Emissions from a Marine Engine Operating on Different Fuels and Engine Conditions

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Worldwide, between 80 and 90% of the global trading volume is moved by ships, while the vast majority of the ships engines is operated on heavy fuel oil (HFO) which features high contents of sulphur, nitrogen and heavy metals. In 2008, the Marine Environmental Protection Committee (MEPC) of International Maritime Organisation (IMO) decided to reduce the sulphur content of marine fuels to generally 0.5 % (from 2020 on) and 0.1% in sulphur emission control areas (SECA, from 2015 on). One the one hand, ship owners can continue to burn HFO if they install sulphur scrubbers as exhaust after treatment. One the other hand, ships can operate on distillate fuels, such as marine gas oil (MGO), with fuel sulphur content (S) of the required 0.1%. The most economic solution is determined by the spread of the prices for HFO and MGO. For a new-build scrubber system, the spread must be lower than 231 €/t fuel to economically explain the usage of MGO (Jiang 2014), which is nowadays the case.

The primary and secondary emissions of a bench-scale marine engine (nominal power of 80 kW), fuelled with HFO (2.3 % S), MGO (0.08 % S) and ultra-low sulphur B7 diesel (ULSD; <15 ppm S) at several conditions (diverse engine loads of 11, 25, 50, 75 and 100 %; injection times, injection pressures) were studied by laser-based time-of-flight mass spectrometry (TOFMS) with single-photon ionisation (SPI) at 118 nm and resonance-enhanced multi-photon ionisation (REMPI) at 266 nm (Hanley & Zimmermann 2009) as well as an aerosol mass spectrometry (AMS) and ABB gas analysers.

Applied fuels and engine loads did not affect the emission of NO_x, ranging between 25 and 45 g/kg fuel, whereas emission factors (EF) of SO_2 were directly proportional to the fuel sulphur content and consumption. EFs of total hydrocarbons (THC) revealed the most complex behaviour concerning the dependence on fuel and engine load: For all fuels, highest emission of THC was observed at 11 % load whereas HFO led to the overall highest emission.

Regarding gas-to-particle conversion as essential mechanism for secondary organic aerosol formation (SOA), the volatile organic compounds (VOC) in the primary emission play a key role for an assessment of the total influence of ship traffic to the atmosphere. In HFO as well as both distillate fuels homologue series of alkylated benzenes and naphthalenes, carbonyls, alkanes and (poly)unsaturated hydrocarbons were observed. Consistent with THC gas analysis, highest volatile emissions appeared apart from 11 % during engine operation with MGO, in particular for m/z of alkylated naphthalenes, phenanthrenes, alkenes and dienes, which are all main ingredients of diesel-like fuel, supporting the hypothesis that unburned fuel is the main contributor to the total organic emission (Sippula 2014) in the gas phase as well. Organic sulphur-containing species were less abundant in the VOC fraction because the sulphur content of the fuels usually increases with its boiling point. Thus, among its conversion into SO_2, organic sulphur emissions are enriched in the particulate phase.

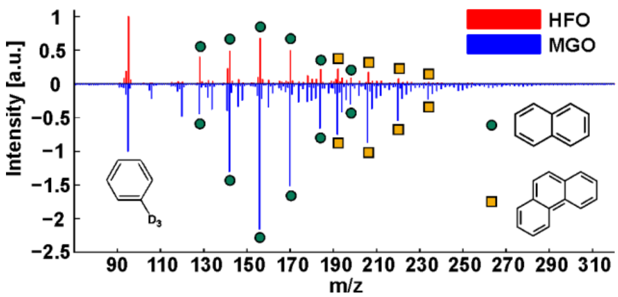

Figure 1. REMPI spectrum of HFO (up) and MGO (down) emission normalised to internal standard of D_3-toluene (equal to 3 ppmv)

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