Emissions from HFO combustion in a ship research engine and associated secondary organic aerosol formation potential
Imad El Haddad – Paul Scherrer Institut
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Maritime transport globally important:
>200 Mio Tons of fuel per year
(21% of the total global fuel consumption)

Substantial contribution anthropogenic PM:
coastal regions up to 50%, but little is known

No stringent regulations:
- Heavy fuel oil (HFO):
  used mainly on open ocean (170 Mio. Tons)
  high sulfur content (limit 3.5%)
- Marine gas oil (MGO):
  used in controlled areas/harbors (43 Mio. Tons)
  less viscous low sulfur content (limit 1%)
HFO emissions: heavy metals and PAHs
MGO emissions: elemental carbon (soot)
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HFO emissions: induce oxidative stress and inflammatory reactions
MGO emissions: genotoxic; affect protein synthesis and mitosis
Only a minor fraction of the organic aerosol emissions is identified...
Ship emissions overview

Sippula et al., EST, 2014

Equilibrium partitioning ($P_V$ or $C_{sat}$)

Emission and atmospheric transformation

VOC
POA
EC (soot)
CO, CO$_2$
Ship emissions overview

Sippula et al., EST, 2014

Emission and atmospheric transformation

VOC

OH

CO,

CO₂

POA

EC (soot)

SOA
Study emissions from ship engines run on HFO and MGO

⇒ Volatility and partitioning
⇒ Reaction rates and atmospheric lifetimes
⇒ SOA potential (possibly with health implications)
Emission measurements at PSI

Mobile chamber

Cool chamber (down to -20°C)

PAM (fast aging)

Platt et al., 2013; Bruns et al., 2014

Biomass burning

Cooking

Road vehicles

Aircraft engines

Biogenic emissions

El Haddad et al., in prep; Klein et al., in prep

Platt et al., 2013, 2014; Zardini et al., 2014

Bruns et al., 2014

Platt et al., 2013; Bruns et al., 2014
Project overview: WOOSHI

*Pieber et al., in prep*

HelmholtzZentrum münchen
Deutsches Forschungszentrum für Gesundheit und Umwelt
Experimental setup 1/2

- 4-stroke single cylinder research engine
- can simulate operation of different modern engines
- operated with HFO and MGO
- operated at cruising conditions (50%)

Setup at the University of Rostock
Experimental setup 2/2

10 m³ mobile chamber with UVA lights

Ejector Dilutor (1:10) 150°C

Ship engine

Dilution

Online instruments

Online gas-phase instruments (CO₂, CO, CH₄, NOₓ, SO₂, PTR-ToF-MS/VOC)

Online aerosol-phase instruments (AMS, CHARON-PTR-ToF-MS/VOC, SMPS-APM, Aethalometer, SP2)

Volatility examination

(1) Dilution
(2) Heat
(3) Chemical composition

Thermodenuder

Offline samples (Filters, sorption tubes)
Example

- **In chamber enrichment**
- **Thermodenuder tests**

- Decay due to losses to the chamber walls
- Reference («Bypass»)
- In chamber dilution...followed by photochemistry experiments

Mass calibration factors not yet entered

Date and Time

AMS UMR PM1 (µg/m³)

0 10 20 30 40 50 60 70 80 90 100 110 120 130 140

02.12.2014

16:00 17:00 18:00 19:00 20:00 21:00 22:00

T1 T2 T3
Response to dilution

OA emission factors [g kg\(^{-1}\) fuel]

$C_{OA}$ [µg m\(^{-3}\)]
Response to heat

The graph shows the response of different temperatures on the number concentration (dN/dlog(Dp)) in cm⁻³ as a function of the particle size (Dp) in nm. The temperatures studied are T = 45°C, T = 60°C, and T = 80°C. The graph includes references for various conditions, such as Ref #1 T = 25°C, Ref #2 T = 25°C, and Ref #3 T = 25°C, among others.
Response to heat

HFO
MGO

50% at ~60-90°C

⇒ Similar behavior as lub-oil
⇒ HFO less volatile than MGO

Grieshop et al. ACP 2009
Most of the compounds are estimated to be semi-volatile (consistent with C_{20}-C_{25} alkanes)
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At atmospherically relevant concentrations (1-10 µg/m³), half-lifes shorter than 1 day