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

Initial results of a Black Carbon measurement campaign with emphasis on the impact of the fuel oil quality on Black Carbon emissions

Submitted by Finland and Germany

SUMMARY	
Executive summary:	This document presents results of a measurement campaign for the analysis of the impact of fuel oil quality on Black Carbon emissions. The results clearly indicate that new blends of marine fuels with 0.50% sulphur content can contain a large percentage of aromatic compounds, which have a direct impact on Black Carbon emissions.
Strategic direction, if applicable:	3
Output:	3.3[1]
Action to be taken:	Paragraph 24
Related documents:	PPR 5/24; MEPC 74/10/8 and MEPC 74/18

Background

1 MEPC 62 agreed on a work plan to consider the impact on the Arctic of Black Carbon (BC) emissions from international shipping and instructed the Sub-Committee on Bulk Liquids and Gases (now PPR) to undertake this work by developing a definition of Black Carbon (BC); identifying the most appropriate measurement method(s) for international shipping; and investigating appropriate control measures. MEPC 68 approved the Bond et al. definition of BC proposed by PPR 2, and PPR 5 identified three most appropriate BC measurement methods, namely FSN, PAS and LII (PPR 5/24, paragraph 7.18).

2 According to the work plan agreed at MEPC 62, PPR 6 had completed its work under the output "Consideration of the impact on the Arctic of emissions of Black Carbon from international shipping" and requested MEPC 74 to provide instruction on further work on the reduction of the impact on the Arctic of Black Carbon emissions from international shipping.

[1] Refers to the list of outputs for the 2018-2019 biennium.

3 Document MEPC 74/10/8 (Finland et al.) suggested draft terms of reference for the PPR Sub-Committee to reduce the impact on the Arctic of Black Carbon emissions from international shipping, which were supported, in principle, by the majority of delegations at MEPC 74 (MEPC 74/18, paragraph 5.67). The draft terms of reference shall be further considered by PPR 7, with a view to advising the Committee accordingly.

4 At MEPC 74, some delegations expressed the view that the recommended BC measurement methods needed further work to achieve convergence of results and agreement, and that the impact of the 0.50% global sulphur limit needed to be taken into account.

5 Germany has therefore carried out a BC measurement campaign with two of the three identified appropriate BC measurement methods (FSN and PAS) to analyse the impact of different fuel oil qualities on BC emissions. Additional analysed parameters and applied instruments are listed in table 4 below but have not been fully evaluated yet. The measurement campaign was conducted by WTZ Roßlau and was assisted by MAN ES, DNV GL and Marena Ltd. The project was funded by the German Environment Agency.

Description of the Black Carbon measurement campaign

6 Emphasis of the measurement campaign was to analyse the BC emissions of future hybrid fuels with 0.50% sulphur content from different sources and different production processes, in comparison to two conventional fuels, HFO and DMA, as reference (Ref.), and a possible future synthetic Gas to Liquid (GtL) fuel, at varying engine ratings on a test bed. All tests were performed with the same lube oil. The tested fuels and their varying sulphur and aromatic content are listed in table 1. The tested 0.50% sulphur fuels have been ordered as possible sample mixtures from refinery-streams most likely to be used in 2020. A high aromatic content in future low sulphur marine fuels after 2020 is expected.[2]

Table 1: Fuel oil qualities tested in the BC measurement campaign as declared by the suppliers

Fuel	Sulphur content [%]	Aromatic content [%]
Gas to Liquid (GtL)	0	0
DMA Ref.	0.1	20
HFO 2.5% sulphur Ref.	2.5	50
0.50% sulphur (70)	0.5	70
0.50% sulphur (80)	0.5	80
0.50% sulphur (95)	0.5	95

7 The test engine was a single-cylinder medium speed marine diesel engine (MAN 1L32/44CR-TS) with a displacement of >30 L, with a modern common-rail injection system and a two-stage turbocharging process. Further details of the engine are listed in table 2. The engine was operated to meet the corresponding IMO Tier-II NO_X limit.

2 Takasaki, K., Tsuru, D. Takahashi, C. and Takaishi, T. (2018) Combustion Quality of low-sulphur Marine Fuels after 2020 – will be better or worse? In: *Proceedings of the 5th Rostock Large Engine Symposium (RGMT)*, by Harndorf, H., 2018, p. 49-62.

Table 2: Technical details of the test engine

Test engine	**MAN 1L32/44CR-TS**
Bore	32 cm
Stroke	44 cm
Nominal speed	750 rpm
Nominal power	640 kW

8 The test cycles of the engine were in accordance with the E2 cycle (table 3; NO_X Technical Code, chapter 3.2.3). The analytical instrumentation, including BC measurement instruments, are listed in table 4.

Table 3: Measurement points according to test cycle E2 according to the NO_X Technical Code, chapter 3.2.3

Engine load [%]	**Speed [rpm]**
25	750
50	750
75	750
100	750

Table 4: Analysed parameters, analytical instruments and methods

Parameter	**Analytical instruments**	**Methods**
Equivalent Black Carbon (eBC)	AVL FSN 415-SE (G003)	ISO-8178-3 (2019) and ISO-10054 (1998), conversion to eBC with AVL-correlation
Equivalent Black Carbon (eBC)	AVL 483 MSS^{plus} Micro Soot Sensor	Photoacoustic Spectroscopy (PAS)
Particulate matter	Microtrol 6 PM gravimetric with dilution tunnel at 47+/- 5°C	ISO-8178-1 (2017)
Real-time particle size / number distributions (5 to 1,000 nm)	Cambustion DMS500	Fast-response differential particle mobility spectrometer
Organic carbon (OC) Elemental carbon (EC)	TGA 502 Thermogravimetric analysis (TGA)	Gravimetric filter analysis
Chemically speciated NMHC incl. mono-aromatics and PAHs	IONICON PTR-TOF 6000 X2	Chemical ionization mass spectrometry

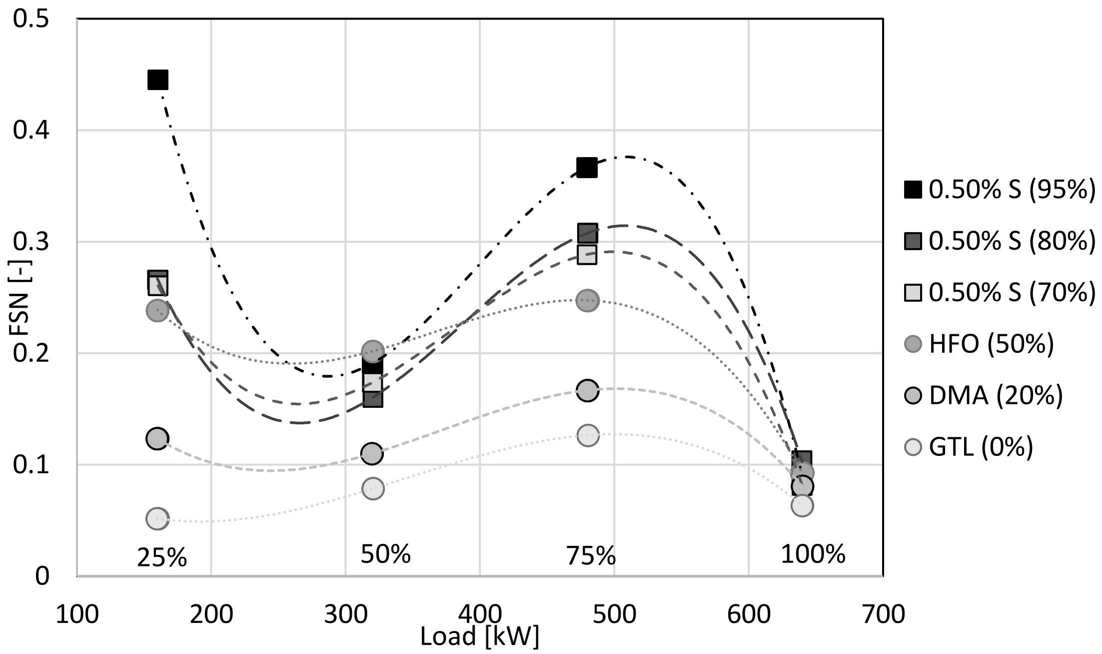

Figure 1: FSN values versus power output [kW] / engine load [%]

9 Figure 1 shows the arithmetic mean value from all repetitive measurements of FSN (raw data) for the different fuels and engine loads. The range of measurement values was very low and narrow for the different fuels at 100% engine load followed by 50% load. At 75% load, the spread of the FSN data from different fuels continues to increase, while at 25% load, the FSN data show the largest differences for the different fuels. The variation of the individual measurement values will be discussed in detail in the following paragraphs.

Table 5: Arithmetic means for the E2 Cycle value of eBC emissions for the fuel oil qualities tested

Fuel (aromatic content [%])	FSN [mg/Nm^3]	PAS [mg/Nm^3]
Gas to Liquid (GtL) (0)	1.49	1.33
DMA Ref. (20)	2.02	2.06
HFO 2.5% sulphur Ref. (50)	3.06	2.73
0.50% sulphur (70)	3.37	4.06
0.50% sulphur (80)	3.63	4.22
0.50% sulphur (95)	4.37	5.05

10 In table 5, the E2 cycle weighted eBC emissions for the different fuels are presented. The ranking of fuel types regarding BC emissions can be established irrespective of the measurement instrument used (FSN or PAS). None of the 0.50% sulphur hybrid fuels caused a reduction of BC emissions compared to the conventional HFO. The conventional DMA grade distillate and especially the GtL fuel provide a reduction in BC emissions compared to HFO. In the measurement campaign, a factor of between 3 and 4 was found between the highest and lowest BC emitting fuels.

11 A high consistency of the FSN and PAS values for the DMA grade fuel was found. This may be explained by the factory calibration of both instruments to a diesel fuel with a polycyclic aromatic hydrocarbon content of maximum 8%, according to the EN 590 standard which does not specify mono-aromatic compounds.

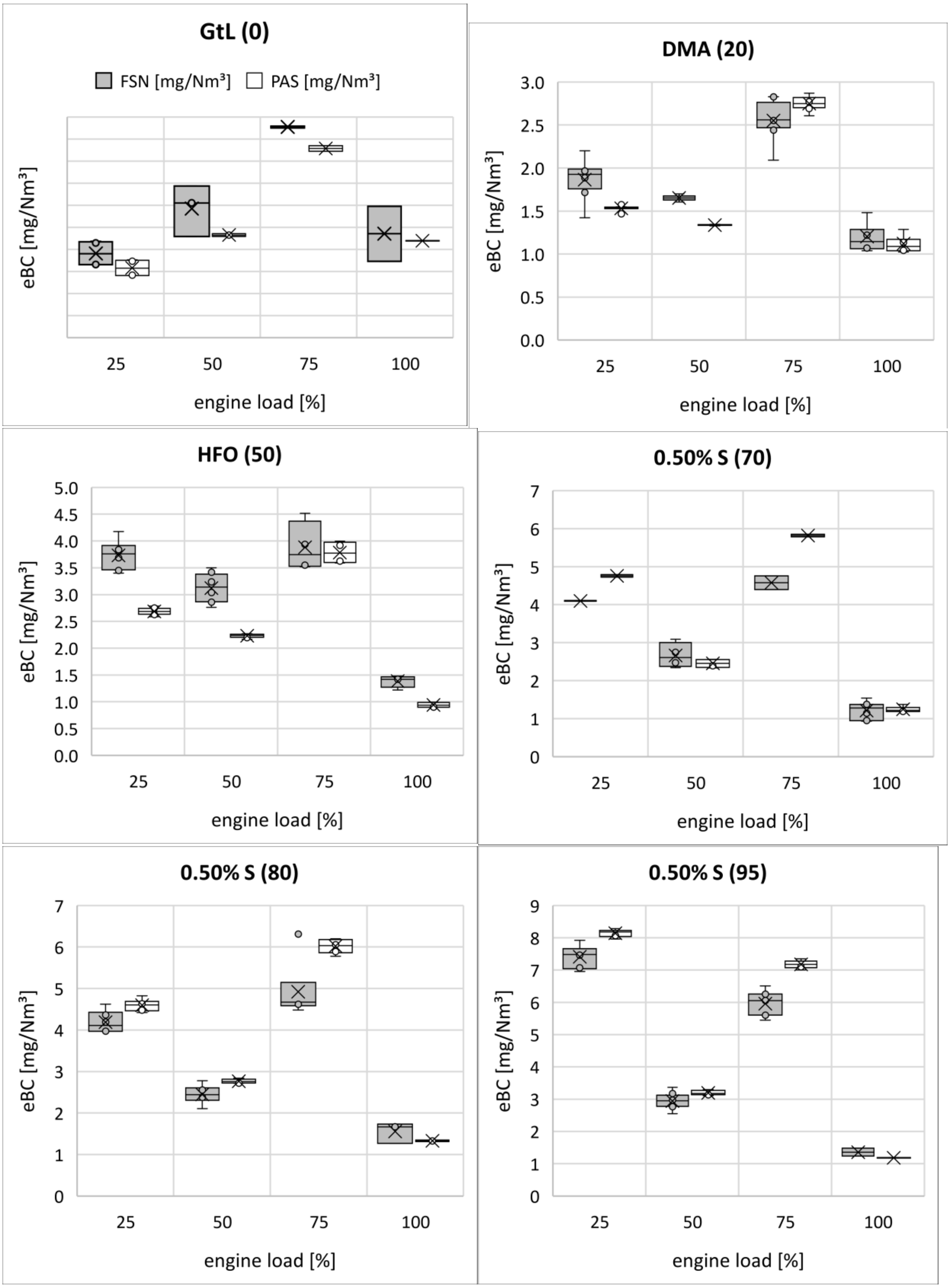

Figure 2: Box and whisker plots for eBC emissions in mg/Nm³ (FSN and PAS) versus engine loads for each tested fuel (GtL, DMA, HFO, and the three 0.50% sulphur fuels; in brackets the aromatic content). The legend can be found in the box plot for GtL. Note: The y-scales vary, due to the different concentration ranges.

12 For a better visualization, the BC emissions are presented separately for each fuel as box and whisker plots in figure 2 above. The box plots are statistical graphs, where the boxes include the upper and lower quartiles (25-75% of the data). Between 2 and 8 repetitive measurements have been performed in the measurement campaign for each load point. The mean value is shown by a cross and the median value as the middle horizontal line in the box. The vertical lines show the concentration spread and any dots inside the boxes are measured data, dots outside the boxes have been assigned as outliers. Please note that the six graphs have varying y-axes.

13 In general, the variance of data is larger for the FSN data (grey boxes), which is represented by the height of the boxes in figure 2. Only one clear outlier has been identified for FSN 0.50% sulphur fuel with 80% aromatic content at 75% engine load.

14 The BC emissions in this study are in a range between 0.56 and 8.3 mg/Nm³. The lowest BC emissions have been observed at 100% engine load for all fuels below 2 mg/Nm³. The highest BC emissions were generally detected at 75% and 25% engine load. The 0.50% sulphur fuel with 95% aromatic compounds showed the highest BC emissions at 25% load with 8 mg/Nm³, followed by 75% load with 7 mg/Nm³.

15 As stated above, the 25% load point had the highest differences in BC emissions between the fuels with the following order (in brackets: aromatic compounds): GtL (0%) < DMA (20%) < HFO (50%) < 0.50% sulphur (70%) < 0.50% sulphur (80%) < 0.50% sulphur (95%). This order leads to the assumption that the concentration of aromatic compounds might have an impact on the BC emissions of the various fuels. Therefore, the BC data in figure 3 are plotted against the aromatic content to see if this hypothesis holds true.

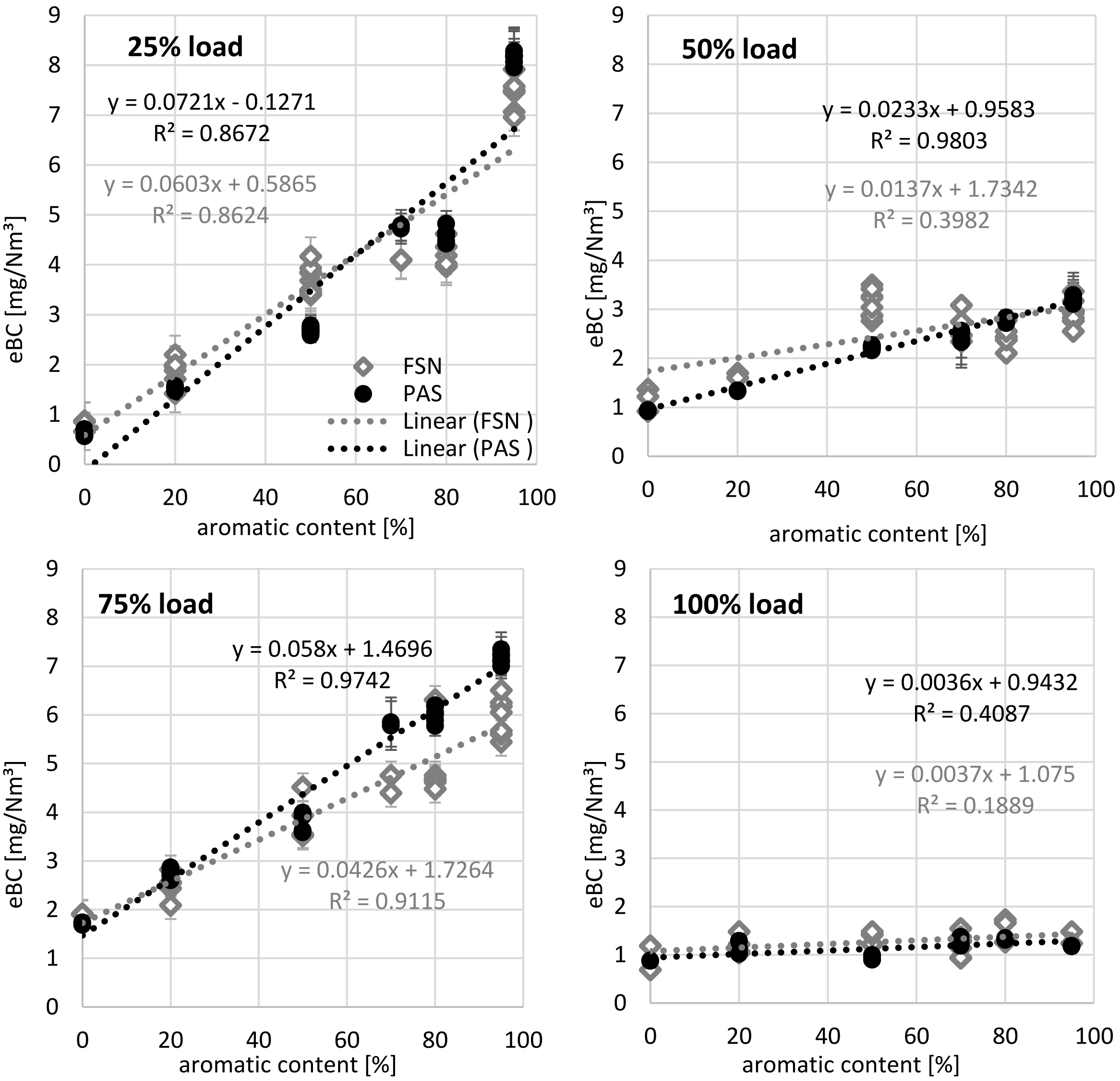

Figure 3: eBC emissions for 25, 50, 75 and 100% engine loads in relation to fuel aromatic content (the legend for FSN and PAS identification is in the diagram for 25% load)

16 Figure 3 shows the eBC emissions for each engine load (25%, 50%, 75% and 100%) in relation to the aromatic content of the fuels (GTL 0%, DMA 20%, HFO 50%, 0.50% sulphur 70%, 80% and 95%):

.1 there is a clear trend for increasing BC emissions with increasing aromatic content in the fuels with correlation coefficients for the PAS data of 0.86; 0.98 and 0.97 for 25%, 50% and 75% engine load, respectively. For the 100% engine load there was no clear trend, possibly due to the comparatively low BC emissions of <2 mg/Nm³;

.2 for the 50% engine load, the FSN BC data for HFO (50% aromatic content) deviate upwards from the linear trend as compared to the PAS data, while for the 75% load, the FSN BC data for the 0.50% sulphur fuels deviate downwards; and

.3 the BC emissions are also influenced by the engine load, with 100% showing the lowest and 75% and 25% showing the highest BC emissions. Furthermore, the spread of the data is much wider for 75% and 25% load as compared to the other engine loads.

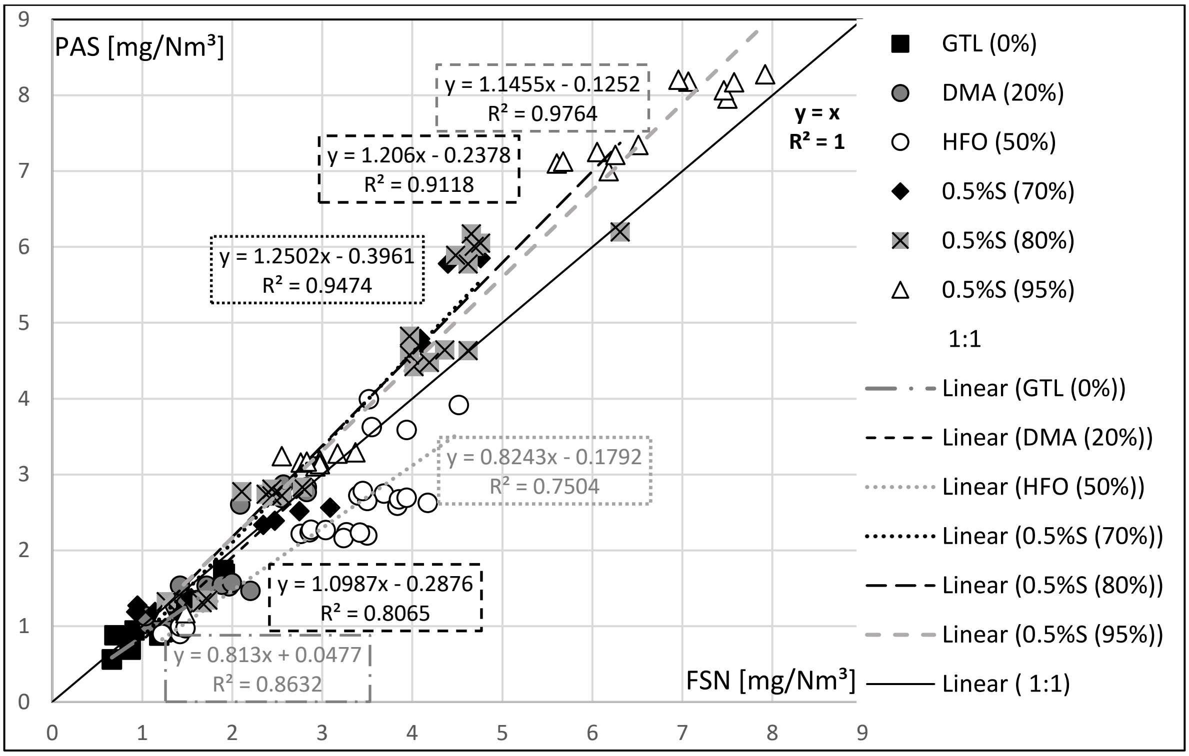

Figure 4: Correlation of FSN and PAS eBC emission measurements

17 Figure 4 shows a correlation graph for the measured FSN and PAS eBC data for each tested fuel type. For HFO fuel, correlation coefficient (R^2 = 0.75) and the slope of the regression line (x = 0.824) are lower than 1. The reason is that the FSN data were generally higher than the PAS data for HFO and that there was a higher scattering of the data for FSN (see also figure 2 for HFO). A similar deviation with a lower slope of the regression line (x = 0.813) has been found for GtL, but the scattering of the data was less than for HFO, with a correlation coefficient of R^2 = 0.863.

18 For the three highly aromatic 0.50% sulphur fuels, the correlation coefficients with R^2 between 0.912 and 0.976 are closer to 1 and the slopes of the regression lines (x between 1.145 and 1.250) are higher than 1. For these three 0.50% sulphur fuels, the scattering of data was significantly lower compared to HFO and GtL. But for the three 0.50% sulphur fuels, the PAS instrument measured higher eBC concentrations than the FSN, contrary to the case for HFO.

19 For the DMA correlation, the slope of the regression line (x = 1.099) is the closest to 1 and the scattering of data (R^2 = 0.806) is within the range of HFO and GtL.

20 In the instances of HFO and GtL, the confidence interval has been determined to occur within a probability of 87 to 93% for FSN and 89 to 99% for PAS. The lower values are related to the measurements of GtL at 25% load with very low BC emissions ranging from 0.025 to 0.87 mg/Nm³. Without this test point, the confidence level is well above 90% for all measurements. Furthermore, it must be stated that there are always some variations due to the engine operation as shown exemplarily in figure 5.

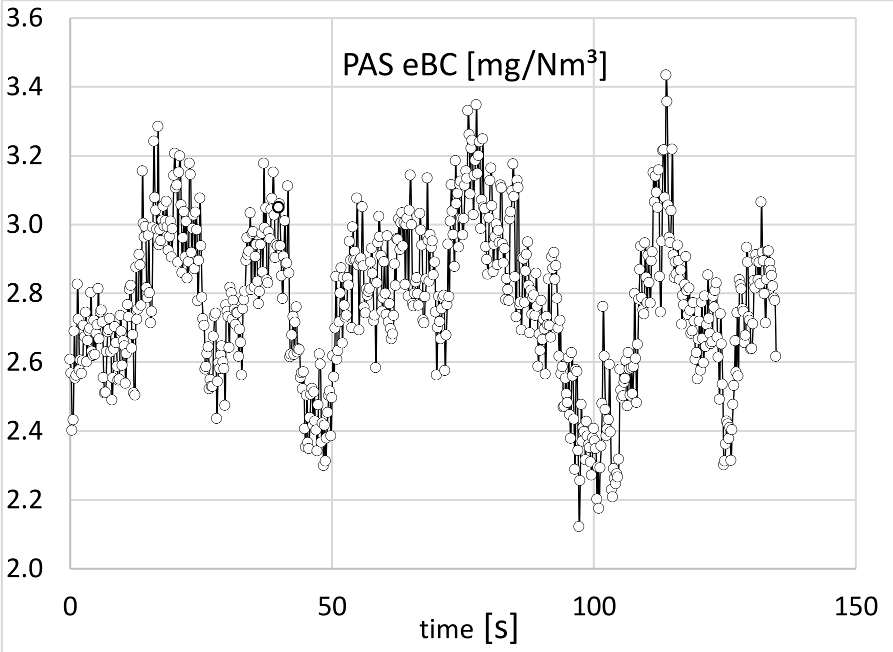

Figure 5: Exemplary variation of eBC emission over time during one integral PAS measurement

Conclusions

21 The PAS instrument measured higher BC emissions for the three 0.50% sulphur fuels as the FSN, while the FSN measured higher BC emissions for the GtL and HFO fuels. For DMA, both instruments agreed well. The FSN data showed a slightly higher scattering than the PAS data and the reproducibility was slightly higher for the PAS instrument.

22 The measurement study has demonstrated that the combustion of fuels with higher aromatic content emits higher concentrations of BC. New hybrid fuels with 0.50% sulphur content used in the study contained a high proportion of aromatic compounds in a range of 70% to 95%, which resulted in increased BC emissions in a range of 10% to 85% compared to HFO and in a range of 67% to 145% (a factor of 2.45) compared to DMA.

23 The results of this measurement campaign imply that it is necessary to implement aromatic content, or H/C ratio, in the specification of marine fuels of the ISO 8217 petroleum standard. This would enable a better qualification of marine fuels with respect to their environmental performance in terms of BC emissions and benefit their characterization for ignition and combustion quality. It is suggested that the International Organization for Standardization review ISO 8217 to include specifications taking into account these results.

Action requested of the Sub-Committee

24 The Sub-Committee is invited to note the information contained in this document and to take action as appropriate.

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