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CONSIDERATION OF THE IMPACT ON THE ARCTIC OF EMISSIONS OF BLACK CARBON FROM INTERNATIONAL SHIPPING

Effective control measures of Black Carbon emissions from marine diesel engines based on the results using measurement methods identified by IMO

Submitted by Finland

SUMMARY

Executive summary:	This document contains the results of the evaluation of the control measures of Black Carbon emissions from marine diesel engines based on the results obtained using measurement methods identified by IMO
Strategic direction if applicable:	3
Output:	3.3
Action to be taken:	Paragraph 18
Related documents:	PPR 4/9/2, PPR 4/9/3, PPR 4/INF.7, PPR 5/7/2, PPR 6/INF.15, PPR 6/INF.11

Introduction

1 At its second session the Sub-Committee, having noted the need for Black Carbon (BC) measurement studies to gain experience with the application of the definition and measurement methods, invited interested Member Governments and international organizations to initiate, on a voluntary basis, BC measurement studies to collect data. At the same time, information on potential options to reduce BC emissions was gathered.

2 In this document, control measures of BC emissions from marine diesel engines are evaluated focusing on the results using the IMO selected BC measurement principles (FSN, PAS, LII). The major part of the evaluated BC emission results are from the voluntary studies conducted in accordance with the invitation by IMO, involving a number of researchers and experts worldwide and discussions in the BC Workshops of ICCT. The evaluated BC emission results and their interpretation are described in detail in document PPR 6/INF.15 (Finland). Several recent BC results included in this evaluation were not covered by

document PPR 5/INF.7 (Canada). The results of the appropriate control measures of the BC emissions from marine diesel engines, introduced in this document are compared with those listed in document PPR 5/INF.7[1] and in the ICCT fifth BC Workshop report, see document PPR 6/INF.11 (Canada, Finland and Republic of Korea).

Criteria of evaluation

3 The evaluation of the control measures to reduce BC emissions from marine diesel engines focuses on the slow-speed diesel (SSD) and medium-speed diesel (MSD) marine engines in engine sizes above 1 MW. The BC emission results from the high-speed diesel (HSD) engines are mentioned only in relation to engine technologies. The criteria of evaluation for the BC emission are as follows:

.1 The evaluated BC emission results are obtained by three BC emission measurement principles identified by IMO: filter smoke number (FSN), photoacoustic spectroscopy (PAS) and laser-induced incandescence (LII). The BC emission results obtained using other measurement principles are used as additional (supporting) information.

.2 The effect of fuel switching (use of distillate fuels, oils and fats instead of residual fuels) on the BC emissions from marine diesel engines is evaluated from the measurement campaigns where different types of fuels are used in the same marine diesel engine, because differences in the amount of BC emissions are typically higher among individual engines than among the fuel types mentioned.

.3 The efficiency of the exhaust gas treatment systems on the BC emissions from marine diesel engines is evaluated based on the results from the measurement campaigns where the results are obtained before and after the exhaust gas treatment system, because the differences in the BC emissions from different ships could mask the effect of the exhaust gas treatment systems.

Results

4 Remarks on control measures for BC emissions from marine diesel engines using different engine sizes, fuel injection systems, fuel types, exhaust gas treatment systems and slow steaming are given below based on the measurement campaigns and meeting the defined criteria of evaluation. Additionally, remarks on the observations based on results other than those meeting the criteria are given.

Engine technology

5 The following remarks on control measures for BC emissions from marine diesel engines using different engine sizes and fuel injection systems can be made:

.1 SSD and MSD engines emit lower BC emissions than HSD engines;

.2 modern SSD and MSD engines emit low BC emissions (e.g. 50-100 mg/kg fuel or below) compared to the BC emission factors used in inventories; and

.3 engines with modern injection systems (particularly common-rail) emit low BC emissions. Old engines with mechanical fuel injection systems emit high BC emissions at low engine loads. Consequently, retrofitting old engines with modern injection systems would reduce the BC emissions.

[1] Document PPR 5/INF.7 presented an update to the investigation of appropriate control measures to reduce BC emissions from international shipping.

6 Furthermore, the following remarks related to engine technology can be made:

.1 tailored solutions, such as slide valves could reduce BC emissions from two-stroke engines, while needle sac volume is already reduced for four-stroke engines; and

.2 engines could be tuned to low BC emissions (combined with NO_X reducing technologies).

Fuel type

7 The following observations on control measures for BC emissions from marine diesel engines using different fuel types can be made:

.1 LNG as a main fuel in gas DF engines resulted in extremely low BC emissions;

.2 methanol as a main fuel in one DF engine studied reduced BC emissions by 55-75% depending on pilot injection when compared with distillate as a main fuel;

.3 distillate fuels reduced the BC emissions in most cases when compared to the residual fuels; and

.4 oxygen-containing biofuels (oils and fats) reduced the BC emissions substantially when compared to the residual or distillate fuels.

8 Furthermore, the following remarks related to fuel technology can be made:

.1 all fossil marine fuels used today can be replaced by their chemically similar liquid or gaseous renewable counterparts (bio-based or synthesized from renewable hydrogen and circular carbon dioxide); and

.2 hydrogen, dimethyl ether (DME) and ammonia are not currently commercial options as a main fuel for large ships.

Exhaust gas treatment systems

9 The following remarks on the use of exhaust gas treatment systems as control measures for BC emissions from marine diesel engines can be made:

.1 particulate filters would efficiently reduce the BC emissions from marine diesel engines. Pre-commercial systems have been demonstrated, but questions remain on the required fuel quality, feasibility of the regeneration technology, as well as on reliability and durability;

.2 electrostatic precipitator (ESP) developments for marine diesel engines are not mature, and it is too early to predict their success for ships; and

.3 exhaust gas treatment systems designed for purposes other than removing particulate matter or BC did not reduce the BC emissions substantially, namely SO_X scrubbers, diesel oxidation catalysts (DOC) and Selective Catalytic Reduction (SCR). However, these technologies might be integrated with the BC reduction technologies.

Slow steaming

10 Slow steaming reduces BC emissions from modern marine diesel engines along with reducing fuel consumption, while the BC emissions from old marine diesel engines equipped with mechanical fuel injection systems may increase when moving to lower than the optimum engine loads (even if compensated for reduced fuel consumption). Engines are typically designed to run at 70-85% engine load, and thus de-rating and retrofitting may be needed when using lower engine loads, however, then an adjusted load range would be used.

Summary of BC emission control measures

11 The quantified effect of the control measures on the BC emissions from marine engines are shown in figure 1 below. The most efficient BC control measures identified were the use of LNG or methanol as a fuel, and particulate filters combined with clean marine distillates (or clean renewable fuels). Technologies to use LNG and methanol as a fuel are already commercialized. Particulate filters are pre-commercial, although the performance and durability of particulate filters needs to be proven. Slight reductions in the BC emissions from marine diesel engines could be achieved by switching to marine distillates or clean renewable fuels from residual fuels. Reduction in the BC emissions was not significant for the SO_X scrubbers in most of the cases evaluated, however, a scrubber might be combined with other solutions. Technologies that cannot be quantified in this study (thus are not shown in figure 1) are hydrogen and full electric solutions (BC-free), renewal or retrofitting of old engines with modern engine injection systems, or tuning engines to low BC emission. Additionally, while slow steaming could offer substantial BC reduction for modern marine diesel engines, it is not necessarily a solution for old engines equipped with mechanical injection systems.

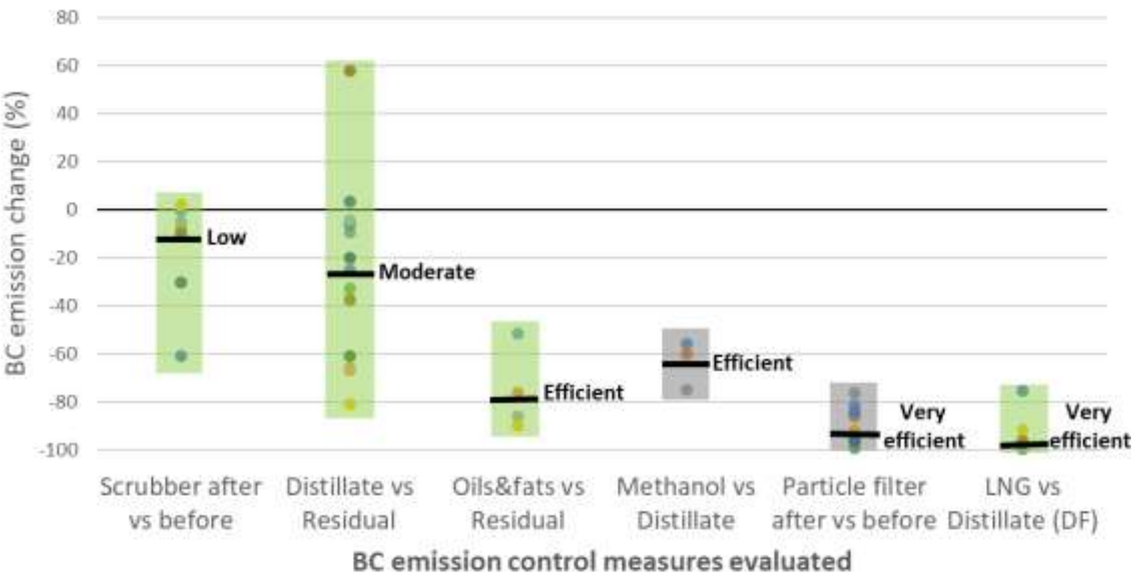

Figure 1: Efficiency of the control measures for BC emissions from marine diesel engines in cases where the change in the BC emissions could be quantified. Each marker illustrates one comparison data point and their averages are marked with a black line. The grey colour indicates limited data or "other" measurement methods

12 The short lists of appropriate control measures of the BC emissions from marine diesel engines set out in this document and in document PPR 5/INF.7 include LNG, particulate filters and distillate fuels (see table 1 below). However, document PPR 5/INF.7 did not list methanol, oxygen-containing biofuels (oils and fats) and engine-related technologies, which were identified as potential in this evaluation. Instead, document PPR 5/INF.7 identified scrubbers as a potential BC reduction technology based mainly on studies on particulate matter (only one BC study). In this document based on eight BC emission studies, SO_X scrubbers were not

substantially effective in reducing the BC emissions from marine diesel engines. It is noticeable that the results of this document and the conclusions from the ICCT fifth BC Workshop are almost identical. However, ESP technology is not listed here as it is in an early development phase for marine engines, and shore power is not within the scope of this study. Additionally, the ICCT fifth BC Workshop did not evaluate slow steaming.

Table 1: Shortlist of potential BC reduction measures from this report and from document PPR 5/INF.7

	This report	**Document PPR 5/INF.7**
Fuel type	• LNG • Distillate fuels (enabling particulate filters) • Methanol • Oxygen-containing biofuels (oils and fats)	• LNG • HFO to distillate fuel • Water in fuel emulsion
Exhaust treatment	• Particulate filters	• Diesel Particulate Filters • Scrubbers
Engine and Propulsion System Design	• Engine retrofit to common-rail • Engine tuning to low BC (NO_X cut with EGR/SCR) • Hybrids • Full batteries or hydrogen/fuel cells	-
Other	• Slow steaming for modern diesel engines, but not for engines equipped with mechanical fuel injection	Slow Steaming with de-rating

Consideration of the BC emission control technologies for different marine diesel engines

13 LNG and methanol are clean-burning fuels already used in shipping, and infrastructure for bunkering is emerging. Hydrogen/fuel cells and batteries have no BC emissions, and can provide solutions for short routes or smaller vessels in the future. Ferries, etc. using marine distillate fuels could consider particulate filters, and a growing market of clean distillate fuels supports this option. Very large ships, such as big container ships and oil tankers using mainly residual fuels, are among the most demanding ships as regards adopting the control measures of BC emissions. However, many of these ships are relatively new and have state-of-the-art diesel engines showing modest BC emissions from 50 to 100 mg/kg fuel or below.[2] For old engines, retrofitting of modern fuel injection systems, or engine tuning are also options to consider. Generally, control measures of BC emissions from marine diesel engines may need case-by-case considerations.

[2] The lowest BC emission observed was for the LNG DF engines (circa 1 mg/kg fuel, 37 µg/m^3), close to the ambient BC concentrations in some regions and not far from the PM2.5 limit (10 µg/m^3) for ambient air (WHO).

Conclusions

14 Control measures of BC emissions from marine diesel engines are available, however, they vary in efficiency, feasibility and maturity as set out in the paragraphs below.

15 BC-free (or almost BC-free) shipping is achieved by:

.1 using LNG or methanol as a main fuel;

.2 using particulate filters in combination with clean marine distillate fuels (if proven); and

.3 using hydrogen/fuel cells or batteries (not mature for the main engines of large ships).

16 Substantial reduction of BC emissions could be achieved by:

.1 using oxygen-containing biofuels (oils and fats) in marine diesel engines;

.2 replacing old mechanical fuel injection systems with modern fuel injection systems;

.3 tuning engines to low BC emissions combined with the NO_X emission reduction technologies; and

.4 slow steaming for modern marine engines (not for old engines equipped with mechanical fuel injection systems).

17 Modest or low reduction of BC emissions could be achieved by:

.1 switching to distillate fuels from residual fuels (enables particulate filters);

.2 slow steaming combined with old engines having mechanical fuel injection systems; and

.3 SO_X scrubbers, DOC, SCR and EGR. However, they could be integrated with technical solutions to reduce BC emissions.

Action requested of the Sub-Committee

18 The Sub-Committee is invited to consider the information provided in this document and take action as appropriate.

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