Black and organic carbon emissions from marine (medium speed) diesel engines

Jyrki Ristimäki[§], Maija Lappi*
[§] Wärtsilä Finland Oy, Järvikatu 2-4, 65101 Vaasa, Finland , jyrki.ristimaki@wartsila.com
* VTT, Biologinkuja 5, 02150 Espoo, Finland

In addition to green house gases, reduction of short lived climate forcers - especially black carbon (BC) emissions has gained more attention as possible measure to limit global warming. To ensure that most efficient steps are taken, correct input data is needed for BC emissions. Currently there is a lack of data and e.g. a significant discrepancy exists between BC emission factors used for ships and what is measured in laboratory. Some emission factors for BC reported in literature [1] are 200-900% higher than what are measured in laboratory (Figure 1) although some lower estimates can also be found [2]. Such large deviations in the emission values can cause significant biases in the calculation of cost effectiveness of BC emission reduction.

Wärtsilä Vasa 4R32 LN (production year 1995) engine was run with 3 different fuels (LFO, HFO1 and HFO2) on 5 different steady state load points (100%, 75%, 50% 25% and 10%) at constant speed. Fuel sulphur levels were <0.05, 0.89 and 2.42 w-% respectively. Filter samples were taken according to ISO8178 measurement standard and elemental- (EC) and organic carbon (OC) was determined with Sunset laboratories instrument.

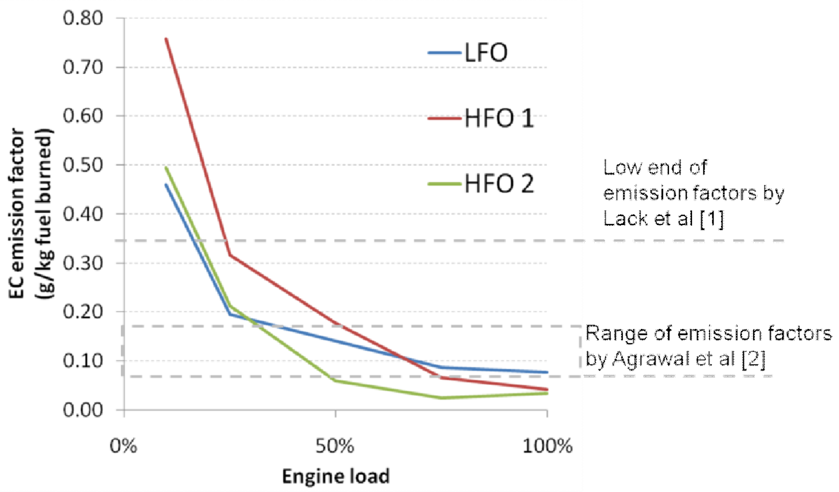

Figure 1 Elemental carbon emissions per fuel burned as a function of engine load with 3 different fuels.

An alternative estimation for BC/EC emission was made with the help of widely used filter smoke number (FSN) measurement. For diesel engines, there is a correlation curve for FSN and soot (BC) concentration in exhaust [5]. Assuming fuel consumption of 200g/kWh and specific exhaust flow of 7.5kg/kWh a relation between FSN value and BC/soot emission can be calculated (presented in poster). As FSN values in our engine tests were below 0.4 with all fuels and loads above 50% load, the soot/BC emission is lower than 0.2g/kWh. The estimate of emission factors below 0.2g/kWh is in good agreement with the EC emission factor (Figure 2) although the approach to calculate the emission is totally different.

In order to get an idea of the specific BC emission level of high efficiency marine diesel engine, a comparison to high speed vehicle engine specific particulate matter (PM) emission is made (Figure 2). This comparison is justified by the fact that with after-treatment and ultra low sulphur fuel, vehicle PM consists mainly (>70%) of soot/BC [3] whereas most of the PM emission from marine medium speed engine running on marine fuel is something else than BC [4]. BC emission comparison reveals that specific BC emission of medium speed engine at high load are below EURO IV emission level of heavy duty vehicles. Therefore the common flaw in the mindset that modern ship engines are high BC emitters should be abandoned. It should be kept in mind that smoke visibility (opacity) depends highly on the exhaust diameter. With the same black carbon concentration as in vehicle exhaust, ship plume has significantly higher opacity and visibility.

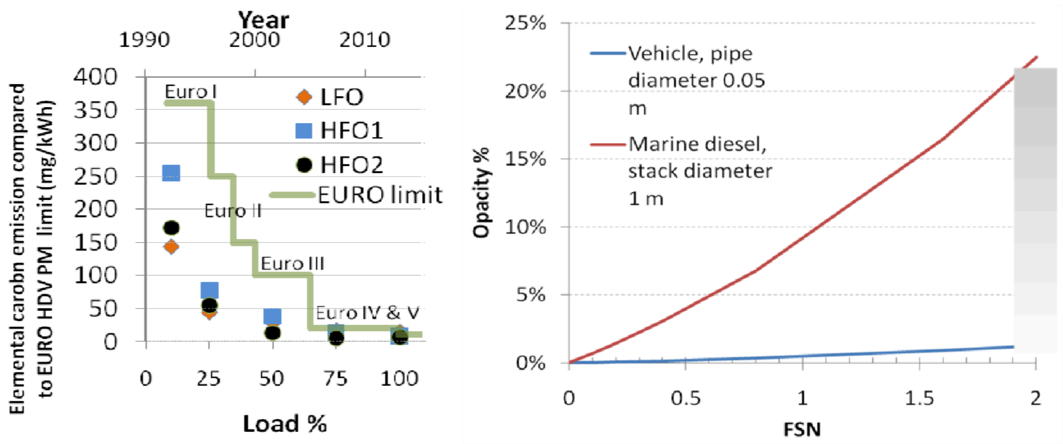

Figure 2 Comparison of specific BC emission from marine medium speed diesel engine to heavy duty vehicle emission levels (left) and comparison of smoke visibility as a function of FSN (right).

In the search for best measures to minimize the contribution of shipping to global warming, it should be kept in mind that oceangoing vessels still use high sulphur fuels, which results in net cooling effect on climate [6] and this is about to change with the forthcoming global limitations for fuel sulphur. Additionally, as the chemical analysis of marine medium speed diesel PM reveal that OC/EC ratio is high and recent peer reviewed report on BC emission by EPA [7] suggests that the mitigation strategies of PM should focus on BC emission sources having high BC to OC ratio, it is surprising that ship BC emissions are ranked high in some lists of measures to limit global BC emissions.. Finally it should be kept in mind that even with the 200-900% overestimated BC emissions, shipping is responsible only ~2% of global light absorbing carbon emission [1].

References

[1] Lack D., Lerner B., Granier C, Baynard T., Lovejoy E., Massoli P., Ravishankara A.R., Williams E (2008) "Light absorbing carbon emissions from shipping" Geophysical research letters 35 ; LI13815
[2] Agrawal H., Malloy Q.J., Welch W.A., Miller J.W., Cocker III D.R.(2008" In-use gaseous and particulate matter emissions from a modern ocean going container vessel", Atmospheric environment 42 5504-5510
[3] Burtscher H. (2005) Physical characterization of particulate emissions from diesel engines: A review ; Journal of Aerosol Science 36 7 896-932 2005 Figure 5
[4] Ristimäki J., Hellén G., Lappi M. (2010) Chemical and physical characterization of exhaust particulate matter from a marine medium speed diesel engine CIMAC paper NO,:73 CIMAC congress 2010 Bergen[
[5] SMOKE VALUE MEASUREMENT WITH THE FILTER-PAPER-METHOD. Application notes of AVL FSN meter. www.avl.com
[6] Fuglestved J., Berentsen T., Eyring V., Isaksen I., Sausen B. (2009) Shipping emissions: From cooling to warming of climate – and reducing impacts on health, Environmental Science & technology 43 9057-9062
[7] US-EPA (March 2011) Report to congress on Black carbon, External peer Reviewed Draft Page ex-6 www.epa.gov

Black and organic carbon emissions from marine (medium speed) diesel engines

Jyrki Ristimäki[§], Maija Lappi*
[§] Wärtsilä Finland Oy, Järvikatu 2-4, 65101 Vaasa, Finland
* VTT, Biologinkuja 5, 02150 Espoo, Finland

Background:

Reduction of short lived climate forcer emissions - especially black carbon (BC) have gained more attention as one possible measure to limit global warming. The urgency of actions to limit global warming needs accurate knowledge on BC emissions: sources and composition of exhaust as a whole. Marine BC emissions especially have gained significant attention in a discussion of measures to hinder melting of arctic ice.

Methods:

Wärtsilä Vasa 4R32 LN (E), production year 1995, was operated on a test bed at VTT with 3 different fuels and 5 different loads (10-100%): One light fuel oil (LFO) and two heavy fuel oils (HFO).

Table 1 Fuel specifications used during tests

Parameter \ Fuel	LFO	HFO1	HFO2
S w-%	<0.05	0.89	2.42
Ash	<0.01	0.02	0.07

Particulates were sampled & collected according to ISO8178 method and classification to organic (OC) and elemental carbon (EC) was performed with Sunset Laboratories instrument.

Results:

Measured black carbon emission factors shown below are significantly below the values reported by Lack et al. [1] with all the fuels tested. However, our values agree rather well with the values reported by Agrawal et al. [2]. Additionally, it should be noted that the black carbon emission is lowest with residual fuel having the highest sulphur and ash content.

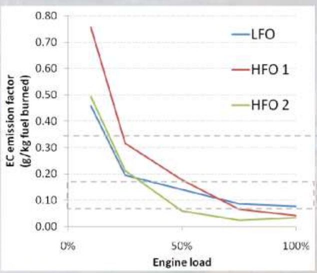

Figure 1 Elemental carbon emissions per fuel burned as a function of engine load with 3 different fuels.

Due to the high sulphur fuels and lack of diesel oxidation catalysts, particulate mass emission from marine engine is higher than emissions from vehicles running on ultra low sulphur fuels.

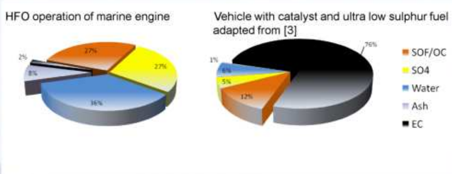

Figure 2 Chemical composition of particulate emission of marine engine running on heavy fuel oil and motor vehicle running on ultra low sulphur diesel

However, it should be noted that the BC emissions in figure 2 are practically equal in terms of specific emission. This can be seen by comparing specific BC emission from ship engine to vehicle particulate mass emissions limits, which consist practically only BC (figure 3). It should be noted that high efficiency ship engines can reach even below EURO IV PM emission levels for heavy duty vehicles if only BC is considered [4].

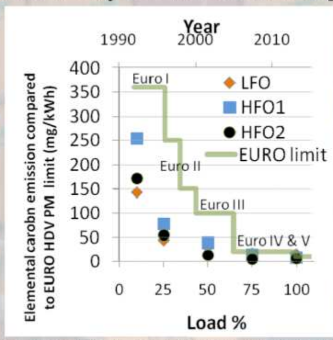

Figure 3 Comparison of specific BC emission of medium speed diesel to particulate mass emission limits for heavy duty vehicles.

Alternative approach to estimate BC emission level can be calculated from filter smoke number (FSN). A correlation curve between FSN and (diesel) soot/BC emission is provided by the instrument manufacturer [5]. Assuming fuel consumption of 200g/kWh for high load and specific exhaust flow of 7.5 kg/kWh, a following graph can be calculated for dependence of BC emission on FSN. This rough estimation provides baseline for estimation of BC emission factor directly from FSN measurement.

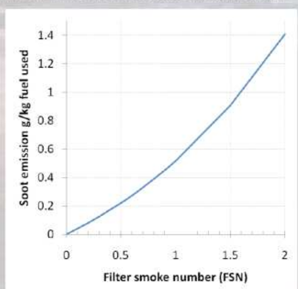

Figure 4 Estimation of BC emission per fuel burned directly from FSN measurement

As the FSN values above 50% engine load were below 0.4 [4] the soot emission is well below 0.2 g/kg fuel burned.

Particle number distributions reveal that FSN correlates with particle concentrations above 70nm diameter. This could imply that particles larger than 70nm are made of soot whereas particles below this size consists more of ash and volatile compounds.

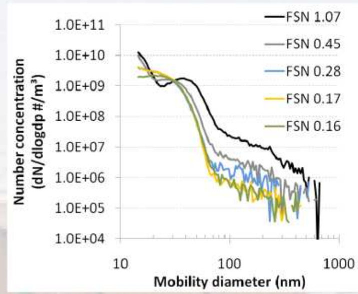

Figure 5 Particle number distributions from HFO1 operation

Conclusion:

Measured BC emissions from marine medium speed diesel engine were lower than typical literature references. This suggests that the costs of mitigation efforts in €/ton are currently underestimated.

Health driven particle matter reduction targets are not necessarily congruent with efforts to limit global warming. Recent peer reviewed report by EPA suggests that the mitigation strategies of PM should focus on BC emission sources having high BC to OC ratio [6]. Current marine engines have high OC to BC ratio. Finally it should be kept in mind that even with probably 200-900% overestimated BC emission, shipping is responsible only about 2% of global light absorbing carbon emission [1].

References:

[1] Lack D., Lerner B., Granier C, Baynard T., Lovejoy E., Massoli P., Ravishankara A.R., Williams E (2008) "Light absorbing carbon emissions from shipping" Geophysical research letters 35 ; LI13815

[2] Agrawal H., Malloy Q.J., Welch W.A., Miller J.W., Cocker III D.R.(2008" In-use gaseous and particulate matter emissions from a modern ocean going container vessel", Atmospheric environment 42 5504-5510

[3] Burtscher H. (2005) Physical characterization of particulate emissions from diesel engines: A review ; Journal of Aerosol Science 36 7 896-932 2005 Figure 5

[4] Ristimäki J., Hellén G., Lappi M. (2010) Chemical and physical characterization of exhaust particulate matter from a marine medium speed diesel engine CIMAC paper NO,:73 CIMAC congress 2010 Bergen[

[5] SMOKE VALUE MEASUREMENT WITH THE FILTER-PAPER-METHOD. Application notes of AVL FSN meter. www.avl.com

[6] US-EPA (March 2011) Report to congress on Black carbon, External peer Reviewed Draft Page ex-6 www.epa.gov

Acknowledgements: The investigation was performed by Wärtsilä in cooperation with VTT Technical Research Centre of Finland and was partly financed by Tekes – the Finnish Funding Agency for Technology and Innovation.

VTT

WÄRTSILÄ