INTERNATIONAL MARITIME ORGANIZATION

IMO

E

SUB-COMMITTEE ON BULK LIQUIDS AND GASES
12th session
Agenda item 6

BLG 12/6/23
30 November 2007
Original: ENGLISH

REVIEW OF MARPOL ANNEX VI AND THE NO_x TECHNICAL CODE

Compliance and testing issues for Tier III engines

Submitted by the United States

SUMMARY

Executive summary:	This document provides suggested changes to the NO_x Technical Code pertaining to supplemental NO_x testing for limiting excessive emissions at low power settings, the definition of installed for engines, and continuous NO_x monitoring. In addition, this document provides further information on technologies for achieving Tier III NO_x reduction, PM measurement, and PM size versus fuel sulfur level.
Action to be taken:	Paragraph 27
Related documents:	BLG-WGAP 2/2/5 and BLG-WGAP 2/2/7

Introduction

1 New emission reduction technologies to be introduced for meeting proposed Tier III emission limits present a number of issues with ensuring emission reduction at low power settings. In addition, there are lingering questions regarding the definition of an installed engine, the fuel economy penalty associated with in-engine Tier III emission reduction technologies, continuous monitoring to insure operation of NO_x reduction technologies for engines that meet Tier III emission limits, methods for measuring particulate matter (PM), and the effects of fuel sulfur level on PM size.

2 This document discusses these issues and where appropriate, provides suggested language to revise Annex VI and the NO_x Technical Code (NTC).

Supplemental Emission Testing and Emission Load Caps

3 In BLG-WGAP 2/2/5 it was proposed to cap in-use emissions at [1.5] times the cycle weighted standard at all power settings for propulsion engines through an amendment to Regulation 13(3)(a) in Annex VI, and section 3.3.1 in chapter 3 of the NTC. These proposed amendments were to ensure that specific NO_x emissions for each individual mode of the test cycle did not exceed the NO_x emission limit for the composite weighted emissions by more than [50]%.

4 During discussion at BLG-WGAP 2, concern was expressed that engine manufacturers would not be able to meet the 1.5 times the cycle weighted standard limit at the 25% power setting for any emission reduction technologies used to meet new Tier II or Tier III emission requirements. While engine load is generally used to describe operational limits of NO_x abatement technologies, the driving issue is actually exhaust gas temperature, since exhaust temperature and engine load are inversely related.

5 Currently, many technologies are available which increase exhaust gas temperature and extend the operating range of emission reduction technologies. One of these options bypasses the water to the charge air cooler at low loads, thus increasing intake air temperature and allowing the exhaust gas temperature to be maintained. For selective catalytic reduction (SCR) applications, catalysts can be installed upstream of the turbocharger to minimize cooling of the exhaust gas during transport. Another technique currently available is to bypass part of the exhaust through a heated hydrolysis catalyst which allows urea to be injected at exhaust gas temperatures as low as 150°C. In another approach, a large portion of the catalyst can be bypassed at low loads when exhaust gas volume is low, thus forcing the exhaust into a smaller catalyst volume - maintaining turbulent flow and catalyst temperature. Additionally many engine manufacturers are moving to common rail fuel injection which provides the ability to perform post injection to raise exhaust gas temperature. Altering the scavenging of the engine may also be used to increase exhaust gas temperatures. These technologies are applicable to both two-stroke and four-stroke engines.

6 Based on this discussion, we are proposing that the Annex VI and NTC amendments as proposed in Annex 1 of BLG-WGAP 2/2/5 be accepted with modifications, since we need to ensure that engines are achieving the emission reductions in port where the health effects are of greatest concern. This includes reduced speed zones (RSZs) where engines operate at a 10 to 40% power setting. Furthermore, the proposal in Annex 1 of BLG-WGAP 2/2/5 should include a supplemental 15% power setting. This is critical to ensure that any NO_x reduction technology is not simply turned off at power settings of 25% or below and will require the use of technologies like those described in paragraph 3.3 to raise exhaust temperatures at these low power settings. This requirement should be applied to all Tier III compliant engines operating in Emission Control Areas (ECAs), although the argument can be made for this to apply to only main propulsion engines. While it was initially proposed in BLG-WGAP 2/2/5 that this apply to all engines installed on a ship on or after January 1, 2011, it would be difficult to enact this requirement given the time frame and the number of different engine models.

7 It is envisioned that this supplemental measurement would take place during the sea trial before issuance of the IAPP Certificate. A simplified calculation for determining compliance would reduce the certification burden on the engine manufacturer by not requiring brake-specific emission calculations. This calculation could be based on the ratio of the NO_x to CO_2 concentration for the composite weighted emissions (certcomp) compared to the ratio of the NO_x to CO_2 concentration for the emissions at the actual test point (act). The equation for determining compliance would be as follows:

$$[1.5]\cdot\frac{NO_{x_{certcomp}}(ppm)}{CO_{2_{certcomp}}(\%)}\geq\frac{NO_{x_{act}}(ppm)}{CO_{2_{act}}(\%)}$$

8 The amendments to regulation 13(3)(a) in Annex VI and NTC 3.1.1 would appear as follows as an additional paragraph at the end of regulation 13(3)(a) and NTC 3.1.1:

For all Tier III compliant engines with a power output of more than 130 kW which are installed on a ship on or after [1 January 2016], or which undergo a major conversion on or after [1 January 2016]. The specific emission value recorded for each individual mode of the applied test cycle, [in addition to a supplemental 15% mode], shall not exceed the NO_x concentration (ppm) to CO_2 concentration (%) ratio given for the weighted composite emission concentrations determined during certification by more than [50]%.

The calculation for determining compliance with the supplemental test procedure could be added as a new section, 5.12.5.4 and would appear as follows:

5.12.5.4 Compliance for supplemental emission testing can be determined as follows:

$$[1.5] \cdot \frac{NO_{x_{\text{certcomp}}}(ppm)}{CO_{2_{\text{certcomp}}}(\%)} \geq \frac{NO_{x_{\text{act}}}(ppm)}{CO_{2_{\text{act}}}(\%)}$$

Definition of Installed Engine

9 Clarification is needed regarding the definition of “installed” as it applies to marine diesel engines subject to Regulation 13(1)(a)(i) of Annex VI and chapter 1.2.1 of the NTC. An engine cannot be simply deemed installed because it is permanently secured or connected to the ship’s structure, fuel, coolant, exhaust, or power systems, as there are engines that are designed to be used solely in marine applications but are not permanently installed on a vessel. Consideration should be given to a definition that would include portable marine engines, since excluding these engines would mean that they would otherwise remain unregulated under Annex VI.

10 An engine should not be considered “installed” if it can easily be removed from a vessel to provide power to another application without modifications. An example of this is a pump engine that is bolted onto the main deck of a vessel. It should not be considered “installed” if it can be readily disconnected from the pump machinery and lifted off the vessel to power a pump (or other device) elsewhere. Such an engine operates more as a stand-alone auxiliary engine than a marine engine.

11 An engine should be considered “installed” if it is mounted in such a way that requires significant effort to remove it. It should also be considered “installed”, even if it is removable, if its fueling, cooling or exhaust systems are integral to the vessel. Such an engine, though conceptually portable because of its relationship to the vessel, cannot operate without a connection to the vessel. For example, if a portable engine is designed with a quick-connect access to the onboard fuel supply or with other hardware that allows the engine to tie into the vessel’s cooling or exhaust systems, such an engine should be considered “installed”, since it cannot be operated once it is removed from the vessel.

12 The suggested amendment is to add a definition of “installed” as it pertains to marine engines in Chapter 1, as a new 1.2.2. The section would read as follows:

1.2.2 An installed engine is a marine engine that is or is intended to be installed on a marine vessel. This includes portable auxiliary marine engines only if the engines fueling, cooling, or exhaust system is an integral part of the vessel. A fueling system is considered integral to the vessel only if it is permanently affixed to the vessel.

Methods for Measuring Particulate Matter

13 PM measurement methods for marine ships ("wet" ISO 8178 vs. "dry" ISO 9096) were debated at BLG-WGAP 2. BLG-WGAP 2/2/7 was discussed, specifically that ISO 9096 grossly underestimates the contributions of semivolatile hydrocarbons and sulfates (which are very important components of respirable PM) to the total PM by sampling at elevated temperatures which keeps these species in the vapor phase as they pass through the sample media. It is noted that EPA Method 5 (equivalent to ISO 9096) has historically been the method of choice for measurement of stationary PM sources in the United States, since the majority of stationary sources in the United States consist of coal fired boilers.[1, 2] In these applications, the PM control measures that are the basis of the "best available control technology" require heated operation to avoid sulfuric acid and water condensation and therefore do not control the condensable fraction.

14 In the United States, beginning in 2007, for stationary source compression ignition engines greater than 10 L/cylinder and less than 30 L/cylinder, PM emissions must be measured using the C2 locomotive test procedure in 40 CFR Part 92, which is equivalent to ISO 8178-1.[3, 4] In 2011, the United States' new PM2.5 NAAQS will take effect, which will require states to measure condensable PM from all stationary sources. Therefore, for stationary source compression ignition engines at or greater than 30 L/cylinder, the United States will soon promulgate a modification to EPA method 202, to approximate the emissions obtained through dilution sampling.[5] EPA will then follow this with a proposal to promulgate a dilution sampling system that can be used in place of the modified impinger method, with the final measurement methodology being very comparable to the ISO 8178-1 method for the quantification of PM.

The Effects of Fuel Sulfur Level on PM Size

15 Particulate matter emissions from diesel engines are a complex mixture of elemental carbon, semi-volatile organic compounds, sulfates (primarily hydrated sulfuric acid), and ash. Greater than 90% of the PM from diesel engines (this includes low speed, medium speed, and high speed engines) is sub-1 micron (sub-1000 nm) in particle size, with > 98% of the number of particles less than 200 nm in size. Thus, from the standpoint of particle number and lung deposition, nearly all of the PM from diesel engines can be classified as a very fine PM with a potentially very high rate of deposition deep within the human respiratory system in the alveolar (or gas-exchange) region of the lungs. Therefore, virtually any means of reducing PM mass and number from diesel sources will reduce deposition in the alveolar region.

16 The contribution of individual PM constituents to particles of different sizes is important from both the contribution to deep-lung penetration of these particles and the ability to control the particle constituents via fuel type. When comparing heavy fuel oil (HFO) and medium distillate oil (MDO), there are some basic differences in the fuel composition that results in lower PM emission rates on both a mass and fine particle number basis when switching C3 engines from HFO to MDO.

17 One of the differences between HFO and MDO is fuel volatility, with MDO having a higher volatility, which impacts both particles mass and number. Organic compounds are present in diesel exhaust in one of three physical states: gaseous, which decreases as the volatility of the

[1] ISO 9096, "Stationary Source Emissions – Manual Determination of Mass Concentration of Particulate Matter".
[2] US EPA Method 5, "Determination of Particulate Matter Emissions from Stationary Sources".
[3] 40 CFR Parts 60.4202, 94.8(b), 94.104(a), and 92.114(c)(4) (http://ecfr.gpoaccess.gov).
[4] ISO 8178-1, "Reciprocating Internal Combustion Engines – Exhaust Emission Measurement", 2006.
[5] US EPA Method 202, "Determination of Condensable Particulate Emissions from Stationary Sources".

fuel is reduced (order of fuel volatility, #2 distillate > MDO > HFO); adsorbed organic PM, which refers to the less volatile, higher molecular weight organic compounds that adsorb to the surfaces of agglomerated elemental carbon soot particles and metallic ash particles; and nucleated organic PM, which refers to less volatile, higher molecular weight organic compounds that form an aerosol via homogenous and heterogeneous nucleation.

18 For C3 marine diesel engines operating on relatively high sulfur HFO, PM would primarily be formed from heterogeneous nucleation of organic compounds onto an ultrafine sulfuric acid aerosol during dilution. The particle size of the resulting nucleation aerosol would range from 3 nm up to approximately 30 or 50 nm. Thus the resulting particles are extremely small with the potential to penetrate deep into the lung. The sulfur compounds in the HFO also contribute significantly to a relatively nonvolatile ultrafine nucleation aerosol and the amount of metallic compounds in the HFO would contribute primarily to a nonvolatile fine aerosol.

19 Since nucleation particles are the largest contributor to particle number and agglomerated particles in the 30 to 200 nm range are the biggest contributor to diesel particle mass, operating C3 marine diesel engines on MDO or distillate fuel instead of HFO would reduce the relative fuel contribution to ultrafine nucleation aerosols by reducing the formation of nucleated sulfuric acid. This directly reduces one constituent of ultrafine PM and nucleation sites for heterogeneous nucleation of organic PM into an ultrafine nucleation aerosol. Furthermore, moving from HFO to MDO or distillate fuel would increase the fuel volatility which would reduce both nucleation and adsorption of organic compounds from the fuel into PM, as well as reduce the contribution of metallic compounds in the fuel to metallic ash PM.

20 Particle number data collected from ocean-going vessels appears to confirm that the number and mass of particles are reduced when changing from HFO to MDO. Fine particle number count during operation on HFO is between 1.5 and 4 times the fine particle number count during operation on MDO.[6, 7]

The Fuel Economy Penalty Associated with In-engine Tier III Emission Reduction Technologies

21 In recent discussions at IMO, it has been proposed that Tier III NO_x reductions of up to 40% from a Tier I baseline can be met using in-engine technology. We would like to point out that many at IMO are in agreement that any technologies used to meet the Tier III requirement should minimize fuel economy penalty. Switching to distillate fuel for Tier III operation will not afford a 40% NO_x reduction, and in fact any reduction in nitrogen content of the distillate is already present in current certifications since engines are certified on distillate fuels, yet operated on HFO. Therefore, this will not alleviate the fuel economy penalty associated with in-engine Tier III NO_x reduction technologies. Furthermore, technologies to reduce NO_x, like the Miller cycle, EGR, and fuel injection timing retard, are associated with large fuel economy penalties when trying to achieve the large NO_x reductions proposed for Tier III. In contrast, technologies like urea SCR and humid air motor (HAM) can work to reduce NO_x with minimal impact on fuel economy.

---

6 Hobbs, P.V.; Garrett, T.J.; Ferek, R.J.; Strader, S.R.; Hegg, D.A.; Frick, G.M.; Hoppel, W.A.; Gasparovic, R.F.; Russell, L.M.; Johnson, D.W.; O'Dowd, C.; Durkee, P.A.; Nielsen, K.E.; Innis, G. Emissions from ships with respect to their effects on clouds. *Journal of Atmospheric Sciences.* **2000**, *57*, 2570.

7 Sinha, P.; Hobbs, P. V.; Yokelson, R. J.; Chrisitan, T. J.; Krichstetter, T. W.; Bruintjes, R. Emissions of trace gases and particles from two ships in the southern Atlantic Ocean. *Atmospheric Environment*. **2003**, *37*, 2139.

NO_x Continuous Monitoring for Engines Meeting Tier III Emission Limits

22 For marine diesel engines using out of engine emission reduction strategies to meet Tier III requirements, as it is currently proposed, the engine will only require its Tier III emission reduction components to be operational when in ECAs. For many of the available technologies, improper operation of the NO_x reduction technology may not affect engine performance, and therefore may not be easily identified. Consequently, we propose that continuous monitoring be used as an efficient method for ensuring in-use emission control when marine diesel engines are operated in designated ECAs. A continuous monitor system should be designed to continuously monitor exhaust emissions, monitor key operating parameters, record the position of the vessel using GPS, and provide notification (alarm) if the emission control system is not operating properly in an ECA.

23 For continuous monitoring in ECAs, the following parameters should be observed: NO_x, CO_2, HC, CO, engine load, exhaust temperature, urea dosing rate (SCR only), and brake-specific fuel consumption. To ease the burden of continuous monitoring, the concentration based scheme proposed for use in the supplemental emissions testing section in paragraph 3 of this document should be considered for use with continuous monitoring. In that case, only NO_x, CO_2, urea dosing rate (SCR only), and exhaust temperature would need to be monitored. Another option that could be made available for engines utilizing SCR based aftertreatment is demonstrating SCR efficiency by continuously monitoring NO_x concentrations at the SRC system inlet and outlet. This NO_x reduction efficiency would then need to be compared back to the Tier II emission values for the engine to determine the Tier III emission values during operation in an ECA.

24 The instantaneous emissions of NO_x in an ECA should not exceed [1.5] times the composite certified emission value for NO_x during engine operation at or above the [15]% power setting. Exemptions shall be allowed during cold start if the emission control system cannot be operated until certain conditions are met (e.g., exhaust temperature, catalyst temperature, etc.). For example a [10 minute] period to allow the SCR system to reach operating temperature is one way to address this. Allowances should also be made to accommodate instrument calibration during continuous monitoring.

25 Chapter 2.3.7 of the NTC will have to be amended to mandate continuous monitoring for Tier III compliant engines when operating inside ECAs. A new section in Chapter 6 (6.4 or 6.5) will have to be developed titled "Continuous Monitoring" that describes the measurement requirements as well as the method for compliance determination.

26 Regulation 13(3)(a) in Annex VI, and section 3.3.1 in chapter 3 of the NTC will each need a paragraph added that states:

For Tier III compliant engines with a power output of more than 130 kW which are installed on a ship on or after [1 January 2016], or which undergoes a major conversion on or after [1 January 2016]. The specific emission value recorded during operation inside an ECA shall not exceed the NO_x concentration (ppm) to CO_2 concentration (%) ratio given for the weighted composite emission concentrations determined during certification by more than [50]%.

Action requested of the Sub-Committee

27 The Sub-Committee is invited to consider the information provided and take action as appropriate.

____