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CONSIDERATION AND ADOPTION OF AMENDMENTS TO MANDATORY INSTRUMENTS

Comments on document MEPC 85/3/2

Submitted by Canada, Finland, Germany, Japan, Norway, United States, IACS and IMarEST

SUMMARY

Executive summary:	This document provides comments and proposed editorial improvements to the annex to document MEPC 85/3/2 (Secretariat) in order to promote unified implementation of those draft amendments to the NO_x Technical Code concerning the certification of marine diesel engines that operate on non-carbon-containing fuel or mixtures of carbon-containing and non-carbon-containing fuels.
Strategic direction, if applicable:	2
Output:	2.4
Action to be taken:	Paragraph 6
Related documents:	MEPC 84/16/Add.1; MEPC 85/3/2; PPR 13/9 and PPR 13/18/Add.1

Introduction

1 At its eighty-fourth session, the Marine Environment Protection Committee (MEPC) considered and approved amendments to the NO_x Technical Code (NTC) providing for the certification of marine diesel engines that operate on non-carbon-containing fuel or mixtures of carbon-containing and non-carbon-containing fuels, with a view to adoption at MEPC 85.

2 These amendments were developed by the Sub-Committee on Pollution Prevention and Response (PPR) in response to instructions by MEPC 83. The basis of these amendments was submitted to PPR 13 as proposals in document PPR 13/9 (Canada et al.) by Canada, Finland, Germany, Japan, Norway, Sweden, the United States, EUROMOT and IMarEST.

3 The co-sponsors have carried out a thorough review of the draft NTC amendments in document MEPC 85/3/2 (Secretariat) to assess clarity and inconsistencies in the text when compared to the existing NTC text. That review identified a number of editorial and technical improvements, together with consequential clarifications, which it is considered are required in order to provide a clear understanding and ensure consistent application of the draft amendments and are given in the annex to this document.

4 Of those proposals, the technical improvements and consequential clarifications affect the following NTC sections:

.1 the introductory text for the abbreviations, subscripts and symbols section;

.2 5.12.5.1.1 and 5.12.5.2;

.3 figure 1 in 1.1 of appendix III;

.4 1.2.3 and 1.2.10 of appendix III;

.5 3.4 of appendix III;

.6 2.1.1.3 of appendix IV;

.7 5.5.1, 5.5.4, 5.5.5 and table 2 of appendix VI; and

.8 5.5.7 of appendix VI.

5 The rationale for each of these is given in the preceding text associated with each proposal. It is the view of the co-sponsors that none of these alters or extends the intent of the amendments to be considered for adoption at this session.

Action requested of the Committee

6 The Committee is invited to consider the comments and suggested improvements set out in the annex to this document and take action as appropriate.

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ANNEX

COMMENTS AND PROPOSED EDITORIAL IMPROVEMENTS TO THE AMENDMENTS TO THE NO_x TECHNICAL CODE 2008 AS SET OUT IN THE ANNEX TO DOCUMENT MEPC 85/3/2

In reviewing the amendments to the NO_x Technical Code 2008 as set out in the annex to document MEPC 85/3/2, the co-sponsors have identified some editorial and technical improvements that are considered necessary to clarify the requirements and facilitate their implementation.

Paragraph references are to paragraphs in MEPC 85/3/2.

New additions are highlighted grey and deletions are ~~struck out~~.

New amended NTC introductory text not in MEPC 85/3/2 - abbreviations, subscripts and symbols

The "introductory" paragraph was not updated to include the new table 5 or a description of its contents. Consequently, a new .5 should also be added to the list of table descriptions. Add "oil" after fuel in .4 of the table 4 description for consistency with the table 4 title.

> "Tables 1, 2, 3, ~~and~~ 4 and 5 below summarize the abbreviations, subscripts and symbols used throughout this Code, including specifications for the analytical instruments in appendix III, calibration requirements for the analytic instruments contained in appendix IV, the formulae for calculation of gas mass flow as contained in chapter 5 and appendix VI of this Code, ~~and~~ the symbols used in respect of data for onboard verification surveys in chapter 6 and chemical component molar masses and densities used in the formulae for calculation of the ratio of exhaust component and exhaust gas in appendix VI of this Code.
>
> .1 table 1: symbols used to represent the chemical components of marine diesel engine gas emissions and calibration and span gases addressed throughout this Code;
>
> .2 table 2: abbreviations for the analysers used in the measurement of gas emissions from marine diesel engines as specified in appendix III of this Code;
>
> .3 table 3: symbols and subscripts of terms and variables used in chapter 5, chapter 6, appendix IV and appendix VI of this Code; ~~and~~
>
> .4 table 4: symbols for fuel oil composition used in chapter 5 and chapter 6 and appendix VI of this Code; and
>
> .5 table 5: chemical components, molar masses and densities used in appendix VI of this Code."

Paragraph 5 – abbreviations, subscripts and symbols – table 4

The Air Pollution Working Group at MEPC 84 added the calculation for the molar hydrogen-to-carbon ratio, α, as a footnote to the table. Calculations should also be added for

the molar sulphur-to-carbon ratio, *γ*, and the molar oxygen-to-carbon ratio, *ε*, for completeness. Update table fonts to equation font style for α, *γ* and *ε*.

"

Table 4 – *Symbols for fuel oil composition*

Symbol	Definition	Unit
w_{ALF}^{*}	H content of fuel	% m/m
w_{BET}^{*}	C content of fuel	% m/m
w_{GAM}^{*}	S content of fuel	% m/m
w_{DEL}^{*}	N content of fuel	% m/m
w_{EPS}^{*}	O content of fuel	% m/m
α^{**}	Molar hydrogen-to-carbon ratio (H/C)	1
γ^{***}	Molar sulphur-to-carbon ratio (S/C)	1
ε^{****}	Molar oxygen-to-carbon ratio (O/C)	1

* "$_1$" denotes fuel fraction for fuel oil type 1 in dual fuel applications.
"$_2$" denotes fuel fraction for fuel oil type 2 in dual fuel applications.

** $\alpha = 11.9164 \cdot \frac{w_{\mathrm{ALF}}}{w_{\mathrm{BET}}}$

*** $\gamma = 0.37464 \cdot \frac{w_{\mathrm{GAM}}}{w_{\mathrm{BET}}}$

**** $\varepsilon = 0.75072 \cdot \frac{w_{\mathrm{EPS}}}{w_{\mathrm{BET}}}$

"

Paragraph 14 – 5.9.2 of NTC 2008

The current order of emission species in the NTC is alphabetical. Revise to maintain alphabetical order.

"5.9.2 Main exhaust components (if applicable, based on fuel type/mixture): *CO, CO_2, H_2, HC, H_2O, NH_3, NO_x, N_2O and O_2, ~~H_2, NH_3, N_2O and H_2O~~*"

Paragraph 19 – 5.12.3.2 of NTC 2008

There are now four different options to determine the dry-to-wet correction factor, k_{wr}, in 5.12.3.2, which are differentiated numerically. Equation 5 does not distinguish between the different methods. To address this, update variable for k_w in equation 5 to include "r" for raw sampling and "#" to denote multiple methods for k_{wr} calculation. Also add a description of "#" after the equation to explain that this refers to the dry-to-wet correction calculation method used.

"5.12.3.1 If the emissions are not measured on a wet basis, the measured concentration shall be converted to a wet basis according to the following formulae:

$$c_{\mathrm{w}} = k_{\mathrm{wr\#}} \cdot c_{\mathrm{d}} \qquad (5)$$

'#' refers to the version of the dry-to-wet correction calculation method used from either chapter 5 or appendix VI of this Code."

Paragraph 21 – 5.12.5.1.1 of NTC 2008

Update the text below table 6 in 5.12.5.1.1 regarding use of multiple fuels to be consistent with the text in the dual fuel section 2 in appendix VI of the NTC and update the text to include a reference to formula 18b, which describes how to calculate the fuel mass rate proportioned u_{gas} values.

5.12.5.1.1 For carbon-containing fuels, or fuel mixtures with α ≤ 4.0, use the applicable u_{gas} values from table 6.

"**Table 6** – *Coefficient u_{gas} and fuel-specific parameters for raw exhaust gas*

Gas		NO_x	CO	HC	CO_2	O_2	NH_3***	H_2***
ρ_{gas} kg/m^3		2.053	1.250	*	1.9636	1.4277	0.771	0.0899
	ρ_e†	Coefficient u_{gas}‡						
Liquid fuel**	1.2943	0.001586	0.000966	0.000479	0.001517	0.001103	-	-
Rapeseed Methyl Ester	1.2950	0.001585	0.000965	0.000536	0.001516	0.001102	-	-
Methanol	1.2610	0.001628	0.000911	0.001133	0.001557	0.001132	-	-
Ethanol	1.2757	0.001609	0.000980	0.000805	0.001539	0.001119	-	-
Natural gas	1.2661	0.001621	0.000987	0.000558	0.001551	0.001128	-	-
Propane	1.2805	0.001603	0.000976	0.000512	0.001533	0.001115	-	-
Butane	1.2832	0.001600	0.000974	0.000505	0.001530	0.001113	-	-
Ammonia	1.1912	0.001723	0.001049	n/a	0.001648	0.001199	0.000647	-
Hydrogen	1.1872	0.001729	0.001053	n/a	0.001654	0.001203	-	0.000076

* Depending on fuel.
** Petroleum derived.
*** For reference only.
† ρ_e is the nominal density of the exhaust gas.
‡ At "λ" = 2, wet air, 273.15 K, 101.325 kPa.

Values for *u* given in table 6 are based on ideal gas properties.

~~In multiple fuel type operation~~ Where two fuel oils, fuel oil type 1 / fuel oil type 2, are concurrently used, the u_{gas} value used shall be determined from the values applicable to those fuels in ~~the~~ table 6, ~~set out above proportioned in accordance with~~ calculated using the proportion of the respective fuel mass ~~ratio used~~ rates in accordance with formula 18b."

Paragraph 22 – 5.12.5.2 of NTC 2008

Update the "Note" below the variable descriptions to include a calculation for fuel mass rate proportioned u_{gas} values for concurrent operation on multiple fuels where the default u_{gas} values from table 6 are used for fuel mixtures with α ≤ 4.0. This calculation is based on the proportioning of fuel mass rates for fuel factors as in table 5 and was implied in the paragraph that describes how to determine u_{gas} for multiple fuel types in 5.12.5.1. The addition of formula 18b provides the actual calculation needed to carry out the u_{gas} determination. The addition of the formula to 5.12.5.2 thereby avoids the need for renumbering of existing formulae and resulting unintended cross referencing issues in other IMO documents.

"Note 1: In the case of CO_2 and O_2 measurement, the concentration will normally be reported in terms of %. With regard to the application of formula 18a, these concentrations will need to be expressed in ppm. 1.0% = 10,000 ppm.

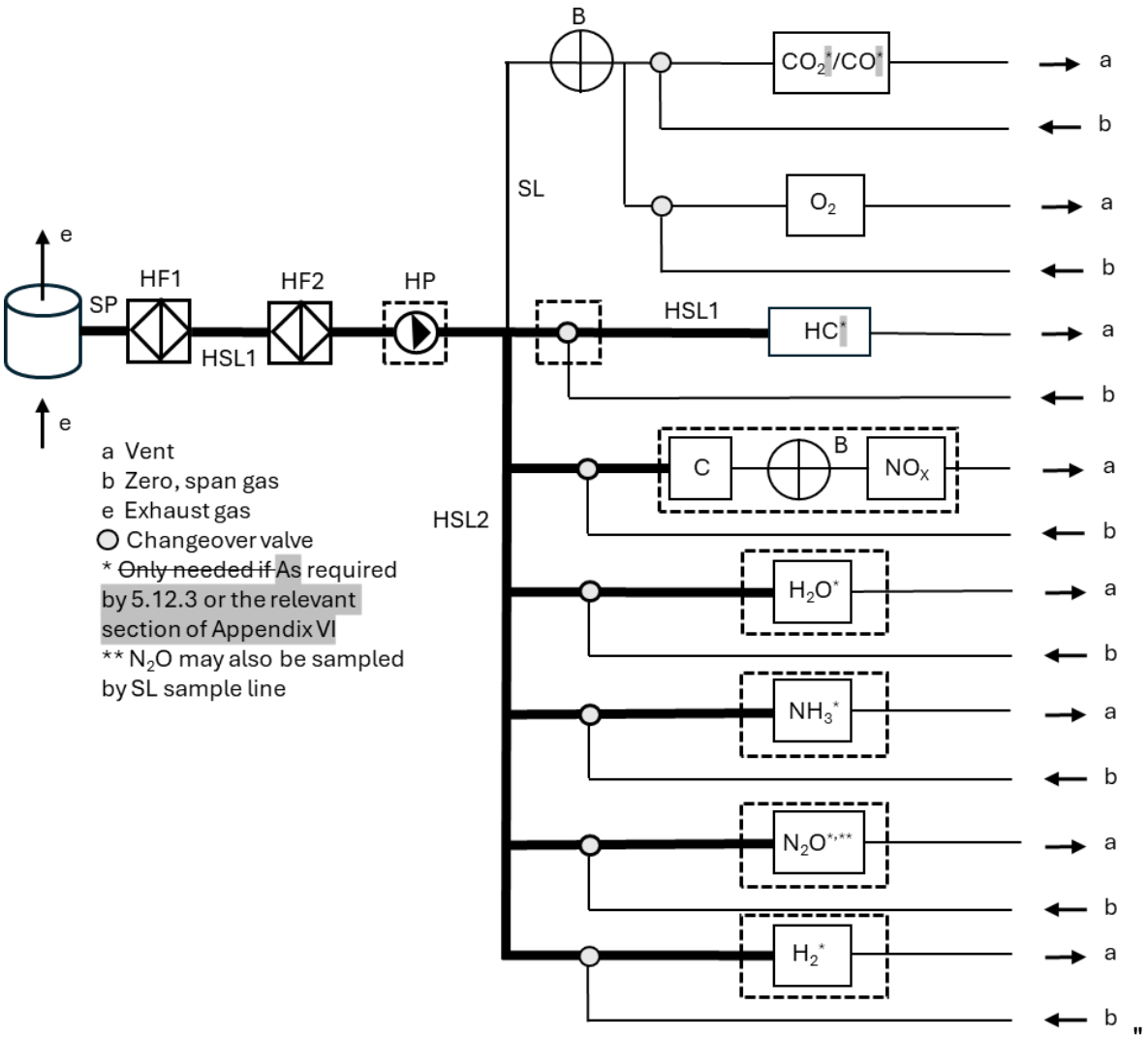
Note 2: In the case where two fuel oils, fuel oil type 1 / fuel oil type 2, are concurrently used, the following formula shall be used to determine the u_{gas} value at each mode point using the appropriate u_{gas} values from table 6 as u_{gasf_1} and u_{gasf_2}:

$$u_{\mathrm{gas}} = \frac{q_{\mathrm{mf_1}} \cdot u_{\mathrm{gasf_1}} + q_{\mathrm{mf_2}} \cdot u_{\mathrm{gasf_2}}}{q_{\mathrm{mf_1}} + q_{\mathrm{mf_2}}} \qquad (18b)"$$

Paragraph 35 – 1.1 of appendix III of NTC 2008 – figure 1

Update figure 1 to denote that measurement of CO_2, CO, and HC is only needed if required by 5.12.3 or the relevant section of appendix VI, as some fuels might contain zero carbon. Also update single asterisk text to provide a reference to sections in NTC that will determine what species need to be measured, which will be based on what exhaust gas mass flow rate calculation option is used.

"



"

Paragraph 36 – 1.2.2.1 and 1.2.2.2 of appendix III of NTC 2008

Update to be consistent with IMO style and to clarify that fuel types are separate.

".1 For ~~non-methanol- and non-ethanol-fuelled engines~~ an engine not using methanol or ethanol as a fuel, if the temperature of the exhaust gas at the sampling probe is equal to or below 191°C, a wall temperature of 191°C ± 11°C as measured at every separately controlled heated section shall be maintained.

If the temperature of the exhaust gas at the sampling probe is above 191°C, a wall temperature greater than 180°C shall be maintained.

Immediately before the heated filter HF2 and the HFID, a gas temperature of 191°C ± 11°C shall be maintained.

.2 For ~~methanol- and ethanol-fuelled engines~~ an engine using methanol or ethanol as a fuel, ~~maintain~~ a wall temperature between 110°C and 202°C, as measured at every separately controlled heated section shall be maintained."

Paragraph 37 – 1.2.3 of appendix III of NTC 2008

Update to include a reminder that the sample pressure also affects the water condensation temperature. Update to clarify that example temperatures to prevent condensation in exhaust gas from diesel and pure hydrogen fuel are at atmospheric pressure.

".3 HSL2 – Heated NO_x, H_2O, NH_3, H_2 and N_2O sampling line

The sampling line shall be made of stainless steel or PTFE and maintain a wall temperature, taking into account the sample pressure, sufficient to prevent water condensation, up to the converter C when using a cooling unit B, and up to the analyser when a cooling unit B is not used. For example, for raw exhaust sampled at atmospheric pressure, this can be achieved at 70°C for diesel fuel and 85°C for pure hydrogen fuel."

Paragraph 37 – 1.2.10 of appendix III of NTC 2008

Update to include a reminder that the sample pressure also affects the water condensation temperature. Update to clarify that example temperatures to prevent condensation in exhaust gas from diesel and pure hydrogen fuel are at atmospheric pressure.

".10 NO_x - Nitrogen oxides analyser

Chemiluminescent detector (CLD) or heated chemiluminescent detector (HCLD). It shall be kept at a temperature, taking into account the sample pressure, to prevent water condensation. For example, for raw exhaust sampled at atmospheric pressure, this can be achieved at 70°C for diesel fuel and 85°C for pure hydrogen fuel."

Paragraph 41 – 3.3 of appendix III of NTC 2008

Update to be consistent with IMO style.

"3.3 **Hydrocarbon (HC) analysis**

The hydrocarbon analyser shall be of the heated flame ionization detector (HFID) type with detector, valves, pipework and associated components heated so as to maintain a gas temperature of 191°C ± 11°C. For ~~methanol- or ethanol-fuelled engines~~ an engine using methanol or ethanol as a fuel, ~~maintain~~ a gas temperature between 110°C and 202°C shall be maintained. Optionally, for ~~gas-fuelled engines~~ an engine using a gas fuel (without liquid pilot injection), the hydrocarbon analyser may be of the non-heated flame ionization detector (FID) type."

Paragraph 42 – 3.4 of appendix III of NTC 2008

Update to clarify that the NO_2/NO converter is required for all types of CLDs, and to remove the minimum converter temperature of 55 °C as the minimum temperature to prevent condensation is now based on fuel type. Also updated to include a reminder that the sample pressure also affects the water condensation temperature. Removed the reference to the water quench check as that is a stand-alone requirement in appendix IV and not relevant to this section.

"3.4 **Nitrogen oxides (NO_x) analysis**

~~T~~If measured on a dry basis, the nitrogen oxides analyser shall be of the chemiluminescent detector (CLD) or heated chemiluminescent detector (HCLD) type with, in either case, an NO_2/NO converter. If measured on a wet basis, the nitrogen oxides analyser shall be of the heated chemiluminescent detector (HCLD) type with an NO_2/NO converter~~, if measured on a dry basis, an HCLD with converter maintained above 55°C shall be used, provided and the water quench check (see section 9.2.2 of appendix IV of this Code) is satisfied~~. For both CLD and HCLD type analysers, the sampling path shall be maintained at a wall temperature, taking into account the sample pressure, sufficient to prevent water condensation up to the converter for dry measurement, and up to the analyser reaction chamber for wet measurement. For example, for raw exhaust sampled at atmospheric pressure, this can be achieved at 70°C for diesel fuel and 85°C for pure hydrogen fuel."

Paragraph 44 – 2.1.1.3 of appendix IV of NTC 2008

Update to clarify that nitrogen could alternatively be used as the balance gas in the fuel for the flame ionization detector (FID) used to measure hydrocarbons where required by 5.9.2.1 since helium is becoming more difficult to source.

".3 hydrogen-helium or hydrogen-nitrogen mixture (40 ± 2% H_2, balance He or N_2), (contamination ≤ 1 ppmC, ≤ 400 ppm CO_2); and"

Paragraph 46 – 2.2.2 of appendix IV of NTC 2008

Update to clarify that the interference tolerances include up to the value and not just "within" the range.

"2.2.2 The true concentration of a calibration and span gas must be ~~within~~ not greater than ± 2% of the nominal value except for NH_3 and H_2O, which must be ~~within~~ not greater than ± 3% of the nominal value. All concentrations of calibration and span gases shall be given on a volume basis (volume per cent or volume ppm)."

Paragraph 50 – 9.4.1 and 9.5.1 of appendix IV of NTC 2008

Update to replace "either" with "any one" as the use of "either" implies that there are two choices when there are actually three or more.

"9.4.1 LIA, FTIR, and NDUV measurement principles are specified for NH_3 measurement and ~~either~~ any one of those measurement principles may be used provided it meets the interference criteria. Gas dryers shall not be permitted for NH_3 measurement. If the analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, a correct result depends on simultaneously conducting these other measurements to test the

compensation algorithms during the analyser interference verification. The amount of interference shall be verified after initial analyser installation and after major maintenance."

"9.5.1 LIA, FTIR, NDIR, and NDUV measurement principles are specified for N_2O measurement and ~~either~~ any one of those measurement principles may be used provided it meets the interference criteria. If the analyser uses compensation algorithms that utilize measurements of other gases to meet this interference verification, a correct result depends on simultaneously conducting these other measurements to test the compensation algorithms during the analyser interference verification. The amount of interference shall be verified after initial analyser installation and after major maintenance."

Paragraph 50 – 9.4.2 and 9.5.2 of appendix IV of NTC 2008

Update to clarify that the interferent species are based on the spectral absorption band chosen by the instrument manufacturer and the instrument manufacturer must declare which species interfere with the measurement of the target analyte.

"9.4.2 ~~Determine interferent species f~~For NDUV, ~~based on~~ the instrument manufacturer~~'s recommendation~~ shall declare the interferent exhaust gas species which could affect the NH_3 analyser's performance. ~~For example,~~This could include CO_2, H_2O, SO_2, NO_2 or NO ~~can interfere with the NDUV NH_3 analyser performance~~depending on the ultraviolet absorption band chosen by the instrument manufacturer."

"9.5.2 ~~Determine interferent species f~~For NDIR and NDUV, ~~based on~~ the instrument manufacturer~~'s recommendation~~ shall declare the interferent exhaust gas species which could affect the N_2O analyser's performance. ~~For example,~~This could include CO, CO_2, H_2O, CH_4~~, and~~ or SO_2 ~~can interfere with the NDIR or NDUV N_2O analyser performance~~ depending on the infrared or ultraviolet absorption band chosen by the instrument manufacturer."

Paragraph 50 – 9.4.3.5, 9.5.3.5 and 9.6.2.5 of appendix IV of NTC 2008

Update to clarify that the cross-interference gases that affect the target analyte are those "expected" based on the exhaust gas matrix for a given fuel type.

"9.4.3.5 the expected cross interference gases ~~for~~ affecting the NH_3 reading based on the exhaust gas matrix for each fuel type and combustion system;"

"9.5.3.5 the expected cross interference gases ~~for~~ affecting the N_2O reading based on the exhaust gas matrix for each fuel type and combustion system;"

"9.6.2.5 the expected cross interference gases ~~for~~ affecting the H_2O reading based on the exhaust gas matrix for each fuel type and combustion system;"

Paragraph 50 – 9.4.4, 9.5.4 and 9.6.3 of appendix IV of NTC 2008

Update to clarify that the interference tolerances include up to the value and not just "within" the range. Delete redundant use of "expected".

"9.4.4 A multicomponent interference span gas made up of concentrations at least as high as the maximum expected during testing shall be used to verify interference.

Alternatively, interference procedures for individual interference gases may also be run separately. If H_2O is one of the interferent species, a humidified gas can be generated by using a heated bubbler or by injecting a known amount of water into the blending gas upstream of the analyser. Generate an H_2O level at least as high as the maximum expected during emission testing. Record the analyser response. The analyser shall have combined interference ~~within~~ not greater than ± 2% of the ~~expected~~ mean NH_3 concentration expected during testing, or 0.0 ± 2.0 ppm NH_3, whichever is larger."

"9.5.4 A multicomponent interference span gas made up of concentrations at least as high as the maximum expected during testing shall be used to verify interference. Alternatively, interference procedures for individual interference gases may also be run separately. If H_2O is one of the interferent species, a humidified gas can be generated by using a heated bubbler or by injecting a known amount of water into the blending gas upstream of the analyser. Generate an H_2O level at least as high as the maximum expected during emission testing, or a level at or above the level at the cooling unit if one is used to dry the sample. Record the analyser response. The analyser shall have combined interference ~~within~~ not greater than 0.0 ± 1.0 ppm.

9.6.3 The analyser shall have combined interference within ± 2% of the ~~expected~~ mean H_2O concentration expected during testing."

Paragraph 50 – 9.7.1 and 9.7.2 of appendix IV of NTC 2008

Update 9.7.1 to clarify that interference affects both CLD and HCLD performance. Update 9.7.2 to address redundant use of "expected", and make interference limit precision consistent with other interference checks. Update to clarify that the interference tolerance includes up to the value and not just "within" the range.

"9.7.1 NH_3 can interfere with the CLD and HCLD NO_x analyser performance. CLD and HCLD NH_3 interference verification is only required for engines running on NH_3 fuels or fuel mixtures with NH_3."

"9.7.2 With the analyser in NO_x mode and the test gas flowing through the NO_2 to NO converter, flow an NH_3 span gas having a concentration at least as high as the maximum expected during testing and record the analyser response. The analyser shall have interference ~~within~~ not greater than ± 2% of the ~~expected~~ mean NO_x concentration expected during testing or ≤ 1.0 ppm NO_x, whichever is larger."

Paragraph 72 – 4.2 of appendix VI of NTC 2008

5.9.7.1 of the NTC gives direction on whether measured emission concentrations are to be recorded in ppm or %. The carbon balance method in section 2 of appendix VI defines the emission concentration variables used in the equations as well as the units of the concentrations. For consistency in appendix VI, this should also be included for the hydrogen balance equations. Update equations 6 through 10 to replace fractions with decimal values, consistent with IMO style.

"4.2 Exhaust gas mass flow rate on wet basis:

$$q_{\mathrm{mew}} = q_{\mathrm{mf}} \cdot \left(1 + A/F_{\mathrm{st}} \cdot \lambda \cdot (1 + H_{\mathrm{a}} \cdot 10^{-3})\right) \qquad (4)$$

with

$$A/F_{\mathrm{st}} = \frac{\left(\frac{w_{\mathrm{BET}}}{12.0107} + \frac{w_{\mathrm{ALF}}}{4.03176} - \frac{w_{\mathrm{EPS}}}{31.9988} + \frac{w_{\mathrm{GAM}}}{32.065}\right) \cdot 138.297}{w_{\mathrm{BET}} + w_{\mathrm{ALF}} + w_{\mathrm{EPS}} + w_{\mathrm{DEL}} + w_{\mathrm{GAM}}} \qquad (5)$$

$$\lambda = \frac{w_{\mathrm{ALF}} \cdot 3.77321 \cdot f_3}{\left(\begin{array}{c}\left(\frac{w_{\mathrm{BET}}}{12.0107} + \frac{w_{\mathrm{ALF}}}{4.03176} + \frac{w_{\mathrm{GAM}}}{32.065} - \frac{w_{\mathrm{EPS}}}{31.9988}\right) \cdot 2.01588 \cdot f_4 \\ \cdot \left(18.01528 + 28.96559 \cdot \left(\frac{1}{2}0.5 - f_1\right) \cdot H_{\mathrm{a}} \cdot 10^{-3}\right)\end{array}\right)} \qquad (6)$$

$$f_1 = \left(\frac{w_{\mathrm{EPS}}}{15.9994} + \frac{w_{\mathrm{DEL}}}{14.0067} + \frac{3.5 \cdot c_{\mathrm{H2w}} \cdot 10^{-4}}{c_{\mathrm{H2Ow}} + 3.5 \cdot c_{\mathrm{H2w}} \cdot 10^{-4}} \cdot \frac{w_{\mathrm{BET}}}{12.0107}\right) \cdot \frac{1.00794}{w_{\mathrm{ALF}}} \qquad (7)$$

$$f_2 = \frac{28.96559 \cdot H_{\mathrm{a}} \cdot 10^{-3}}{18.01528 + \left(\frac{1}{2}0.5 - f_1\right) \cdot 28.96559 \cdot H_{\mathrm{a}} \cdot 10^{-3}} \qquad (8)$$

$$f_3 = \begin{pmatrix} 1 - \left(\frac{1}{2}0.5 + f_1\right) \cdot c_{\mathrm{H2Ow}} \cdot 10^{-2} \\ -(1 + f_1) \cdot c_{\mathrm{H2w}} \cdot 10^{-6} \\ -\left(\frac{1 + 3 \cdot f_1}{2}\right) \cdot c_{\mathrm{NH3w}} \cdot 10^{-6} \end{pmatrix} \qquad (9)$$

$$f_4 = \begin{pmatrix} -f_2 + \left(1 + f_2 \cdot \left(\frac{1}{2}0.5 + f_1\right)\right) \cdot c_{\mathrm{H2Ow}} \cdot 10^{-2} \\ +\left(1 + f_2 \cdot (1 + f_1)\right) \cdot c_{\mathrm{H2w}} \cdot 10^{-6} \\ +\left(\frac{3}{2}1.5 + f_2 \cdot \left(\frac{1 + 3 \cdot f_1}{2}\right)\right) \cdot c_{\mathrm{NH3w}} \cdot 10^{-6} \end{pmatrix} \qquad (10)$$

With

c_{H2Ow} = wet H_2O concentration in the raw exhaust, %
c_{H2w} = wet H_2 concentration in the raw exhaust, ppm
c_{NH3w} = wet NH_3 concentration in the raw exhaust, ppm"

Paragraph 72 – 4.3.2 of appendix VI of NTC 2008

Update to clarify that the saturation vapour pressure, p_a, is calculated as a function of temperature, T_a, by solving for the intermediary term "$log_{10}(p_a)$", in which 10 is raised to the power of the intermediary.

"4.3.2 The following formula calculates the saturation vapour pressure, p_a, as a function of the temperature T_a, by solving for the intermediary term '$log_{10}(p_a)$'.

$$p_a = 10^{log_{10}(p_a)} \qquad (13)"$$

Paragraph 72 – 4.4.1 and 4.4.2 of appendix VI of NTC 2008

Update to include direction to set value to zero if measurement of the specific emission is not required. This update is consistent with other sections in the NTC. Also update for proper use of "only" and to begin the sentences with "The".

"4.4.1 The c_{H2w} measurement is ~~only~~ required only for hydrogen fuel and fuel mixtures containing hydrogen fuel. Otherwise, set this value to zero.

4.4.2 The c_{NH3w} measurement is ~~only~~ required only for ammonia fuel and fuel mixtures containing ammonia fuel. Otherwise, set this value to zero."

Paragraph 73 – 5.3 of appendix VI of NTC 2008

Update the oxygen balance procedure to require that if the humidity of the intake is greater than or equal to the humidity of the charge air, $H_a \geq H_{sc}$, then the humidity of the charge air, H_{sc}, shall be used instead. This is consistent with what is already being done for the carbon and hydrogen balance procedures and the density and molar mass based u_{gas} calculations in 6.2.1.1 and 6.2.2.1, and should equally be applied to the oxygen balance procedures. Update to clarify that the iteration tolerance includes up to the value and not just "within" the range.

"5.3 After each iteration use the calculated mass flows of air and exhaust to calculate new values for ρ_{ed} and k_{wr4} for the next iteration using equations 17 and 18. The values of f_{fw} and f_{fd} are calculated using equations 19 and 20. The calculations are repeated for an iteration until the calculated wet exhaust mass flow, q_{mew}, from equation 21 is ~~within~~ not greater than 0.1% of the calculated wet exhaust mass flow from the previous iteration. Determine H_a as described in section 4.3 of this appendix VI."

Paragraph 73 – 5.4 of appendix VI of NTC 2008

In equation (25) there should be a space between the "+" and "0.713813". The parentheses should be removed from equation (26) as they are not necessary and for consistency with equation (20). Also update to define the emission concentration variables used in the equations as well as the units of the concentrations for consistency in appendix VI.

"$$f_1 = \frac{14{,}276.3 \cdot c_{\mathrm{O2d}} + 1.42763 \cdot c_{\mathrm{NO2d}} - 1.07072 \cdot c_{\mathrm{NH3d}}}{+\,0.713813 \cdot \left(c_{\mathrm{NOd}} + c_{\mathrm{N2Od}} - c_{\mathrm{COd}} - c_{\mathrm{H2d}} - \left(\frac{\alpha}{2} + 2 + 2 \cdot \gamma - \varepsilon\right) \cdot c_{\mathrm{HCd}}\right)} \quad (25)$$

$$f_2 = ~~(~~2.66419 \cdot w_{\mathrm{BET}} + 7.93668 \cdot w_{\mathrm{ALF}} + 0.997935 \cdot w_{\mathrm{GAM}}~~)~~ \quad (26)$$"

At the end of 5.4, after equation (28), add:

"with

c_{O2d} = dry O_2 concentration in the raw exhaust, %
c_{NO2d} = dry NO_2 concentration in the raw exhaust, ppm
c_{NH3d} = dry NH_3 concentration in the raw exhaust, ppm
c_{NOd} = dry NO concentration in the raw exhaust, ppm
c_{N2Od} = dry N_2O concentration in the raw exhaust, ppm
c_{COd} = dry CO concentration in the raw exhaust, ppm
c_{H2d} = dry H_2 concentration in the raw exhaust, ppm
c_{HCd} = dry HC concentration in the raw exhaust, ppm"

Paragraph 73 – 5.5.1 of appendix VI of NTC 2008

Table 2 at the end of section 5 lists which concentrations are required to be measured based on fuel type. Update 5.5.1 to reference table 2. Also update to include the oxygen concentration measurement as that measurement is also required in equation (25).

"5.5.1 The concentrations c_{O2d}, c_{COd}, c_{HCd}, c_{H2d}, c_{NH3d}, c_{NOd}, c_{NO2d} and c_{N2Od} shall be measured ~~unless otherwise noted~~ based on fuel type as described in table 2 of this appendix VI."

Paragraph 73 – 5.5.4 and 5.5.5 of appendix VI of NTC 2008

Update for proper use of "only" and to begin the sentences with "The".

"5.5.4 The c_{H2d} measurement is ~~only~~ required only for hydrogen fuel and fuel mixtures containing hydrogen fuel. Otherwise, set this value to zero.

5.5.5 The c_{NH3d} measurement is ~~only~~ required only for ammonia fuel and fuel mixtures containing ammonia fuel. Otherwise, set this value to zero."

Paragraph 73 – 5.5.7 of appendix VI of NTC 2008

Given that N_2O will most likely not have an emission limit, but rather will just be required to be reported, update text to require N_2O measurement if there is a reporting requirement. Also update to add the word "only" for consistency with other sections of the NTC where measurement requirement is based on fuel oil type and to begin the sentence with "The".

"5.5.7 The c_{N2Od} measurement is required only for ammonia fuel and fuel mixtures containing ammonia fuel or if an emission ~~limit applies~~ value for N_2O is to be reported. Otherwise, set this value to zero."

Paragraph 73 – Table 2 of appendix VI of NTC 2008

Update to change "liquid fuel" to "carbon based liquid fuel" to ensure that this includes all carbon containing fuel irrespective of the fuel's origin. Added column for oxygen measurement as that is also required in equation (25). Delete double asterisk footnote as it is no longer needed.

"**Table 2** – *Required exhaust gas concentration measurements by fuel oil type for the oxygen balance measurement method*

		Exhaust gas concentration measurement required*							
Fuel oil type		c_{O2d}	c_{COd}	c_{HCd}	c_{H2d}	c_{NH3d}	c_{NOd}	c_{NO2d}	c_{N2Od}
Carbon based ~~L~~liquid fuel**		Yes	Yes	Yes			Yes	Yes	
Natural gas, bio-methane and e-methane		Yes	Yes	Yes			Yes	Yes	
Ammonia		Yes				Yes	Yes	Yes	Yes
Hydrogen		Yes			Yes		Yes	Yes	

* Where two or more fuel oil types are used concurrently, measurement requirements for exhaust gas concentrations shall be based on all fuel types used.
~~** Petroleum derived.~~"

Paragraph 74 – 6.1.1 of appendix VI of NTC 2008

Update to require that if the humidity of the intake air is greater than or equal to the humidity of the charge air, $H_a \geq H_{sc}$, then the humidity of the charge air, H_{sc}, shall be used. This is consistent with what is already being done for the carbon and hydrogen balance procedures and the density and molar mass based u_{gas} calculations in 6.2.1.1 and 6.2.2.1. Also update to define the emission concentration variables used in the equations as well the concentration units for consistency in appendix VI. Update equations (29), (31) and (32) to replace fractions with decimal values, consistent with IMO style. Also update for proper use of "only".

"6.1.1 Calculate the molar mass of the exhaust, M_e, from H_a from section 4.3 of this appendix VI and measured wet concentrations of c_{H2O}, c_{H2}, and c_{NH3}, as follows:

$$M_e = \begin{pmatrix} f_3 - f_4 \cdot f_2 \\ + \left(f_4 - (f_3 - f_4 \cdot f_2) \cdot \left(\frac{1}{2}0.5 + f_1\right)\right) \cdot c_{H2Ow} \cdot 10^{-2} \\ + \left(f_4 - (f_3 - f_4 \cdot f_2) \cdot (1 + f_1)\right) \cdot c_{H2w} \cdot 10^{-6} \\ + \left(f_4 \cdot \frac{3}{2}1.5 - (f_3 - f_4 \cdot f_2) \cdot \left(\frac{1 + 3 \cdot f_1}{2}\right)\right) \cdot c_{NH3w} \cdot 10^{-6} \end{pmatrix} \quad (29)$$

with:

$$f_1 = \left(\frac{w_{EPS}}{15.9994} + \frac{w_{DEL}}{14.0067} + \frac{3.5 \cdot c_{H2w} \cdot 10^{-4}}{c_{H2Ow} + 3.5 \cdot c_{H2w} \cdot 10^{-4}} \cdot \frac{w_{BET}}{12.0107}\right) \cdot \frac{1.00794}{w_{ALF}} \quad (30)$$

$$f_2 = \frac{28.96559 \cdot H_a \cdot 10^{-3}}{18.01528 + \left(\frac{1}{2}0.5 - f_1\right) \cdot 28.96559 \cdot H_a \cdot 10^{-3}} \quad (31)$$

$$f_3 = \frac{(1 + H_a \cdot 10^{-3}) \cdot 521.823}{18.01528 + 28.96559 \cdot \left(\frac{1}{2}0.5 - f_1\right) \cdot H_a \cdot 10^{-3}} \quad (32)$$

$$f_4 = (w_{BET} + w_{ALF} + w_{EPS} + w_{DEL} + w_{GAM}) \cdot \frac{2.01588}{w_{ALF}} \quad (33)$$

with

c_{H2Ow} = wet H_2O concentration in the raw exhaust, %
c_{H2w} = wet H_2 concentration in the raw exhaust, ppm
c_{NH3w} = wet NH_3 concentration in the raw exhaust, ppm

c_{H2w} measurement is ~~only~~ required only for hydrogen fuel and fuel mixtures containing hydrogen fuel. Otherwise, set this value to zero.

c_{NH3} measurement is ~~only~~ required only for ammonia fuel and fuel mixtures containing ammonia fuel. Otherwise, set this value to zero."