MEASUREMENTS OF MARINE VESSEL EMISSIONS

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INTRODUCTION

Nitrogen and sulfur emissions from large marine vessels are a significant source of these species to the atmosphere. Since approximately 70% of all ship emissions occur within 400 km of land, marine vessel emissions are important to air quality regionally in coastal areas and locally in ports. Surface plumes depend on the sulfur content of fuel and nitrogen emissions depend on the vessel engine type. In emission inventories MVE are calculated from fuel usage and the engine type. The last available emission factors come from a Lloyd’s Register of Shipping sponsored emissions research program. Measurements were made using a network of fixed and moving observation sites, bench tests and from in-service marine vessels directly. In the marine environment the size and shape of the ship and the significance of MVE suggests that additional evaluations of emission factors be conducted. During the 2002 New England Air Quality Study (NEAQS) measurements were made of MVE off the east coast of the U.S. This paper presents these results and relates them to current emission factor estimates.

The background during this encounter was relatively clean, so the plume from the ship exhaust stands out clearly. The fine structure in the data correlates well for all measurements except SO2, which is due to slower chemistry in the exhaust gas due to excess O2 (typically 10-15% excess) or a significant organic component to the particles which likely comes from the ship fuel oil.

The data traces are slightly offset for clarity. The plume transit times were estimated to be less than ~3% per hour at 2200 UTC and dropping to near 0% after 0030 UTC. Since there were no clouds or fog present during this time, which includes rapid liquid-phase conversion to soot, it is likely that a substantial fraction of the aerosol soot in the exhaust plumes was formed at the point of emission. Possible mechanisms for this are SO2 chemistry in the exhaust gas due to excess O2 (typically 10-15% excess) or heterogeneous SO2 conversion on the aerosol surface. There is also a need for more data to get a better estimate of the particles which likely comes from lubrication oil or unburnt fuel.

Marine Vessel Emission Characteristics

N emissions: Mostly from combustion (temperature dependent)
S emissions: from fuel S-content (typically <1% to 5% by weight)
C emissions: Virtually complete combustion!! (CO/CO2 << 1%)

Marine Vessel Propulsion Characteristics

High speed ferry: 35% of total fuel; ~80,000 vessels (~90% comm.)
low-grade residual fuel oils (‘bunkers’; high S content)
power: < 10 MW up to ~100 MW directly coupled to propeller shaft
Medium speed: 40% of total fuel; ~2,000,000 vessels (40% military)
uses residual or distillate fuels; power: < 10 MW diesel-electric (motor powers propeller shaft coupled via gears to propeller)
Steam turbine: ~5% of total fuel; ~5,000,000 vessels (70% military) uses distillate fuel (OIL; more expensive; steam generation drives turbine; powers prop)

Marine Vessel Emission Factors (per 1000 kg [tonne] fuel)

<table>
<thead>
<tr>
<th>Source</th>
<th>NOx (kg NOx/kg SO2)</th>
<th>SO2 (ppmv SO2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lloyd’s Register of Shipping, 1995</td>
<td>57 (MSD)</td>
<td>22 X (fuel wt. % S)</td>
</tr>
<tr>
<td>Marine Exhaust Emission Research Program</td>
<td>78</td>
<td>22 X (fuel wt. % S)</td>
</tr>
<tr>
<td>Emission Characterization Program</td>
<td>57 (MSD)</td>
<td>17</td>
</tr>
<tr>
<td>Port of Vancouver Marine Vessel</td>
<td>57 (MSD)</td>
<td>17</td>
</tr>
<tr>
<td>Report</td>
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</tbody>
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Emission Factors

Emission factors were calculated using the relationships shown above and the data below were calculated using the relationships shown above and the data above are 1 second measurements close to one. The fine structure in the data correlates well for all measurements except SO2, which is due to slower chemistry in the exhaust gas due to excess O2 (typically 10-15% excess) or a significant organic component to the particles which likely comes from the ship fuel oil.

Though the correlation between SO2 and CO2 is not as high as with NOx, the slope is sufficiently well-defined to provide an estimate of the amount of S emitted relative to CO2.

A Canadian tanker was encountered outbound from Portmouth, NH, on the morning of August 8th, 2002. The ship was sailing north, northwest at about 21 lts. The nearest approach of the tanker to Brown was about 3 nms, so the plume was about 9 minutes old when the measurements were taken.

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