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INFLUENCE OF FUEL QUALITY ON BLACK CARBON EMISSIONS IN THE ARCTIC REGION CAUSED BY INTERNATIOAL SHIPPING

Comments to discussions at IMO by WG5

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The International Council
on Combustion Engines

Conseil International
des Machines a Combustion

Contents

1 FOREWORD

Discussions have started up at IMO about the need and potential for restricting black carbon (BC) emissions in the Arctic region caused by international shipping.

Especially regarding switch of fuel quality – from residual fuel (HFO) to low sulphur distillate fuel (LFO) – as a measure for reducing black carbon emissions from ships, various contradictory opinions have been expressed. Some investigators are stating that switching to LFO (from HFO) would be an efficient measure to reduce black carbon emissions but many others are of the opinion that this measure would not have any significant effect.

In 2012 CIMAC Working Group 5 "Exhaust Emissions Control" (WG 5) published the document "Background information on Black Carbon Emissions from Marine and Stationary Diesel Engines – Definition, Measurement Methods, Emission Factors and Abatement Technologies". The conclusion in this document is that "switching to low sulphur and distillate fuel will typically not result in reduced black carbon emissions". This conclusion was based on real measurements and evaluation of existing literature data.

At the IMO BLG 16 meeting in January 2012 a presentation was made by Dan Lack from The National Oceanic and Atmospheric Administration & University of Colorado, concluding that "black carbon emissions drop by at least 50% when switching from low to high quality fuels" i.e. switching from HFO to LFO.

As the conclusion made by Dan Lack is different from that of CIMAC Working Group 5 publication, this CIMAC document was prepared by WG 5 providing comments to Dan Lack´s presentation.

CIMAC Working Group 5 comments to the presentation by Dan Lack on "Fuel Quality and Black Carbon from Ships" given on 31st January 2012 during the IMO BLG 16 meeting in London

Author´s reference article: Atmospheric chemistry and Physics (ACPD) article DOI:10.5194/acpd-12-3509-2012: Lack, D.A. & Corbett, J. J. "Black Carbon from Ships: A Review of the Effects of Ship Speed, Fuel Quality and Exhaust Gas Scrubbing, Atmos. Chem. Phys. Discuss., Under Review, 2012.

2 "Define Fuel Quality" – comments to page 5 in the presentation

Statements about sulphur: "*Sulfurous organic compounds can lower combustion quality*" and about ash: "*Quench sites in flame*".

According to the reference article[1)] these claims refer to ABS notes[2)] on residual fuel (HFO). However, the ABS summary document (from year 1984) contains neither references nor results supporting this claim.

Although sulphur in fuel lowers the energy content of the fuel, we do not agree that sulphur would lower the combustion quality in large diesel engines designed for HFO operation. Several scientific studies are showing that metal components (ash in HFO) lower the oxidation temperature of soot / elemental carbon. Actually there exist commercial products utilizing metal additives for lowering the soot oxidation temperature and also several manufacturers of metal based fuel additives/combustion catalysts which are said to improve combustion and ensure more complete combustion of carbon.

3 "BC Emission Factors and Fuel Quality – All Studies" – comments to page 7 in the presentation

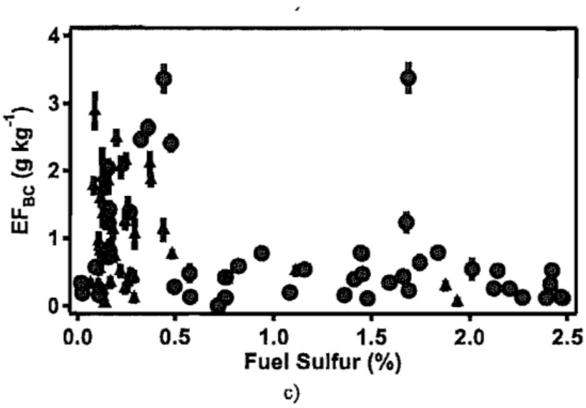
The 19 points presented in the table represent 5 different engines. 10 points out of the 19 represent a single one-cylinder research engine (Petzold et al. [3)]). 8 out of the 19 are comparisons between HFO and biogenic fuels.

Biodiesels (FAME fuels / bio-oils) can contain metals that potentially lower the oxidation temperature of soot. The chemical composition of biogenic fuels is different from hydrocarbon fuels. This is why biogenic fuels should not be used as a substitute for LFO in the comparison.

In the Petzold et al. [3)] study soya bean and sunflower oil produce higher EC emission than HFO at 75 % load. At 100 % load sunflower oil produces the highest EC emission while operation on soya bean is shown to result in slightly lower EC emission compared to HFO – table 3 in the Petzold et al. [3)] study.

HFO measurement was done only once in the study by Petzold et al. [3)], therefore in case of an error, it is "multiplied" in this kind of comparison and biasing the outcome conclusion.

Data presented in table 7 (page 7) appears to be contradicted by data presented separately by the same author in another publication i.e. Lack D., Corbett J.J. et al 2009 "Particulate emissions from commercial shipping: Chemical, physical and optical properties" published in Journal of Geophysical Research (doi: 10.1029/2008JD011300) 4) from where the graph below is copied. The abstract says: "We characterize particulate emissions on the basis of chemical, physical, and optical properties from commercial vessels. Observations during the Texas Air Quality Study/Gulf of Mexico Atmospheric Composition and Climate Study 2006 field campaign".



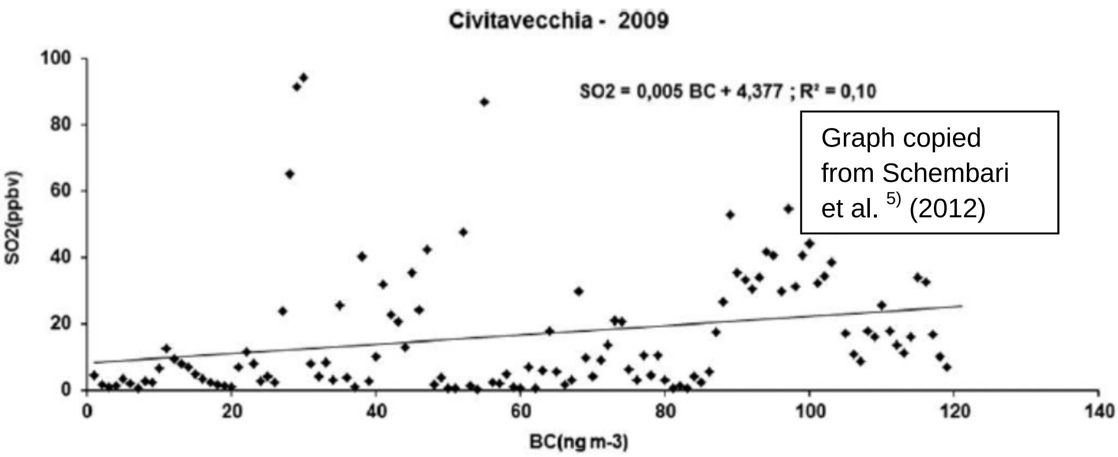
Graph copied from Lack et al 2009 [4)]

Figure 5. Comparison of (a) SO_4^{2-}, (b) OM, and (c) BC with fuel sulfur content. Circles indicate SSD vessels, and triangles indicate MSD vessels. (SO_4^{2-} slope = 1.4, Int = 0.05, and R^2 = 0.71. OM slope = 0.65, Int = 0.5, and R^2 = 0.62.)

On the contrary to the limited number of data shown in the presentation (page 7), the graph above is representing several different engines and fuel types.

The above graph does not indicate that BC emissions would be reduced as a function of fuel sulphur content. This graph does not support the claim on page 9: *"Majority of Literature data shows: A shift from low to high quality fuel leads to a decrease in BC emissions"* and neither the claim on page 2 "*An overview of all literature available*". For some reasons the presenter has disqualified own data showing opposite trends.

Schembari et al. (2012) "Impact of a European directive on ship emissions on air quality in Mediterranean harbours" ;http://dx.doi.org/10.1016/j.atmosenv.2012.06.047, Atmospheric Environment [5)], is stating that: "While SO_2 was decreased 66% by daily means, neither NOx or BC were changed significantly in EU harbours due to EU directive limiting FSC to 0.1%". The graph below is from the same source. We notice only very weak correlation between SO2 and black carbon emissions.



Graph copied from Schembari et al. [5)] (2012)

In the CIMAC publication "Background Information on Black Carbon Emissions from Large Marine and Stationary Diesel Engines – Definition, Measurement Methods, Emission factors and Abatement Technologies, January 2012"[6)] real measured data from large diesel engines operating on HFO and LFO/MDO are presented and no clear difference between HFO and LFO/MDO in terms of BC/EC emissions could be noticed.

Conclusion: Literature data does not support the claim that shift to LFO/MDO from HFO would reduce BC emissions.

4 “BC Emission Factors and Fuel Quality – All Studies” – comments to page 9 in the presentation

Statement “*Majority of Literature data shows: A shift from low to high quality fuel leads to a decrease in BC emissions”*

A lot of the author´s own previously published data along with other published data not supporting this statement, are missing from the study. See comments to page 7 above. On the contrary literature data does not support the claim that shift to LFO/MDO from HFO would reduce BC emissions.

5 “BC Emission Factors and Fuel Quality – What about the data >1?” – comments to page 10 in the presentation

As stated in the reference article[1)], “*irregularities highlight the importance of careful measurement protocols*” it should be kept in mind that optical methods can be affected by other substances than black/elemental carbon e.g. amount of condensable compounds, depending on humidity/temperature.

Further, it is necessary to discuss the absorption enhancement that is caused by condensed material on top of the carbon core. This effect is studied in the scientific literature e.g. by Lack D.A. and Cappa C.D. (ACP doi:10.5194/acp-10-4207-2010) [7)] (see below on left) and Shiraiwa et al. (Aerosol science & technology 2010 ; DOI: 10.1080/02786820903357686) [8)] (see below on right). Shiraiwa et al obtained a factor of 2 as maximum enhancement factor for absorption as a result of coating.

As HFO originated BC particles have significant amounts of condensable material on the surface, it is likely that BC particles emitted from HFO operation have enhanced light absorption, already at fresh emission, compared to same size/mass of BC core emitted from LFO combustion.

Conclusion: Difference between the results is due to different measurement methods.

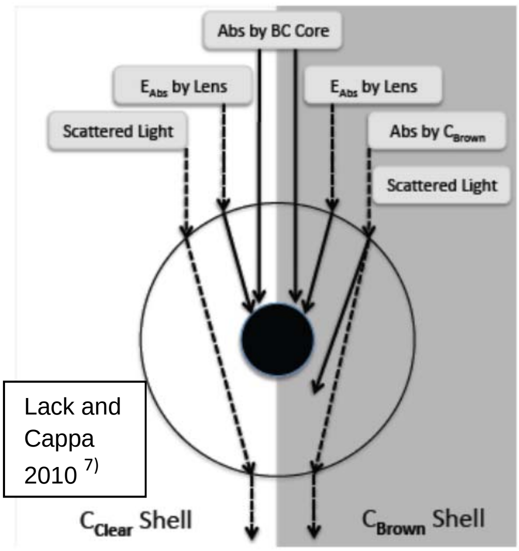
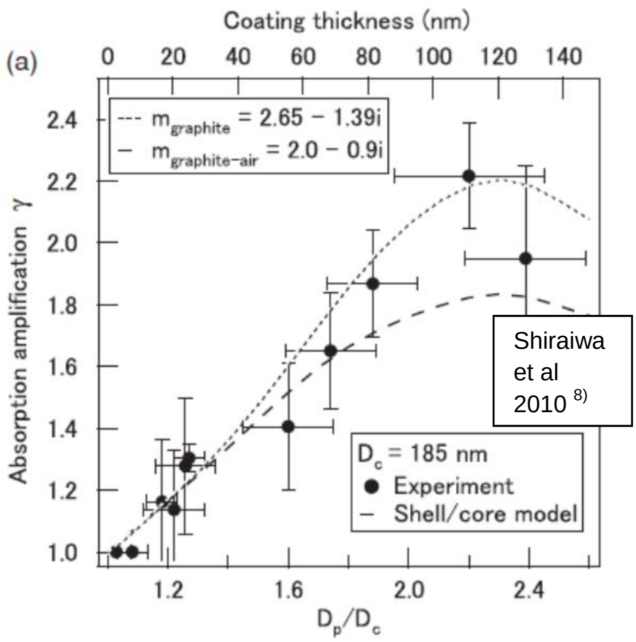
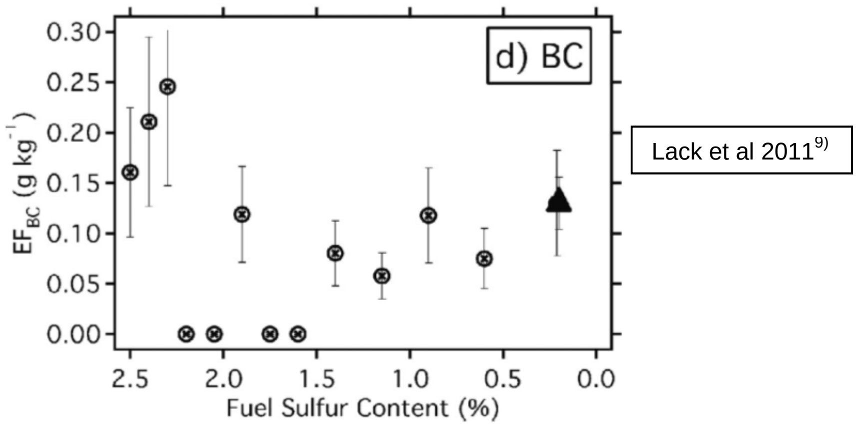


Fig. 1. Schematic of the effect of C_{Clear} and C_{Brown} shells on BC absorption.



6 "BC Emission Factors and Fuel Quality - Field Measurements" – comments to pages 13 and 14 in the presentation

The BC emission factors from a single engine operating on different fuel sulphur levels e.g. from Lack et al. 2011 [9)] (graph below) should also be plotted on the same chart for comparison. Compared to the data shown in the presentation by D. Lack, the BC emission level in graph below (Lack et al 2011) is 75% lower (0.1g/kg fuel vs. 0.4g/kg fuel) and there is, again (as in graph in Lack & Corbett et al 2009 [4)], see comment to page 7), very little change in BC emission due to fuel sulphur, at least up to 2 w-% fuel sulphur. From the fuel sulphur effect point of view the data in Lack & Corbett et al 2009 (shown above) agrees with Lack et al 2011 (shown below) but is in disagreement with the data shown in the presentation by D. Lack.



7 "BC & Fuel Quality Summary" – comments to page 15 in the presentation

In the data presented, there is significant reliance on one single cylinder test engine rather than a more representative multicylinder engine. Of the unfiltered data set, 10 out of 19 are from one single cylinder test engine. Similar bias is regarding fuels – HFO is compared against biogenic fuels. From the unfiltered dataset 8 points out of 19 are comparisons between HFO and biogenic fuels (measured with one single cylinder test engine) – biogenic fuels which are not a feasible alternative to HFO use and differ also chemically from fossil fuels.

The claim that "..using all measurements found in literature.." is misleading, as for example Lack et al. 2011 [9)] and 2009 [4)] data (presenter´s own published data) are excluded and those results show no clear influence of fuel quality on BC.

In the CIMAC publication "Background information on Black Carbon Emissions from Large Marine and Stationary Diesel Engines – Definition, Measurement Methods, Emission factors and Abatement Technologies, January 2012"[6)] real measured data from large diesel engines operating on HFO and LFO/MDO are presented and no clear difference between HFO and LFO/MDO in terms of BC/EC emissions could be noticed.

8 "Regulation of Fuel Quality" – comments to page 16 in the presentation

Statement: *"From this data we can say a fuel with less a) sulphur and b) ash and c) large molecular weight hydrocarbons emits less BC"*

This statement is not supported by data found in the literature. The data set reviewed by the presenter is incomplete.

9 "Fuel Quality in the Arctic" – comments to page 17 in the presentation

Discussion is missing about the cooling effect of sulphates and the small contribution of shipping to BC emissions.

Quote from Eyring V., Isaksen I., Berntsen T., Collins W., Corbett J., Endresen O., Grainger R., Moldanova J., Schlager H., Stevenson D. (2010) "Transport impacts on atmosphere and climate: Shipping" Atmospheric Environment 44 (2010) 4735–4771 (doi:10.1016/j.atmosenv.2009.04.059) [10)] on **shipping impact** on global warming: "*The CO2 equivalent emissions using the global temperature change potential (GTP) metric indicate that after 50 years the* ***net global mean effect of current emissions is close to zero through cancellation of warming by CO2 and cooling by sulphate and nitrogen oxides****.*" By changing from high sulphur fuels to low sulphur distillates, this cooling effect is taken out.

Another quote from Lack et al 2008 (doi:10.1029/2008GL033906) [11)], also cited in the presentation : "*Shipping fuel consumption data (2001) was used to calculate a global LAC (light absorbing carbon) contribution of 133(+-27)Gg/yr, or* ***1.7% of global LAC***" The 1.7% of global LAC is calculated using emission factor of 0.4g/kg fuel and 75% lower emission factors (0.1g/kg fuel) have also been published (Lack et al 2011)[9)] for high sulphur fuels.

10 References

[1] Lack, D.A. and Corbett, J.J.: "Black Carbon from Ships: A Review of the Effects of Ship Speed, Fuel Quality and Exhaust Gas Scrubbing, Atmos. Chem. Phys. ,12, 3985-4000, doi:10.5194/acp-12-3985-2012

[2] ABS notes on HFO (1984)

[3] Petzold, A., Lauer, P., Frische, U., Hasselbach, J., Lichtenstern, M., Schlager, H., and Fischer, F. "Operation of Marine Diesel Engines on Biogenic Fuels: Modification of Emissions and Resulting Climate Effects, Environ. Sci. Technol., ASAP, 10.1021/es2021439, 2011"

[4] Lack D., Corbett J.J. et al 2009 "Particulate emissions from commercial shipping: Chemical, physical and optical properties" published in Journal of geophysical research (doi: 10.1029/2008JD011300)

[5] Schembari, C., Cavalli, F., Cuccia, E., Hjorth, J., Calzolai, G., Noemi, P., Pey, J., Prati, P., Raes, F.: "Impact of a European directive on ship emissions on air quality in Mediterranean harbours", Atmospheric Environment, Volume 61, December 2012, Pages 661-669, ISSN 1352-2310, 10.1016/j.atmosenv.2012.06.047

[6] Cimac publication "Background information on Black Carbon Emissions from Large Marine and Stationary Diesel Engines – Definition, Measurement Methods, Emission factors and Abatement Technologies, January 2012"

[7] Lack, D.A. and Cappa, C.D. : "Impact of Brown and Clear Carbon on Light Absorption Enhancement, Single Scatter Albedo and Absorption Wavelength Dependence of Black Carbon", Atmos. Chem. Phys., 10,4207-4220, doi:10.5194/acp-10-4207-2010)

[8] Shiraiwa et al. "Amplification of Light Absorption of Black Carbon by Organic Coating, Volume 44, Issue 1, 2010, Aerosol Science and Technology ; doi: 10.1080/02786820903357686)

[9] Lack et al. 2011: "Impact of Fuel Quality Regulation and Speed Reductions on Shipping Emissions: Implications for Climate and Air Quality; dx.doi.org/10.1021/es2013424; Environ. Sci. Technology 2011, 45, 9052-9060

[10] Eyring V., Isaksen I., Berntsen T., Collins W., Corbett J., Endresen O., Grainger R., Moldanova J., Schlager H., Stevenson D. (2010) "Transport impacts on atmosphere and climate: Shipping" Atmospheric Environment 44 (2010) 4735–4771; doi:10.1016/j.atmosenv.2009.04.059)

[11] Lack. D., Lerner, B., Granier, C., Baynard, T., Lovejoy, E., Massoli, P., Ravishankara. A.R., Williams, E., 2008: " Light Absorbing Carbon Emissions from Commercial Shipping" Geophys. Res. Lett., 35, L13815, doi:10.1029/2008GL033906