission levels.

6.2.1.3 In addition, when a diesel engine is designed to run within the prescribed NO_x emission limits, it is most likely that within the marine life of the engine, the NO_x emission limits may be adhered to. The prescribed NO_x emission limits may, however, be contravened by adjustments or modification to the engine. Therefore, an engine parameter check method shall be used to verify whether the engine is still within the prescribed NO_x emission limits.

6.2.1.4 Engine component checks, including checks of settings and an engine's operating values, are intended to provide an easy means of deducing the emissions performance of the engine for the purpose of verification that an engine with no, or minor, adjustments or modifications complies with the applicable NO_x emission limits.

6.2.1.5 The purpose of such checks is to provide a ready means of determining that an engine is correctly adjusted in accordance with the manufacturer´s specification and remains in a condition of adjustment consistent with the initial certification by the Administration as compliant with regulation 13 of Annex VI.

6.2.1.6 If an electronic engine management system is employed, this shall be evaluated against the original settings to ensure that appropriate parameters are operating within "as-built" limits.

6.2.1.7 For the purpose of assessing compliance with regulation 13 of Annex VI, it is not always necessary to measure the NO_x level to know that an engine, not equipped with an after-treatment device, is likely to comply with the NO_x emission limits. It may be sufficient to know that the present state of the engine corresponds to the specified components, calibration or parameter-adjustment state at the time of initial certification. If the results of an engine parameter check method indicate the likelihood that the engine complies with the NO_x emission limits, the engine may be re-certified without direct NO_x measurement.

6.2.1.8 For engines equipped with after-treatment devices, it will be necessary to check the operation of the after-treatment device as part of the parameter check.

6.2.2 Procedures for an engine parameter check method

6.2.2.1 An engine parameter check method shall be carried out using the two procedures as follows:

.1 a documentation inspection of engine parameter(s) shall be carried out in addition to other inspections and include inspection of record books covering engine parameters and verification that engine parameters are within the allowable range specified in an engine’s Technical File; and

.2 an actual inspection of engine components and adjustable features shall be carried out in addition to the documentation inspection as necessary. It shall then be verified, referring to the results of the documentation inspection, that the engine adjustable features are within the allowable range specified in an engine’s Technical File.

6.2.2.2 The surveyor shall have the option of checking one or all of the identified components, settings or operating values to ensure that the engine with no, or minor, adjustments or modifications complies with the applicable emission limits and that only components of the current specification are being used. Where adjustments and/or modifications in a specification are referenced in the Technical File, they must fall within the range recommended by the manufacturer and approved by the Administration.

6.2.3 Documentation for an engine parameter check method

6.2.3.1 Every marine diesel engine shall have a Technical File as required in 2.3.6 which identifies the engine’s components, settings or operating values which influence exhaust emissions and must be checked to ensure compliance.

6.2.3.2 Shipowners or persons responsible for ships equipped with diesel engines required to undergo an engine parameter check method shall maintain on board the following documentation in relation to the on-board NO_x verification procedures:

.1 a record book of engine parameters for recording of all the changes made relative to an engine’s components and settings;

.2 an engine parameter list of an engine's designated components and settings and/or the documentation of an engine's load-dependent operating values submitted by an engine manufacturer and approved by the Administration; and

.3 technical documentation of an engine component modification when such a modification is made to any of the engine's designated engine components.

6.2.3.3 Record book of engine parameters

Descriptions of any changes affecting the designated engine parameters, including adjustments, parts replacements and modifications to engine parts, shall be recorded chronologically in an engine's record book of engine parameters. These descriptions shall be supplemented with any other applicable data used for the assessment of the engine's NO_x levels.

6.2.3.4 List of NO_x influencing parameters sometimes modified on board

6.2.3.4.1 Dependent on the specific design of the particular engine, different NO_x influencing modifications and adjustments are possible and usual. These include the engine parameters as follows:

.1 injection timing,
.2 injection nozzle,
.3 injection pump,
.4 fuel cam,
.5 injection pressure for common rail systems,
.6 combustion chamber,
.7 compression ratio,
.8 turbocharger type and build,
.9 charge air cooler, charge air pre-heater,
.10 valve timing,
.11 NO_x abatement equipment "water injection",
.12 NO_x abatement equipment "emulsified fuel" (fuel water emulsion),
.13 NO_x abatement equipment "exhaust gas recirculation",
.14 NO_x abatement equipment "selective catalytic reduction", or
.15 other parameter(s) specified by the Administration.

6.2.3.4.2 The actual Technical File of an engine may, based on the recommendations of the engine manufacturer and the approval of the Administration, include less components and/or parameters than discussed above depending on the particular engine and the specific design.

6.2.3.5 Check list for the engine parameter check method

For some parameters, different survey possibilities exist. Approved by the Administration, the ship operator, supported by the engine manufacturer, may choose what method is applicable. Any one of, or a combination of, the methods listed in appendix 7 of this Code may be sufficient to show compliance.

6.2.3.6 Technical documentation of engine component modification

Technical documentation for inclusion in an engine's Technical File shall include details of modification and their influence on NO_x emissions, and it shall be supplied at the time when modifications are carried out. Test bed data obtained from a later engine, which is within the applicable range of the engine group concept, may be accepted.

6.2.3.7 Initial condition of engine components, adjustable features and parameters

An engine's Technical File shall contain all applicable information, relevant to the NO_x emission performance of the engine, on the designated engine's components, adjustable features and parameters at the time of the engine's pre-certification (EIAPP Certificate) or initial certification (IAPP Certificate), whichever occurred first.

6.3 SIMPLIFIED MEASUREMENT METHOD

6.3.1 General

6.3.1.1 The following simplified test and measurement procedure specified in this section shall be applied only for on-board confirmation tests and periodical and intermediate surveys when required. Every first engine testing on a test bed shall be carried out in accordance with the procedure specified in chapter 5 using a DM-grade marine diesel fuel. Corrections for ambient air temperature and humidity in accordance with 5.12.3 are essential as ships are sailing in cold/hot and dry/humid climates, which may cause a difference in NO_x emissions.

6.3.1.2 To gain meaningful results for on-board confirmation tests and on-board periodical and intermediate surveys, as an absolute minimum, the gaseous emission concentrations of NO_x, together with O_2 and/or CO_2 and CO, shall be measured in accordance with the appropriate test cycle. The weighting factors (W_F) and the number of modes (n) used in the calculation shall be in accordance with 3.2.

6.3.1.3 The engine torque and engine speed shall be measured but, to simplify the procedure, the permissible deviations of instruments (see 6.3.7) for measurement of engine-related parameters for on board verification purposes is different than from those permissible deviations allowed under the test bed testing method. If it is difficult to measure the torque directly, the brake power may be estimated by any other means recommended by the engine manufacturer and approved by the Administration.

6.3.1.4 In practical cases, it is often impossible to measure the fuel consumption once an engine has been installed on board a ship. To simplify the procedure on board, the results of the measurement of the fuel consumption from an engine's pre-certification test bed testing may be accepted. In such cases, especially concerning heavy fuel operation, an estimation with a corresponding estimated error shall be made. Since the oil fuel flow rate used in the calculation (G_{FUEL}) must relate to the oil fuel composition determined in respect of the fuel sample drawn during the test, the measurement of G_{FUEL} from the test bed testing shall be corrected for any difference in net calorific values between the test bed and test oil fuels. The consequences of such an error on the final emissions shall be calculated and reported with the results of the emission measurement.

6.3.1.5 Except as otherwise specified, all results of measurements, test data or calculations required by this chapter shall be recorded in the engine's test report in accordance with 5.10.

6.3.2 Engine parameters to be measured and recorded

Table 6 lists the engine parameters that shall be measured and recorded during on-board verification procedures.

Table 6. Engine parameters to be measured and recorded

Symbol	Parameter	Dimension
$b_{x,i}$	specific fuel consumption (if possible) (at the i^{th} mode during the cycle)	kg/kWh
H_a	absolute humidity (mass of engine intake air water content related to mass of dry air)	g/kg
$n_{d,i}$	engine speed (at the i^{th} mode during the cycle)	min^{-1}
$n_{turb,i}$	turbocharger speed (if applicable) (at the i^{th} mode during the cycle)	min^{-1}
p_B	total barometric pressure (in ISO 3046-1, 1995: p_x = Px = site ambient total pressure)	kPa
$p_{be,i}$	air pressure after the charge air cooler (at the i^{th} mode during the cycle)	kPa
P_i	brake power (at the i^{th} mode during the cycle)	kW
s_i	fuel rack position (of each cylinder, if applicable) (at the i^{th} mode during the cycle)	
T_a	temperature at air inlet (in ISO 3046-1, 1995: T_x = TTx = site ambient thermodynamic air temperature)	K
$T_{ba,i}$	air temperature after the charge air cooler (if applicable) (at the i^{th} mode during the cycle)	K
T_{clin}	Coolant temperature inlet	K
T_{clout}	Coolant temperature outlet	K
$T_{Exh,i}$	Exhaust Gas Temperature at the sampling point (at the i^{th} mode during the cycle)	K
T_{Fuel}	Fuel oil temperature before the engine	K
T_{Sea}	Sea water temperature	K
$T_{oil\ out/in}$	Lubricating oil temperature, outlet / inlet	K

6.3.3 Brake power

6.3.3.1 The point regarding the ability to obtain the required data during on-board NO_x testing is particularly relevant to brake power. Although the case of directly coupled gearboxes is considered in chapter 5, the engines, as may be presented on board, could in many applications, be arranged such that the measurements of torque (as obtained from a specially installed strain gauge) may not be possible due to the absence of a clear shaft. Principal in this group would be generators, but engines may also be coupled to pumps, hydraulic units, compressors, etc.

6.3.3.2 The engines driving such machinery would typically have been tested against a water brake at the manufacture stage prior to the permanent connection of the power consuming unit when installed on board. For generators this should not pose a problem to use voltage and amperage measurements together with a manufacturer's declared generator efficiency. For propeller law governed equipment, a declared speed power curve may be applied together with ensured capability to measure engine speed, either from the free end or by ratio of, for example, the camshaft speed.

6.3.4 Test fuels

6.3.4.1 Generally all emission measurements shall be carried out with the engine running on marine diesel fuel oil of an ISO 8217, 1996, DM-grade.

6.3.4.2 To avoid an unacceptable burden to the shipowner, the measurements for confirmation tests or re-surveys may, based on the recommendation of the engine manufacturer and the approval of the Administration, be allowed with an engine running on heavy fuel oil of an ISO 8217, 1996, RM-grade. In such a case the fuel bound nitrogen and the ignition quality of the fuel may have an influence on the NO_x emissions of the engine.

6.3.5 Sampling for gaseous emissions

6.3.5.1 The general requirements described in 5.9.3 shall be applied for on-board measurements as well.

6.3.5.2 The installation on board of all engines shall be such that these tests may be performed safely and with minimal interference to the engine. Adequate arrangements for the sampling of the exhaust gas and the ability to obtain the required data shall be provided on board a ship. The uptakes of all engines shall be fitted with an accessible standard sampling point.

6.3.6 Measurement equipment and data to be measured

The emission of gaseous pollutants shall be measured by the methods described in chapter 5.

6.3.7 Permissible deviation of instruments for engine related parameters and other essential parameters

Tables 3 and 4 contained in paragraph 1.3.2 of appendix 4 of this Code list the permissible deviation of instruments to be used in the measurement of engine-related parameters and other essential parameters during on-board verification procedures.

6.3.8 Determination of the gaseous components

The analytical measuring equipment and the methods described in chapter 5 shall be applied.

6.3.9 Test cycles

6.3.9.1 Test cycles used on board shall conform to the applicable test cycles specified in 3.2.

6.3.9.2 Engine operation on board under a test cycle specified in 3.2 may not always be possible, but the test procedure shall, based on the recommendation of the engine manufacturer and approval by the Administration, be as close as possible to the procedure defined in 3.2. Therefore, values measured in this case may not be directly comparable with test bed results because measured values are very much dependent on the test cycles.

6.3.9.3 If the number of measuring points on board is different than those on the test bed, the measuring points and the weighting factors shall be in accordance with the recommendations of the engine manufacturer and approved by the Administration.

6.3.10 Calculation of gaseous emissions

The calculation procedure specified in chapter 5 shall be applied, taking into account the special requirements of this simplified measurement procedure.

6.3.11 Allowances

6.3.11.1 Due to the possible deviations when applying the simplified measurement procedures of this chapter on board a ship, an allowance of 10% of the applicable limit value may be accepted for confirmation tests and periodical and intermediate surveys only.

6.3.11.2 The NO_x emission of an engine may vary depending on the ignition quality of the fuel and the fuel bound nitrogen. If there is insufficient information available on the influence of the ignition quality on the NO_x formation during the combustion process and the fuel bound nitrogen conversion rate also depends on the engine efficiency, an allowance of 10% may be granted for an on-board test run carried out on a RM-grade fuel (ISO 8217, 1996) except that there will be no allowance for the pre-certification test on board. The fuel oil used shall be analysed for its composition of carbon, hydrogen, nitrogen, sulphur and, to the extent given in ISO 8217, 1996, any additional components necessary for a clear specification of the fuel.

6.3.11.3 In no case shall the total granted allowance for both the simplification of measurements on board and the use of heavy fuel oil of an ISO 8217, 1996, RM-grade fuel, exceed 15% of the applicable limit value.

APPENDIX 1

Form of EIAPP Certificate

(Refer to 2.2.9 of the NO_x Technical Code)

ENGINE INTERNATIONAL AIR POLLUTION PREVENTION CERTIFICATE

Issued under the provisions of the Protocol of 1997 to the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 related thereto (hereinafter referred to as "the Convention") under the authority of the Government of:

....
(full designation of the country)

by..
(full designation of the competent person or organization authorized under the provisions of the Convention)

Engine Manufacturer	**Model number**	**Serial number**	**Test Cycle(s)**	**Rated Power (kW) and Speed (RPM)**	**Engine Approval number**

THIS IS TO CERTIFY:

1. That the above-mentioned marine diesel engine has been surveyed for pre-certification in accordance with the requirements of the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines made mandatory by Annex VI of the Convention; and

2. That the pre-certification survey shows that the engine, its components, adjustable features, and Technical File, prior to the engine's installation and/or service on board a ship, fully comply with the applicable regulation 13 of Annex VI of the Convention.

This certificate is valid for the life of the engine subject to surveys in accordance with regulation 5 of Annex VI of the Convention, installed in ships under the authority of this Government.

Issued at ....
(Place of issue of certificate)

.............................20.. ....
(Date of issue) *(signature of duty authorized official issuing the certificate)*

(Seal or Stamp of the authority, as appropriate)

Supplement to Engine International Air Pollution Prevention Certificate
(EIAPP Certificate)

RECORD OF CONSTRUCTION, TECHNICAL FILE AND MEANS OF VERIFICATION

In respect of the provisions of Annex VI of the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocols of 1978 and 1997 relating thereto (hereinafter referred to as "the Convention") and of the Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines (hereinafter referred to as the "NO_x Technical Code").

Notes:

1 This Record and its attachments shall be permanently attached to the **EIAPP** Certificate. The **EIAPP** Certificate shall accompany the engine throughout its life and shall be available on board the ship at all times.

2 If the language of the original Record is neither English nor French, the text shall include a translation into one of these languages.

3 Unless otherwise stated, regulations mentioned in this Record refer to regulations of Annex VI of the Convention and the requirements for an engine's Technical File and means of verifications refer to mandatory requirements from the NO_x Technical Code.

1 Particulars of the engine

1.1 Name and address of manufacturer..

1.2 Place of engine build..

1.3 Date of engine build..

1.4 Place of pre-certification survey ....

1.5 Date of pre-certification survey..

1.6 Engine type and model number..

1.7 Engine serial number ....
....

1.8 If applicable, the engine is a parent engine ☐ or a member engine ☐ of the following engine family ☐ or engine group ☐ ....
....

1.9 Test cycle(s) (see chapter 3 of the NO_x Technical Code)...

1.10 Rated Power (kW) and Speed (RPM) ....

1.11 Engine approval number ....

1.12 Specification(s) of test fuel ....
1.13 NO_x reducing device designated approval number (if installed)....................................

1.14 Applicable NO_x Emission Limit (g/kWh) (regulation 13 of Annex VI) ....
....

1.15 Engine's actual NO_x Emission Value (g/kWh) ....
....

2 Particulars of the Technical File

2.1 Technical File identification/approval number..
....

2.2 Technical File approval date ....
....

2.3 The Technical File, as required by chapter 2 of the NO_x Technical Code, is an essential part of the EIAPP Certificate and must always accompany an engine throughout its life and always be available on board a ship.

3 Specifications for the On-board NO_x Verification Procedures for the Engine Parameter Survey

3.1 On-board NO_x verification procedures identification/approval number ....
....

3.2 On-board NO_x verification procedures approval date ....
....

3.3 The specifications for the on-board NO_x verification procedures, as required by chapter 6 of the NO_x Technical Code, is an essential part of the EIAPP Certificate and must always accompany an engine through its life and always be available on board a ship.

THIS IS TO CERTIFY that this Record is correct in all respects.

Issued at...
(*Place of issue of the record*)

..............................20.. ....
(*Date of issue*) (*signature of duly authorized official issuing the Record*)

(*Seal or Stamp of the authority, as appropriate*)

APPENDIX 2

FLOW CHARTS FOR SURVEY AND CERTIFICATION OF MARINE DIESEL ENGINES

(Refer to 2.2.8 and 2.3.13 of the NO_x Technical Code)

Guidance for compliance with survey and certification of marine diesel engines, as described in chapter 2 of this Code, are shown in the flow charts on the next three pages as follows:

Figure 1. Flow Chart, Step 1 - Pre-certification Survey at the manufacturer's shop

Figure 2. Flow Chart, Step 2 - Initial Survey on board the ship

Figure 3. Flow Chart, Step 3 - Periodical Survey on board a ship

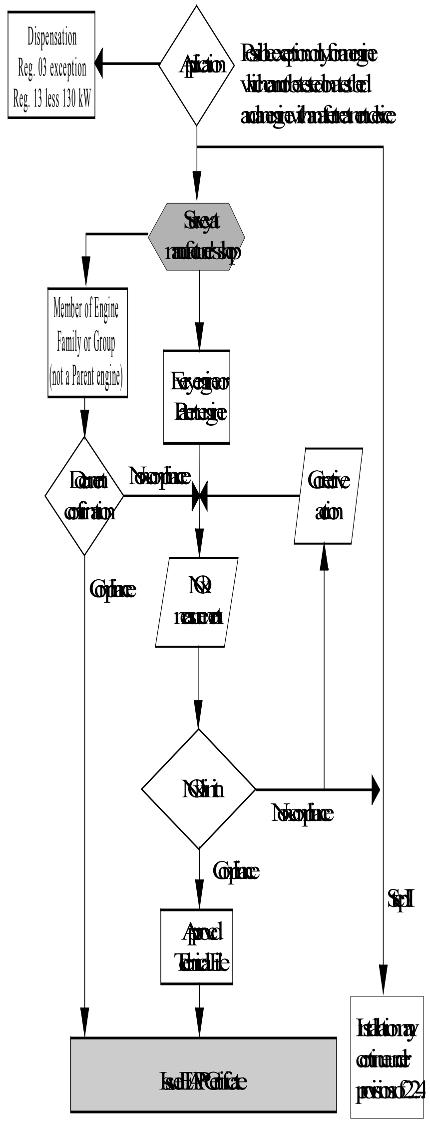

Dispensation
Reg. 03 exception
Reg. 13 less 130 kW
Member of Engine
Family or Group
(not a Parent engine)

Figure 1. Flow Chart, Step I - Pre-certification Survey at the manufacturer's shop

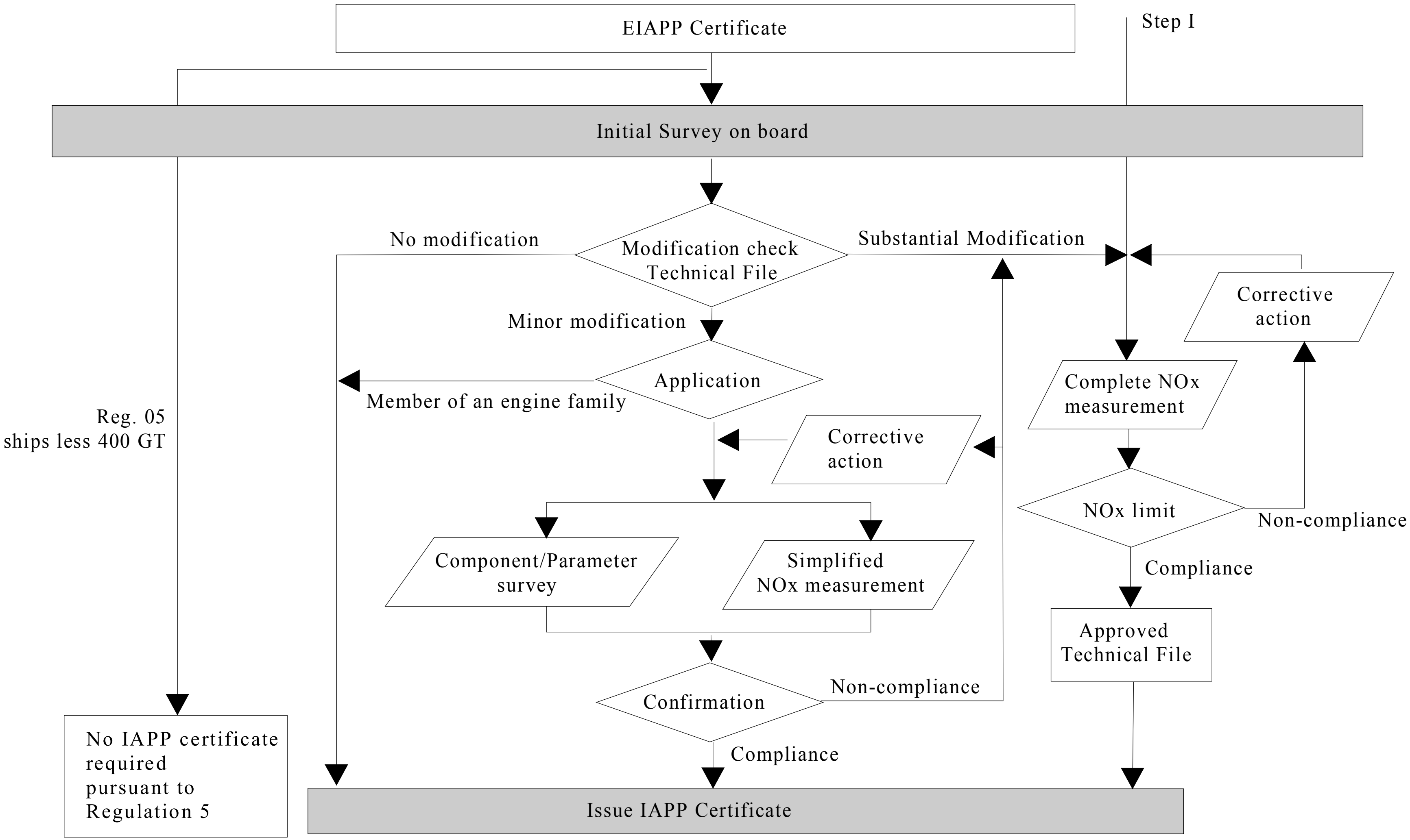

EIAPP Certificate
Step I
Initial Survey on board
No modification
Modification check
Technical File
Substantial Modification
Minor modification
Application
Member of an engine family
Reg. 05
ships less 400 GT
Corrective
action
Corrective
action
Complete NOx
measurement
NOx limit
Non-compliance
Compliance
Component/Parameter
survey
Simplified
NOx measurement
Approved
Technical File
Confirmation
Non-compliance
Compliance
No IAPP certificate
required
pursuant to
Regulation 5
Issue IAPP Certificate

Figure 2. Flow Chart, Step II - Initial Survey on board a ship

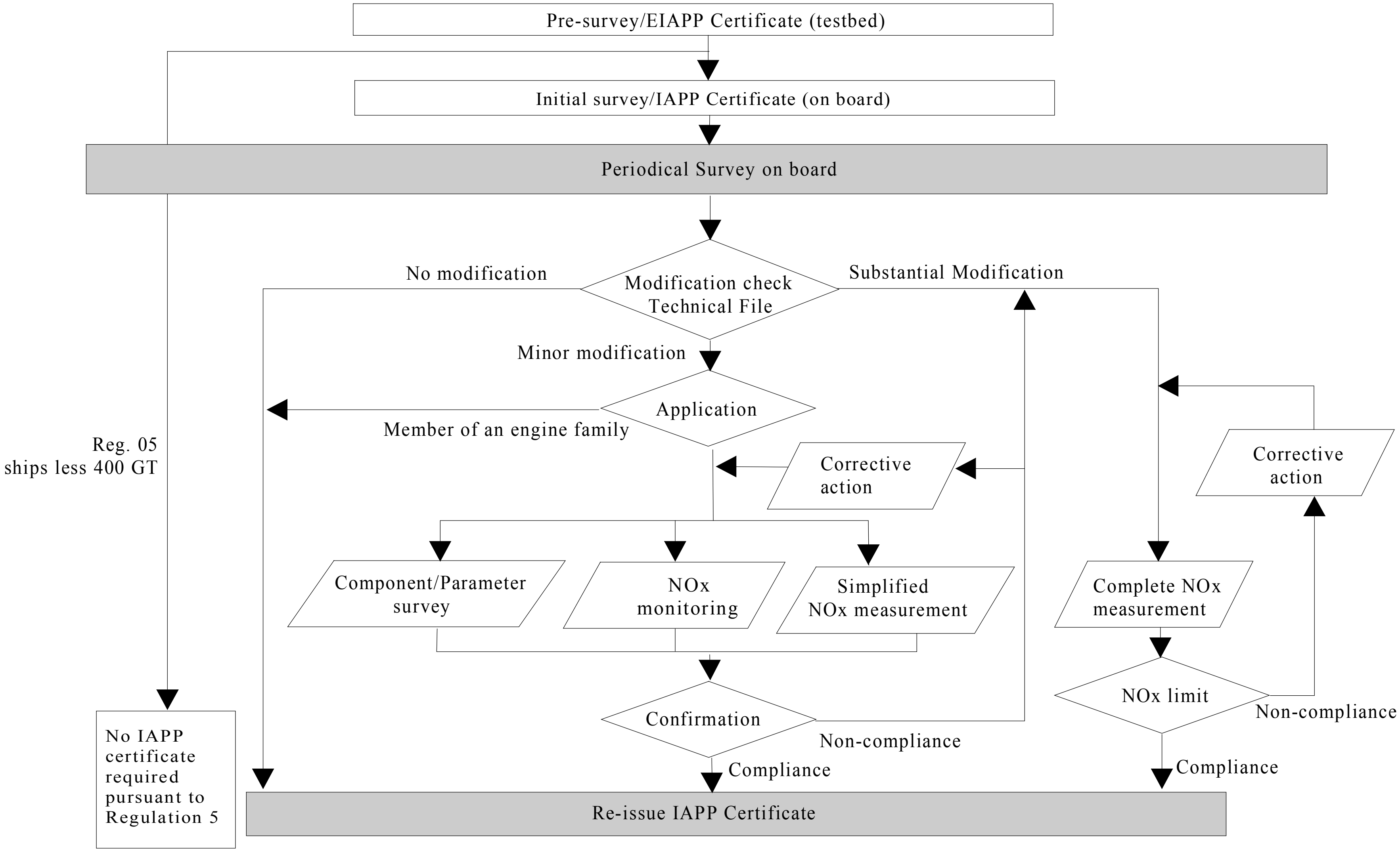

Pre-survey/EIAPP Certificate (testbed)
Initial survey/IAPP Certificate (on board)
Periodical Survey on board
No modification
Modification check
Technical File
Substantial Modification
Minor modification
Application
Member of an engine family
Reg. 05
ships less 400 GT
Corrective
action
Corrective
action
Component/Parameter
survey
NOx
monitoring
Simplified
NOx measurement
Complete NOx
measurement
NOx limit
Non-compliance
Confirmation
Non-compliance
Compliance
Compliance
No IAPP
certificate
required
pursuant to
Regulation 5
Re-issue IAPP Certificate

Figure 3. Flow Chart, Step III - Periodical Survey on board a ship

APPENDIX 3

SPECIFICATIONS FOR ANALYSERS TO BE USED IN THE DETERMINATION OF GASEOUS COMPONENTS OF DIESEL ENGINE EMISSIONS

(Refer to chapter 5 of the NO_x Technical Code)

1 General

1.1 The analysers shall have a measuring range appropriate for the accuracy required to measure the concentrations of the exhaust gas components (see 1.5). All analysers shall be capable of continuous measurement from the gas stream and provide a continuous output response capable of being recorded. It is recommended that the analysers be operated such that the measured concentration falls between 15% and 100% of full scale.

1.2 If read-out systems (computers, data loggers, etc.) that provide sufficient accuracy and resolution below 15% of full scale are used, concentrations below 15% of full scale may also be acceptable. In this case, additional calibrations shall be made to ensure the accuracy of the calibration curves (see 5.5.2 of appendix 4 of this Code).

1.3 The electromagnetic compatibility (EMC) of the equipment shall be on a level to minimise additional errors.

1.4 Definitions

.1 The *repeatability* of an analyser is defined as 2.5 times the standard deviation of 10 repetitive responses to a given calibration or span gas.

.2 The *zero response* of an analyser is defined as the mean response, including noise, to a zero gas during a 30 seconds time interval.

.3 *Span* is defined as the difference between the span response and the zero response.

.4 The *span response* is defined as the mean response, including noise, to a span gas during a 30 seconds time interval.

1.5 Measurement error

The total measurement error of an analyser, including the cross sensitivity to other gases (see section 8 of appendix 4 of this Code), shall not exceed ± 5% of the reading or ± 3.5% of full scale, whichever is smaller. For concentrations of less than 100 ppm, the measurement error shall not exceed ± 4 ppm.

1.6 Repeatability

The repeatability of an analyser shall be no greater than ± 1% of full scale concentration for each range used above 155 ppm (or ppm C) or ± 2% of each range used below 155 ppm (or ppm C).

1.7 Noise

The analyser peak-to-peak response to zero and calibration or span gases over any 10 seconds period shall not exceed 2% of full scale on all ranges used.

1.8 Zero drift

The zero drift during a one hour period shall be less than 2% of full scale on the lowest range used.

1.9 Span drift

The span drift during a one hour period shall be less than 2% of full scale on the lowest range used.

2 Gas drying

The optional gas drying device shall have a minimal effect on the concentration of the measured gases. Chemical dryers are not an acceptable method of removing water from the sample.

3 Analysers

The gases to be measured shall be analysed with the following instruments. For non-linear analysers, the use of linearising circuits is permitted.

.1 **Carbon monoxide (CO) analysis**

The carbon monoxide analyser shall be of the Non-Dispersive InfraRed (NDIR) absorption type.

.2 **Carbon dioxide (CO_2) analysis**

The carbon dioxide analyser shall be of the Non-Dispersive InfraRed (NDIR) absorption type.

.3 **Oxygen (O_2) analysis**

Oxygen analysers shall be of the ParaMagnetic Detector (PMD), ZiRconium DiOxide (ZRDO) or ElectroChemical Sensor (ECS) type.

Note: Electrochemical sensors shall be compensated for CO_2 and NO_x interference.

.4 **Oxides of nitrogen (NO_x) analysis**

The oxides of nitrogen analyser shall be of the ChemiLuminescent Detector (CLD) or Heated ChemiLuminescent Detector (HCLD) type with a NO_2/NO converter, if measured on a dry basis. If measured on a wet basis, an HCLD with converter maintained above 333 K (60°C) shall be used, provided the water quench check (see 8.2.2 of appendix 4 of this Code) is satisfied.

APPENDIX 4

CALIBRATION OF THE ANALYTICAL INSTRUMENTS

(Refer to chapter 5 of the NO_x Technical Code)

1 Introduction

1.1 Each analyser used for the measurement of an engine's parameters shall be calibrated as often as necessary in accordance with the requirements of this appendix.

1.2 Except as otherwise specified, all results of measurements, test data or calculations required by this appendix shall be recorded in the engine's test report in accordance with section 5.10 of this Code.

1.3 Accuracy of analytical instruments

1.3.1 Permissible deviation of instruments for measurements on a test bed

The calibration of all measuring instruments shall comply with the requirements as set out in tables 1 and 2 and shall be traceable to national or international standards.

Table 1. Engine related permissible deviations for measurements on a test bed

No.	Item	Permissible Deviation ($\pm$% values based on engines' maximum values)	Calibration Intervals (months)
1	Engine speed	2%	3
2	Torque	2%	3
3	Power	2%	not applicable
4	Fuel consumption	2%	6
5	Air consumption	2%	6
6	Exhaust gas flow	4%	5

Table 2. Permissible deviations of essential measured parameters for measurements on a test bed

No.	Item	Permissible Deviation ± absolute values	Calibration Intervals (months)
1	Coolant temperature	2 K	3
2	Lubricant temperature	2 K	3
3	Exhaust gas pressure	5% of maximum	3
4	Inlet manifold depressions	5% of maximum	3
5	Exhaust gas temperature	15 K	3
6	Air inlet temperature (combustion air)	2 K	3
7	Atmospheric pressure	0.5% of reading	3
8	Intake air humidity (relative)	3%	1
9	Fuel temperature	2 K	3

1.3.2 Permissible deviation of instruments for measurements on board a ship for verification purposes

The calibration of all measuring instruments shall comply with the requirements as set out in tables 3 and 4 and shall be traceable to national or international standards.

Table 3. Permissible deviation of instruments for engine related parameters for measurements on board a ship

No.	Item	Permissible Deviation (±% based on maximum engines' values)	Calibration Intervals (month)
1	engine speed	2%	3
2	torque	5%	3
3	power	5%	not applicable
4	fuel consumption	4% / 6% diesel/residual	6
5	specific fuel consumption	not applicable	not applicable
6	air consumption	5%	6
7	exhaust gas flow	5% calculated	6

Table 4. Permissible deviations of instruments for other essential parameters for measurements on board a ship

No.	Item	Permissible Deviation ± absolute values or "of reading"	Calibration Intervals (months)
1	coolant temperature	2 K	3
2	lubricating oil temperature	2 K	3
3	exhaust gas pressure	5% of maximum	3
4	inlet manifold depressions	5% of maximum	3
5	exhaust gas temperature	15 K	3
6	air inlet temperature	2 K	3
7	atmospheric pressure	0.5% of reading	3
8	intake air humidity (relative)	3%	1
9	fuel temperature	2 K	3

2 Calibration gases

The shelf life of all calibration gases as recommended by the manufacturer shall not be exceeded. The expiration date of the calibration gases stated by the manufacturer shall be recorded.

2.1 Pure gases

2.1.1 The required purity of the gases is defined by the contamination limits given below. The following gases shall be available for operation of the test bed measurement procedures:

.1 purified nitrogen (contamination ≤ 1 ppm C, ≤ 1 ppm CO, ≤ 400 ppm CO_2, ≤ 0.1 ppm NO);

.2 purified oxygen (purity > 99.5% volume O_2);

.3 hydrogen-helium mixture (40 ± 2% hydrogen, balance helium), (contamination ≤ 1 ppm C, ≤ 400 ppm CO); and

.4 purified synthetic air (contamination ≤ 1 ppm C, ≤ 1 ppm CO, ≤ 400 CO_2, ≤ 0.1 ppm NO), (oxygen content between 18-21% volume).

2.2 Calibration and span gases

2.2.1 Mixtures of gases having the following chemical compositions shall be available:

.1 CO and purified nitrogen;

.2 NO_x and purified nitrogen (the amount of NO_2 contained in this calibration gas must not exceed 5% of the NO content);

.3 O_2 and purified nitrogen; and

.4 CO_2 and purified nitrogen.

Note: Other gas combinations are allowed provided the gases do not react with one another.

2.2.2 The true concentration of a calibration and span gas shall be within ± 2% of the nominal value. All concentrations of calibration gas shall be given on a volume basis (volume percent or volume ppm).

2.2.3 The gases used for calibration and span may also be obtained by means of a gas divider, diluting with purified N_2 or with purified synthetic air. The accuracy of the mixing device shall be such that the concentration of the diluted calibration gases may be determined to within ± 2%.

3 Operating procedure for analysers and sampling system

The operating procedure for analysers shall follow the start-up and operating instructions specified by the instrument manufacturer. The minimum requirements given in sections 4 to 9 shall be included.

4 Leakage test

4.1 A system leakage test shall be performed. The probe shall be disconnected from the exhaust system and the end plugged. The analyser pump shall be switched on. After an initial stabilisation period, all flow meters shall read zero; if not, the sampling lines shall be checked and the fault corrected.

4.2 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. The analyser flows and bypass flows may be used to estimate the in-use flow rates.

4.3 Another method that may be used is the introduction of a concentration step change at the beginning of the sampling line by switching from zero to span gas. After an adequate period of time, the reading should show a lower concentration compared to the introduced concentration; this points to calibration or leakage problems.

5 Calibration procedure

5.1 Instrument assembly

The instrument assembly shall be calibrated and the calibration curves checked against standard gases. The same gas flow rates shall be used as when sampling exhaust.

5.2 Warming-up time

The warming-up time shall be according to the recommendations of the analyser's manufacturer. If not specified, a minimum of two hours is recommended for warming up the analysers.

5.3 NDIR and HFID analyser

The NDIR analyser shall be tuned, as necessary.

5.4 Calibration

5.4.1 Each normally used operating range shall be calibrated.

5.4.2 Using purified synthetic air (or nitrogen), the CO, CO_2, NO_x and O_2 analysers shall be set at zero.

5.4.3 The appropriate calibration gases shall be introduced to the analysers, the value recorded, and the calibration curve established according to 5.5 below.

5.4.4 The zero setting shall be rechecked and the calibration procedure repeated, if necessary.

5.5 Establishment of the calibration curve

5.5.1 General guidelines

5.5.1.1 The analyser calibration curve shall be established by at least five calibration points (excluding zero) spaced as uniformly as possible. The highest nominal concentration shall be greater than or equal to 90% of full scale.

5.5.1.2 The calibration curve is calculated by the method of least squares. If the resulting polynomial degree is greater than 3, the number of calibration points (zero included) shall be at least equal to this polynomial degree plus 2.

5.5.1.3 The calibration curve shall not differ by more than ± 2% from the nominal value of each calibration point and by more than ± 1% of full scale at zero.

5.5.1.4 From the calibration curve and the calibration points, it is possible to verify that the calibration has been carried out correctly. The different characteristic parameters of the analyser shall be indicated, particularly:

.1 the measuring range,

.2 the sensitivity, and

.3 the date of carrying out the calibration.

5.5.2 Calibration below 15% of full scale

5.5.2.1 The analyser calibration curve shall be established by at least 10 calibration points (excluding zero) spaced so that 50% of the calibration points are below 10% of full scale.

5.5.2.2 The calibration curve shall be calculated by the method of least squares.

5.5.2.3 The calibration curve shall not differ by more than ± 4% from the nominal value of each calibration point and by more than ± 1% of full scale at zero.

5.5.3 Alternative methods

If it can be shown that alternative technology (e.g., computer, electronically controlled range switch, etc.) provides equivalent accuracy, then these alternatives may be used.

6 Verification of the calibration

Each normally used operating range shall be checked prior to each analysis in accordance with the following procedure:

.1 the calibration shall be checked by using a zero gas and a span gas whose nominal value shall be more than 80% of full scale of the measuring range; and

.2 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 this is not the case, a new calibration curve shall be established in accordance with 5.5 above.

7 Efficiency test of the NO_x converter

The efficiency of the converter used for the conversion of NO_2 into NO shall be tested as given in 7.1 to 7.8 below.

7.1 Test set-up

Using the test set-up as shown in figure 1 below (see also 3.4 of appendix 3 of this Code) and the procedure below, the efficiency of converters shall be tested by means of an ozonator.

7.2 Calibration

The CLD and the HCLD shall be calibrated in the most common operating range following the manufacturer's specifications using zero and span gas (the NO content of which should amount to about 80% of the operating range and the NO_2 concentration of the gas mixture to less than 5% of the NO concentration). The NO_x analyser must be in the NO mode so that the span gas does not pass through the converter. The indicated concentration shall be recorded.

7.3 Calculation

The efficiency of the NO_x converter shall be calculated as follows:

$$Efficiency(\%) = \left(1 + \frac{ab}{cd}\right) \bullet 100 \qquad (1)$$

where:

a = NO_x concentration according to 7.6 below
b = NO_x concentration according to 7.7 below
c = NO concentration according to 7.4 below
d = NO concentration according to 7.5 below

7.4 Adding of oxygen

7.4.1 Via a T-fitting, oxygen or zero air shall be added continuously to the gas flow until the concentration indicated is about 20% less than the indicated calibration concentration given in 7.2 above (the analyser must be in the NO mode).

7.4.2 The indicated concentration "c" shall be recorded. The ozonator must be kept deactivated throughout the process.

7.5 Activation of the ozonator

The ozonator shall now be activated to generate enough ozone to bring the NO concentration down to about 20% (minimum 10%) of the calibration concentration given in 7.2 above. The indicated concentration (d) shall be recorded (the analyser must be in the NO mode).

7.6 NO_x mode

The NO analyser shall then be switched to the NO_x mode so that the gas mixture (consisting of NO, NO_2, O_2 and N_2) now passes through the converter. The indicated concentration "a" shall be recorded (the analyser must be in the NO_x mode).

7.7 Deactivation of the ozonator

The ozonator shall now be deactivated. The mixture of gases described in 7.6 above passes through the converter into detector. The indicated concentration "b" shall be recorded (the analyser must be in the NO_x mode).

7.8 NO mode

Switched to NO mode with the ozonator deactivated, the flow of oxygen or synthetic air shall also be shut off. The NO_x reading of the analyser shall not deviate by more than ± 5% from the value measured according to 7.2 above (the analyser must be in the NO_x mode).

7.9 Test interval

The efficiency of the converter shall be tested prior to each calibration of the NO_x analyser.

g7.10 Efficiency requirement

The efficiency of the converter shall not be less than 90%, but a higher efficiency of 95% is strongly recommended.

Note: If, with the analyser in the most common range, the NO_x converter cannot give a reduction from 80% to 20% according to 7.2 above, then the highest range which will give the reduction shall be used.

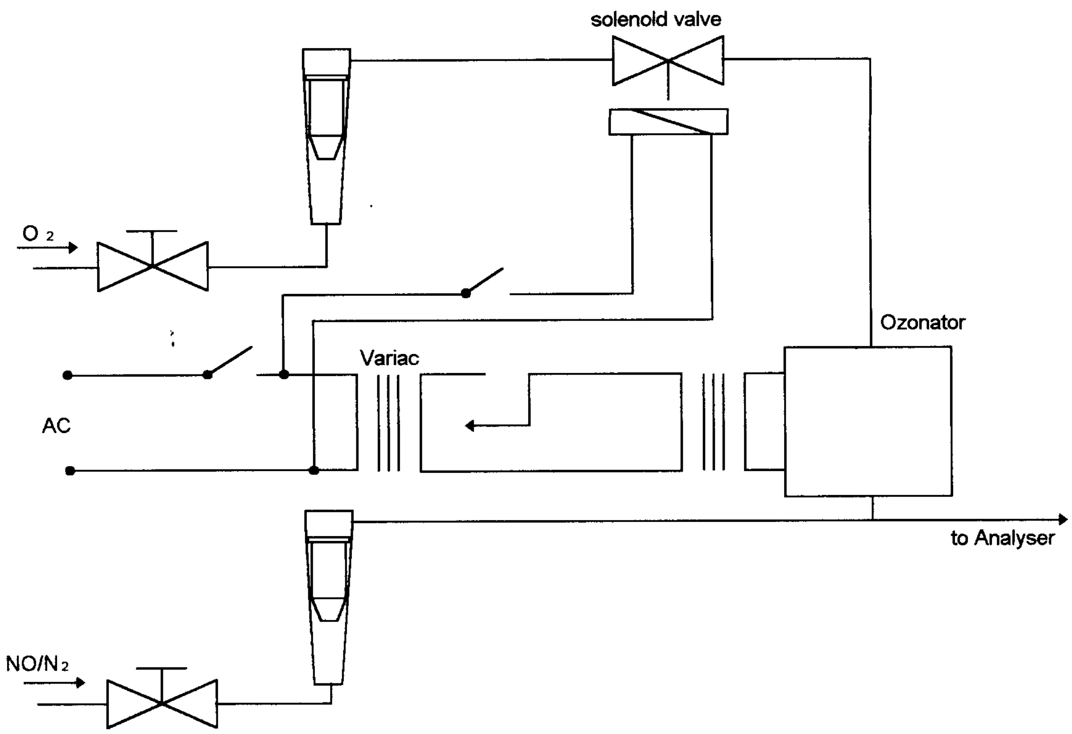


Figure 1. Schematic of NO_2 converter efficiency device

8 Interference effects with CO, CO_2, NO_x and O_2 analysers

Gases present in the exhaust other than the one being analysed may interfere with the reading in several ways. Positive interference may occur in NDIR and PMD instruments where the interfering gas gives the same effect as the gas being measured, but to a lesser degree. Negative interference may occur in NDIR instruments by the interfering gas broadening the absorption band of the measured gas, and in CLD instruments by the interfering gas quenching the radiation. The interference checks in 8.1 and 8.2 below shall be performed prior to an analyser's initial use and after major service intervals.

8.1 CO analyser interference check

Water and CO_2 may interfere with the CO analyser performance. Therefore, a CO_2 span gas having a concentration of 80 to 100% of full scale of the maximum operating range used during testing shall be bubbled through water at room temperature and the analyser response recorded. The analyser shall not be more than 1% of full scale for ranges greater than or equal to 300 ppm or more than 3 ppm for ranges below 300 ppm.

8.2 NO_x analyser quench checks

The two gases of concern for CLD (and HCLD) analysers are CO_2 and water vapour. Quench responses to these gases are proportional to their concentrations, and therefore require test techniques to determine the quench at the highest expected concentrations experienced during testing.

8.2.1 CO_2 quench check

8.2.1.1 A CO_2 span gas having a concentration of 80 to 100% of full scale of the maximum operating range shall be passed through the NDIR analyser and the CO_2 value recorded as A. It shall then be diluted approximately 50% with NO span gas and passed through the NDIR and (H)CLD, with the CO_2 and NO values recorded as B and C, respectively. The CO_2 shall then be shut off and only the NO span gas shall be passed through the (H)CLD and the NO value recorded as D.

8.2.1.2 The quench shall be calculated as follows:

$$\%\,Quench = \left[1\left(\frac{(C \bullet A)}{(D \bullet A)\ (D \bullet B)}\right)\right] \bullet 100 \qquad (2)$$

and shall not be greater than 3% of full scale.

where:

A =	Undiluted CO_2 concentration measured with NDIR	%
B =	Diluted CO_2 concentration measured with NDIR	%
C =	Diluted NO concentration measured with (H)CLD	ppm
D =	Undiluted NO concentration measured with (H)CLD	ppm

8.2.1.3 Alternative methods of diluting and quantifying of CO_2 and NO span gas values, such as dynamic mixing/blending, may be used.

8.2.2 Water quench check

8.2.2.1 This check applies to wet gas concentration measurements only. The calculation of water quench shall take into consideration the dilution of the NO span gas with water vapour and scaling of water vapour concentration of the mixture to that expected during testing.

8.2.2.2 A NO span gas having a concentration of 80 to 100% of full scale of the normal operating range shall be passed through the (H)CLD and the NO value recorded as D. The NO span gas shall then be bubbled through water at room temperature and passed through the (H)CLD and the NO value recorded as C. The analyser's absolute operating pressure and the water temperature shall be determined and recorded as E and F, respectively. The mixture's saturation vapour pressure that corresponds to the bubbled water temperature (F) shall be determined and recorded as G. The water vapour concentration (in %) of the mixture shall be calculated as follows:

$$H = 100 \bullet \left(\frac{G}{E}\right) \qquad (3)$$

and recorded as H. The expected diluted NO span gas (in water vapour) concentration shall be calculated as follows:

$$De = D \bullet \left(1\ \frac{H}{100}\right) \qquad (4)$$

and recorded as De. For diesel exhaust, the maximum exhaust water vapour concentration (in %) expected during testing shall be estimated, under the assumption of a fuel atom hydrogen/carbon (H/C) ratio of 1.8/1, from the undiluted CO_2 span gas concentration (A, as measured in 8.2.1 above) as follows:

$$Hm = 0.9 \bullet A \tag{5}$$

and recorded as Hm.

8.2.2.3 The water quench shall be calculated as follows:

$$\%\ Quench = 100 \bullet \frac{(De\ \ C)}{De} \bullet \frac{Hm}{H} \tag{6}$$

and shall not be greater than 3%.

where:

De	=	Expected diluted NO concentration	ppm
C	=	Diluted NO concentration	ppm
Hm	=	Maximum water vapour concentration	%
H	=	Actual water vapour concentration	%

Note: It is important that the NO span gas contains minimal NO_2 concentration for this check, since absorption of NO_2 in water has not been accounted for in the quench calculations.

8.3 O_2 analyser interference

8.3.1 Instrument response of a PMD analyser caused by gases other than oxygen is comparatively slight. The oxygen equivalents of the common exhaust gas constituents are shown in table 5.

Table 5. Oxygen equivalents

100% gas concentration	Equivalent % O_2
Carbon dioxide, CO_2	- 0.623
Carbon monoxide, CO	- 0.354
Nitric oxide, NO	+ 44.4
Nitrogen dioxide, NO_2	+ 28.7
Water, H_2O	- 0.381

8.3.2 The observed oxygen concentration shall be corrected by the following formula if high precision measurements are to be done:

$$Interference = (Equivalent\,\%\, O_2 \bullet ObservedConcentration\ ) / 100 \qquad (7)$$

8.3.3 For ZRDO and ECS analysers, instrument interference caused by gases other than oxygen shall be compensated for in accordance with the instrument supplier's instructions.

9 Calibration intervals

The analysers shall be calibrated according to section 5 at least every 3 months or whenever a system repair or change is made that could influence calibration.

APPENDIX 5 - SAMPLE TEST REPORT

(Refer to 5.10 of the NO_x Technical Code)

Emissions Test Report No. .... **Engine Information*** **Sheet 1/5**

Engine				
Manufacturer				
Engine type				
Family or Group identification				
Serial number				
Rated speed				rpm
Rated power				kW
Intermediate speed				rpm
Maximum torque at intermediate speed				Nm
Static injection timing				deg CA BTDC
Electronic injection control		no:	yes:	
Variable injection timing		no:	yes:	
Variable turbocharger geometry		no:	yes:	
Bore				mm
Stroke				mm
Nominal compression ratio				
Mean effective pressure, at rated power				kPa
Maximum cylinder pressure, at rated power				kPa
Cylinder number and configuration	Number:		V:	In-line:
Auxiliaries				
Specified ambient conditions:				
Maximum seawater temperature				°C
Maximum charge air temperature, if applicable				°C
Cooling system spec. intermediate cooler		no:	yes:	
Cooling system spec. charge air stages				
Low/high temperature cooling system set points		/		°C
Maximum inlet depression				kPa
Maximum exhaust back pressure				kPa
Fuel oil specification				
Fuel oil temperature				°C
Lubricating oil specification				
Application/Intended for:				
Customer				
Final application/installation, Ship				
Final application/installation, Engine		Main:	Aux:	

Emissions test results:				
Cycle				
NO_x				g/kWh

Test identification	
Date/time	
Test site/bench	
Test number	
Surveyor	
Date and Place of report	
Signature	

* If applicable

Emissions Test Report No. .... **Engine Family Information*** **Sheet 2/5**

Engine Family Information/Group Information (Common specifications)	
Combustion cycle	2 stroke cycle/4 stroke cycle
Cooling medium	air/water
Cylinder configuration	Required to be written, only if the exhaust cleaning devices are applied
Method of aspiration	natural aspired/pressure charged
Fuel type to be used on board	distillate/distillate or heavy fuel/dual
Combustion chamber	Open chamber/divided chamber
Valve port configuration	Cylinder head/cylinder wall
Valve port size and number	
Fuel system type	

Miscellaneous features:	
Exhaust gas recirculation	no / yes
Water injection/emulsion	no / yes
Air injection	no / yes
Charge cooling system	no / yes
Exhaust after-treatment	no / yes
Exhaust after-treatment type	
Dual fuel	no / yes

Engine Family/Group Information (Selection of parent engine for test bed test)					
Family /Group Identification					
Method of pressure charging					
Charge air cooling system					
Criteria of the Selection (specify)	Maximum fuel delivery rate / another method (specify)				
Number of cylinder					
Max. rated power per cylinder					
Rated speed					
Injection timing (range)					
Max. fuel parent engine					
Selected parent engine					Parent
Application					

* If applicable

Emissions Test Report No. .... **Test Cell Information*** **Sheet 3/5**

Exhaust Pipe	
Diameter	mm
Length	m
Insulation	no: yes:
Probe location	
Remark	

Measurement equipment					
	Manufacturer	Model	Measurement ranges	Calibration	
				Span gas conc.	Deviation
Analyser					
NO_x Analyser			ppm		%
CO Analyser			ppm		%
CO2 Analyser			%		%
O2 Analyser			%		%
HC Analyser			ppm		%
Speed			rpm		%
Torque			Nm		%
Power, if applicable			kW		%
Fuel flow					%
Air flow					%
Exhaust flow					%
Temperatures					
Coolant			°C		°C
Lubricant			°C		°C
Exhaust gas			°C		°C
Inlet air			°C		°C
Intercooled air			°C		°C
Fuel			°C		°C
Pressures					
Exhaust gas			kPa		%
Inlet manifold			kPa		%
Atmospheric			kPa		%
Vapour pressure					
Intake air			kPa		%
Humidity					
Intake air			%		%

Fuel Characteristics

Fuel type				
Fuel properties:			**Fuel elemental analysis**	
Density	ISO 3675	kg/l	Carbon	% mass

Viscosity	ISO 3104	mm^2/s	Hydrogen	% mass
			Nitrogen	% mass
			Oxygen	% mass
			Sulphur	% mass
			LHV/Hu	MJ/kg

* If applicable

Mode		1	2	3	4	5	6	7	8	9	10
Power/Torque	%										
Speed	%										
Time at beginning of mode											

Ambient Data											
Atmospheric pressure	kPa										
Intake air temperature	°C										
Intake air humidity	g/kg										
Atmospheric factor (fa)											

Gaseous Emissions Data:											
NO_x concentration dry/wet	ppm										
CO concentration dry/wet	ppm										
CO2 concentration dry/wet	%										
O2 concentration dry/wet	%										
HC concentration dry/wet	ppm										
NO_x humidity correction factor											
Fuel specification factor (FFH)											
Dry/wet correction factor											
NO_x mass flow	kg/h										
CO mass flow	kg/h										
CO2 mass flow	kg/h										
O2 mass flow	kg/h										
HC mass flow	kg/h										
SO2 mass flow	kg/h										
NO_x specific	g/kWh										

* If applicable

Emissions Test Report No. .... **Engine Test Data*** **Sheet 5/5**

Mode		1	2	3	4	5	6	7	8	9	10
Power/Torque	%										
Speed	%										
Time at beginning of mode											

Engine Data											
Speed	rpm										
Auxiliary power	kW										
Dynamometer setting	kW										
Power	kW										
Mean effective pressure	bar										
Fuel rack	mm										
Uncorrected spec. fuel consumption	g/kWh										
Fuel flow	kg/h										
Air flow	kg/h										
Exhaust flow (gexhw)	kg/h										
Exhaust temperature	°C										
Exhaust back pressure	mbar										
Cylinder Coolant temperature out	°C										
Cylinder Coolant temperature in	°C										
Cylinder Coolant pressure	bar										
Temperature intercooled air	°C										
Lubricant temperature	°C										
Lubricant pressure	bar										
Inlet depression	mbar										

* If applicable

APPENDIX 6

CALCULATION OF EXHAUST GAS MASS FLOW (CARBON BALANCE METHOD)

(Refer to chapter 5 of the NO_x Technical Code)

1 INTRODUCTION

1.1 This appendix addresses the calculation of the exhaust gas mass flow and/or of the combustion air consumption. Both methods given in the following are based on exhaust gas concentration measurement, and on the knowledge of the fuel consumption. Symbols and descriptions of terms and variables used in the formulae for the carbon balance measurement method are summarized in table 4 of the Abbreviations, Subscripts, and Symbols of this Code.

1.2 This appendix includes two methods for calculating the exhaust gas mass flow as follows: Method 1 (Carbon balance) is only valid using fuels without oxygen and nitrogen content; and, Method 2 (Universal, carbon/oxygen-balance) is applicable for fuels containing H, C, S, O, N in known composition.

1.3 Method 2 provides an easy understandable but universal derivation of all formulae including all constants. This method is provided because there are many cases where the present available constants, neglecting essential parameters, may lead to results with avoidable errors. Using the formulae within Method 2, it may also be possible to calculate the essential parameters under conditions deviating from standard conditions.

1.4 Examples of parameters for some selected fuels are offered in table 1. The values for fuel composition are for reference purposes only and shall not be used in place of the composition values of the oil fuel actually used.

Table 1. Parameters for some selected fuels (examples)

Fuel	C %	H %	S %	O %	I	FFH	FFW	FFD	EXH DENS
Diesel	86.2	13.6	0.17	0	1 1.35 3.5	1.835 1.865 1.920	0.749	-0.767	1.294 1.293 1.292
RME	77.2	12.0		10.8	1 1.35 3.5	1.600 1.63 1.685	0.734	-0.599	1.296 1.295 1.292
Methanol	37.5	12.6	0	50.0	1 1.35 3.5	1.495 1.565 1.705	1.046	-0.354	1.233 1.246 1.272
Ethanol	52.1	13.1	0	34.7	1 1.35 3.5	1.65 1.704 1.807	0.965	-0.49	1.26 1.265 1.281
Natural	60.6	19.3	0	1.9	1	2.509	1.078	-1.065	1.257

Fuel	**C %**	**H %**	**S %**	**O %**	**I**	**FFH**	**FFW**	**FFD**	**EXH DENS**
Gas *					1.35 3.5	2.572 2.689			1.265 1.28
Propane	81.7	18.3	0	0	1 1.35 3.5	2.423 2.473 2.564	1.007	-1.025	1.268 1.273 1.284
Butane	82.7	17.3	0	0	1 1.35 3.5	2.298 2.343 2.426	0.952	-0.97	1.273 1.277 1.285

* Volumetric composition: CO_2 1.10%; N_2 12.10%; CH_4 84.20%; C_2H_6 3.42%; C_3H_8 0.66%; C_4H_{10} 0.22%; C_5H_{12} 0.05%; C_6H_{14} 0.05%

1.5 Except as otherwise specified, all results of calculations required by this appendix shall be reported in the engine's test report in accordance with section 5.10 of this Code.

2 METHOD 1, CARBON BALANCE

2.1 This method includes six steps that shall be used in the calculation of the exhaust gas concentrations with regard to the fuel characteristics.

2.2 The given formulae of Method 1 are only valid in the absence of oxygen in the fuel.

2.3 **First step:** Calculation of the stoichiometric air demand

2.3.1 Process of complete combustion:

$$C + O_2 \rightarrow CO_2 \tag{1-1}$$

$$4H + O_2 \rightarrow 2H_2O \tag{1-2}$$

$$S + O_2 \rightarrow SO_2 \tag{1-3}$$

$$STOIAR = (BET / 12.011 + ALF / (4 \cdot 1.00794) + GAM / 32.060) \cdot 31.9988 / 23.15 \tag{1-4}$$

2.4 **Second step:** Calculation of the excess-air-factor based on complete combustion and the CO_2 - concentration

$$EAFCDO = ((BET \cdot 10 \cdot 22.262 / (12.011 \cdot 1000)) / (CO2D / 100) + STOIAR \cdot 0.2315 / 1.42895 - BET \cdot 10 \cdot 22.262 / (12.011 \cdot 1000) - GAM \cdot 10 \cdot 21.891 / (32.060 \cdot 1000)) / (STOIAR \cdot (0.7685 / 1.2505 + 0.2315 / 1.42895)) \tag{1-5}$$

2.5 **Third step:** Calculation of the hydrogen-to-carbon ratio

$$HTCRAT = ALF \cdot 12.011 / (1.00794 \cdot BET) \tag{1-6}$$

2.6 **Fourth step**: Calculation of the dry hydrocarbon-concentration based on the ECE R49-procedure with respect to fuel characteristics and air fuel ratio

2.6.1 The conversion of dry to wet concentration is given by:

$conc_{wet} = conc_{dry} \cdot (1 - FFH \cdot (fuel\ consumption\ /\ dry\ air\ consumption))$ (1-7)

$$FFH \bullet \frac{Fuel\ consumption}{Dry\ air\ consumption} = \frac{Volume\ of\ water\ of\ the\ combustion\ process}{Total\ wet\ exhaust\ volume} \quad (1\text{-}8)$$

Total wet exhaust volume = Nitrogen of combustion air +
excess oxygen +
argon of the combustion air +
water of the combustion air +
water of the combustion process +
CO_2 of the combustion process +
SO_2 of the combustion process (1-9)

$FFH \bullet \frac{GFUEL}{GAIRD}$ = (10 · *ALF* · *MVH2O* / (2 · 1.0079 · 1000)) · *GFUEL* / ((0.7551
/ 1.2505 · (*GAIRD* / (*GFUEL* · *STOIAR*)) · *STOIAR* + 0.2315
/ 1.42895 · ((*GAIRD* / (*GFUEL* · *STOIAR*)) -1) · *STOIAR* + 0.0129
/ 1.7840 · (*GAIRD* / (*GFUEL* · *STOIAR*)) · *STOIAR* + 0.0005
/ 1.9769 · (*GAIRD* / (*GFUEL* · *STOIAR*)) · *STOIAR* + (*ALF* · 10 · *MVCO2*
/(2 · 1.0079 · 1000)) + (*BET* · 10 · *MVCO2*/(12.001 · 1000)) + (*GAM* · 10 · *MVSO2*
/(32.060 · 1000))) · *GFUEL*) (1-10)

where:

MVH2O = 22.401 dm^3/mol
MVCO = 22.262 dm^3/mol
MVSO2 = 21.891 dm^3/mol

2.6.2 The formula results:

$FFH \bullet \frac{GFUEL}{GAIRD}$ = (0.111127 · *ALF*) / (0.0555583 · *ALF* - 0.000109 · *BET* - 0.000157 · *GAM*
+ 0.773329 · (*GAIRD* / *GFUEL*)) (1-11)

and

FFH = (0.111127 · *ALF*) / (0.773329 + (0.0555583 · *ALF* - 0.000109 ·
BET - 0.000157 · *GAM*) · (*GFUEL* / *GAIRD*)) (1-12)

2.6.3 The excess air factor is defined as:

l_V = *air consumption / (fuel consumption · stoichiometric air demand)* (1-13)

EAFCDO = *GAIRD* / (*GFUEL* · *STOIAR*) (1-14)

GAIRD = EAFCDO · GFUEL · STOIAR (1-15)

CWET = CDRY · (1 - *FFH* · *GFUEL* / *GAIRD*)
= CDRY · (1 - *FFH* · *GFUEL* / (*EAFCDO* · *GFUEL* · *STOIAR*))

$$= \text{CDRY} \cdot (1 - FFH / (EAFCDO \cdot STOIAR)) \qquad (1\text{-}16)$$

$$CDRY = \text{CWET} \cdot (1 - FFH / (EAFCDO \cdot STOIAR))$$
$$= \text{CWET} \cdot EAFCDO \cdot STOIAR / (EAFCDO \cdot STOIAR - FFH) \qquad (1\text{-}17)$$

$$HCD = \text{HCW} \cdot EAFCDO \cdot STOIAR / (EAFCDO \cdot STOIAR - FFH) \qquad (1\text{-}18)$$

2.7 **Fifth step**: Calculation of the excess air factor based on the procedures specified in Title 40, United States Code of Federal Regulations (40CFR86.345-79).

$$EXHCPN = (CO2D / 100) + (COD / 10^6) + (HCD / 10^6) \qquad (1\text{-}19)$$

$$l_V = EAFEXH = (1 / EXHCPN - COD / (10^6 \cdot 2 \cdot EXHCPN) - HCD / (10^6 \cdot EXHCPN) + HTCRAT / 4 \cdot (1 - HCD / (10^6 \cdot EXHCPN)) - 0.75 \cdot HTCRAT / (3.5 / (COD / (10^6 \cdot EXHCPN)) + ((1 - 3.5) / (1 - HCD / (10^6 \cdot EXHCPN))))) / (4.77 \cdot (1 + HTCRAT / 4)) \qquad (1\text{-}20)$$

2.8 **Sixth step**: Calculation of the exhaust mass

Exhaust mass flow = Fuel consumption + combustion air consumption (1-21)

(with the excess air factor defined in step four)

air consumption = l_V *· fuel consumption · stoichiometric air demand* (1-22)

Exhaust mass flow = Fuel consumption · (1 + l_V · *stoichiometric air demand*) (1-23)

$$GEXHW = GFUEL \cdot (1 + EAFEXH \cdot STOIAR) \qquad (1\text{-}24)$$

3 METHOD 2, UNIVERSAL, CARBON / OXYGEN-BALANCE

3.1 Introduction

The described method gives an easily understandable description of the carbon and oxygen balance method. It may be used when the fuel consumption is measurable and when the fuel composition and the concentrations of the exhaust components are known.

3.2 Calculation of the exhaust mass flow on the basis of the carbon balance

$$GEXHW = \frac{GFUEL \bullet BET \bullet EXHDENS \bullet 10^4}{AWC} \bullet \frac{1}{\left(\frac{CO2W \bullet 10^4}{MVCO2} + \frac{COW}{MVCO} + \frac{HCW}{MVHC} + \frac{CW}{AWC}\right)} \qquad (2\text{-}1)$$

3.2.1 Simplification with complete combustion:

$$GEXHW = \frac{GFUEL \bullet BET \bullet EXHDENS \bullet MVCO2}{AWC \bullet (CO2W \;\; CO2AIR)} \qquad (2\text{-}2)$$

3.3 Calculation of exhaust mass flow on the basis of oxygen balance

$$GEXHW = GFUEL \bullet \left(\frac{\frac{Factor1}{1000 \bullet EXHDENS} + 10 \bullet Factor210 \bullet EPS}{10 \bullet T\ AU\ \frac{Factor1}{1000 \bullet EXDENS}} + 1 \right) \tag{2-3}$$

where:

$$\begin{aligned} Factor\ 1 = 10^4 \bullet \frac{MWO2 \bullet O2W}{MVO2} - \frac{AWO}{MVCO} \bullet COW + \frac{AWO}{MVNO} \bullet NOW + \\ + \frac{2 \bullet AWO}{MVNO2} \bullet NO2W - \frac{3 \bullet AWO}{MVHC} \bullet HCW - \frac{2 \bullet AWO}{AWC} \bullet CW \end{aligned} \tag{2-4}$$

and

$$Factor2 = ALF \bullet \frac{AWO}{2 \bullet AWH} + BET \bullet \frac{2 \bullet AWO}{AWC} + GAM \bullet \frac{AWO}{AWS} \tag{2-5}$$

3.3.1 Simplification with complete combustion:

$$Factor\ 1_{compl.} = 10^4 \bullet \frac{MWO2}{MVO2} \bullet O2W \tag{2-6}$$

3.4 Derivation of the oxygen balance for incomplete combustion

3.4.1 The oxygen input in g/h is:

$$GAIRW \cdot TAU \cdot 10 + GFUEL \cdot EPS \cdot 10 \tag{2-7}$$

3.4.2 The oxygen output in g/h is:

$$\begin{aligned} GO2 + GCO2 \bullet \frac{2 \bullet AWO}{MWCO\ 2} + GCO \bullet \frac{AWO}{MWCO} + GNO \bullet \frac{AWO}{MWNO} \\ + GNO2 \bullet \frac{2 \bullet AWO}{MWNO\ 2} + GSO2 \bullet \frac{2 \bullet AWO}{MWSO\ 2} + GH2O \bullet \frac{AWO}{MWH20} \end{aligned} \tag{2-8}$$

based on the following definitions and formulae, the individual gas components are calculated in g/h related on wet exhaust gas (GC is the soot in g/h).

$$GO2 = \frac{MWO2 \bullet 10}{MVO2 \bullet EXHDENS} \bullet O2W \bullet GEXHW \tag{2-9}$$

$$GCO = \frac{MWCO}{MVCO \bullet EXHDENS \bullet 1000} \bullet COW \bullet GEXHW \tag{2-10}$$

$$GNO = \frac{MWCO}{MVNO \bullet EXHDENS \bullet 1000} \bullet NOW \bullet GEXHW \tag{2-11}$$

$$GNO2 = \frac{MWNO2}{MVNO2 \bullet EXHDENS \bullet 1000} \bullet NO2W \bullet GEXHW \tag{2-12}$$

$$GCO2 = \frac{MWCO2}{AWC} \bullet GFUEL \bullet BET \bullet 10 \;\; GCO \bullet \frac{MWCO2}{MWCO} \;\; GHC \bullet \frac{MWCO2}{MWHC} GC \bullet \frac{MWCO2}{AWC} \qquad (2\text{-}13)$$

$$GH2O = \frac{MWH2O}{2 \bullet AWH} \bullet GFUEL \bullet ALF \bullet 10 \;\; GHC \bullet \frac{MWH2O}{MWHC} \qquad (2\text{-}14)$$

$$GSO2 = \frac{MWSO2}{AWS} \bullet GFUEL \bullet GAM \bullet 10 \qquad (2\text{-}15)$$

$$GHC = \frac{MWHC}{MVHC \bullet EXHDENS \bullet 1000} \bullet HCW \bullet GEXHW \qquad (2\text{-}16)$$

$$GC = \frac{1}{EXHDENS \bullet 1000} \bullet CW \bullet GEXHW \qquad (2\text{-}17)$$

3.4.3 EXHDENS is calculated using formula (2-42) in 3.6 of this section.

$$GAIRW \cdot TAU \cdot 10 + GFUEL \cdot EPS \cdot 10 =$$

$$= \frac{GEXHW}{10^3 \_ EXHDENS} - \left(\frac{MWO2 \_ 02W \_ 10^4}{MVO2} - \frac{AWO \bullet COW}{MVCO} + \frac{AWO \bullet NOW}{MVNO} + \frac{2 \bullet AWO \bullet NO2W}{MVNO2} - \frac{3 \bullet AWO \bullet}{MVH} \right.$$

$$+ 10 \bullet GFUEL \bullet \left(\frac{ALF \bullet AWO}{2 \bullet AWH} + \frac{BET \bullet 2 \bullet AWO}{AWC} + \frac{GAM \bullet AWO}{AWS} \right) \qquad (2\text{-}18)$$

3.4.4 The first bracket is defined as Factor 1, the second one as Factor 2 (see also formulae (2-4) and (2-5)).

where:

$$GEXHW = GAIR + GFUEL \qquad (2\text{-}19)$$

3.4.5 The consumed air mass and the exhaust gas mass may be calculated using the following formulae:

$$GAIRW = GFUEL \bullet \left(\frac{\frac{Factor1}{1000 \bullet EXHDENS} + 10 \bullet Factor2 \;\; 10 \bullet EPS}{T\;AU \bullet 10 \;\; \frac{Factor1}{1000 \bullet EXHDENS}} \right) \qquad (2\text{-}20)$$

and accordingly:

$$GEXHW = GFUEL \bullet \left(\frac{\frac{Factor1}{1000 \bullet EXHDENS} + 10 \bullet Factor210 \bullet EPS}{T\;AU \bullet 10 \;\; \frac{Factor1}{1000 \bullet EXHDENS}} + 1 \right) \qquad (2\text{-}21)$$

3.5 Derivation of the carbon balance for the incomplete combustion

3.5.1 Carbon input in g/h:

$$GFUEL \bullet BET \bullet 10 \quad (2\text{-}22)$$

3.5.2 Carbon output in g/h:

$$GCO2 \bullet \frac{AWC}{MWCO2} + GCO \bullet \frac{AWC}{MWCO} + GHC \bullet \frac{AWC}{MWHC} + GC \bullet \frac{AWC}{AWC} \quad (2\text{-}23)$$

3.5.3 Based on the following definitions and formulae, the individual gas components are calculated in g/h related on wet exhaust gas (GC is the soot in g/h).

$$GCO2 = \frac{MWCO2 \bullet 10}{MVCO2 \bullet EXHDENS} \bullet CO2W \bullet GEXHW \quad (2\text{-}24)$$

$$GCO = \frac{MWCO}{MVCO \bullet EXHDENS \bullet 1000} \bullet COW \bullet GEXHW \quad (2\text{-}25)$$

$$GHC = \frac{MWHC}{MVHC \bullet EXHDENS \bullet 1000} \bullet HCW \bullet GEXHW \quad (2\text{-}26)$$

$$GC = \frac{1}{EXHDENS} \bullet CW \bullet GEXHW \quad (2\text{-}27)$$

3.5.4 For the balance condition:

Carbon input = Carbon output

$$GFUEL \bullet BET \bullet 10 = \frac{GEXHW \bullet AWC}{EXHDENS \bullet 1000} \bullet \left(\frac{CO2W}{MVCO2} \bullet 10^4 + \frac{COW}{MVCO} + \frac{HCW}{MVHC} + \frac{CW}{AWC} \right) \quad (2\text{-}28)$$

3.5.5 Calculation of the exhaust mass flow on the basis of the carbon balance:

$$GEXHW = \frac{GFUEL \bullet BET \bullet EXHDENS \bullet 10^4}{AWC} \bullet \frac{1}{\left(\frac{CO2W \bullet 10^4}{MVCO2} + \frac{COW}{MVCO} + \frac{HCW}{MVHC} + \frac{CW}{AWC} \right)} \quad (2\text{-}29)$$

3.6 Calculation of the volumetric exhaust composition and exhaust density with incomplete combustion

$$VCO = COW \bullet 10^6 \bullet VEXHW \quad (2\text{-}30)$$

$$VNO = NOW \bullet 10^6 \bullet VEXHW \quad (2\text{-}31)$$

$$VNO2 = NO2W \bullet 10^6 \bullet VEXHW \quad (2\text{-}32)$$

$$VHC = HCW \bullet 10^6 \bullet VEXHW \quad (2\text{-}33)$$

$$VH2O = \frac{\left(\frac{GAIRW \bullet NUE \bullet MVH2O}{MWH2O} + \frac{GFUEL \bullet ALF \bullet MVH2O}{2 \bullet AWH} \right)}{100} - VHC$$