Traffic emission factors of particle number measured in a street canyon in Stockholm, Sweden

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INTRODUCTION

- Road traffic is one of the major sources for particulate matter in urban areas. Some studies have shown that traffic exhaust particles have the adverse health effects due to their higher number and surface area to larger particles, and to their increased toxicity on a per mass basis (Nel, 2005).

- Emission factors (EFs), which are defined as the mass or number of an air pollutant emitted per vehicle and distance traveled or mass of fuel used, are widely used to characterize road traffic particle emissions.
INTRODUCTION

- In this work, a data analysis of the measurements of particle size number and in a congested urban street canyon, Stockholm, is conducted.

- One year measurements of particle number and traffic and meteorological data are used to estimate average particle number EFs by using an inverse modeling method.

- The size resolved particle number EFs for passenger cars (PC), medium-duty (MD) diesel trucks and heavy-duty (HD) buses are estimated by using multilinear regression.

- The results are compared to those of previously published values determined by similar method and conditions in recent years.
EXPERIMENTAL

- The first monitoring site: Hornsgatan street canyon, located in central Stockholm, Sweden, is a four lane street 24m wide, surrounded by 24 m high buildings on both sides.

- The second monitoring site: Rosenlundsgatan, corresponding to the urban background site, is located on the roof (25 m above the street level) of a building ca. 600 m southeast from Hornsgatan street.

- The measurements were simultaneously performed at two monitoring sites.
EXPERIMENTAL

- Monitoring station
- Traffic lights
EXPERIMENTAL

- The particle number concentration, at both street and background roof sites, was measured using identical Condensation Particle Counters (CPC TSI 3022) that has a lower cut-off size of 7 nm (PN7).

- The particle number size distribution measurements were conducted with differential mobility analyzer (DMA) coupled with a condensation particle counter (CPC TSI 3010).

- Distribution consisted of 16 size bins from 20 to 400 nm. Another size channel ($D_p \sim 10$ nm) was added by subtracting the integrated number concentration obtained with the DMA, from the total number concentration measured with the CPC 3022.
EXPERIMENTAL

- Meteorological parameters including wind speed, wind direction, temperature and relative humidity are also observed at roof level.
- For traffic, hourly mean values of categorized traffic volumes and speed were obtained from automatic counters at the street canyon site.
- According to the characteristic of urban vehicles in Stockholm, 
  - **PC**: vehicle with a wheel pair distance smaller than 5.0 m.
  - **MD**: vehicles with 5-10 m wheel pair distance, mainly being diesel powered trucks or vans
  - **HD**: larger 10 m distance vehicle, almost being ethanol powered public buses
RESULTS AND DISCUSSION

Traffic flow rate

- Hourly average of traffic flow rate measured during the measurement campaign. During working days, the average traffic volume per day was 32202 vehicles, and the fraction of PC, MD, and HD buses were 87.7%, 9.0% and 3.3%, respectively.
RESULTS AND DISCUSSION

Diurnal patterns of the concentrations for NOx, CO and PN₇

- The variation characteristic of the traffic source is clearly visible both on working days for the street concentrations and the difference street-roof with the morning rush hour peak and the broader afternoon rush hour.
RESULTS AND DISCUSSION

Average particle size distribution

- The maximum particle number concentrations are found in the sizes around 20 nm.

- At roof level, we found a rather wide maximum shifted to larger particle sizes in the range 20-100nm.
Averaged diurnal evolution of particle size distributions at Hornsgatan and the roof background and the difference street-roof
Estimation of PN emission factors

According to OSPM (the Operational Street Pollution Model) (Berkowicz et al. 1997), the average emission strength in a street canyon can be calculated as

\[ Q_h = q_h N_h = \frac{c_{h,\text{street}} - c_{h,\text{background}}}{F_h(\text{meteorology,traffic})} = \frac{c_{h,\text{diff}}}{F_h} \]

- \( Q_h \) is the emission density (pollutant m\(^{-1}\) s\(^{-1}\)); \( q_h \) is the EF (pollutant vehicle\(^{-1}\) m\(^{-1}\)); \( N_h \) is total traffic volume (vehicle s\(^{-1}\)); \( c_{h,\text{street}} \) and \( c_{h,\text{background}} \) are the concentrations measured in the street canyon and in the urban background (pollutant m\(^{-3}\)),

- \( F \) is dilution, factors, calculated by OSPM, (s/m\(^2\)), using the meteorological parameters and traffic flow data.
Estimation of PN emission factors

- For a specific hour, $h$, it is possible to estimate EFs for each categorized vehicle. The total emission density can be expressed as

$$Q_h = \sum_{k} N_{k,h} \times q_{k,h}$$

- Applying multiple regression analysis methods, the EFs for any type $k$ of vehicles can be determined as a solution of this linear equation system.
Estimation of PN emission factors

Emission factors for Particle number are obtained by using above equations

<table>
<thead>
<tr>
<th>Particle number</th>
<th>Vehicle type</th>
<th>Units</th>
<th>Coefficients</th>
<th>Std. Error</th>
<th>t Stat</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{PN}_{7-20\text{nm}}$</td>
<td>Total fleet</td>
<td>Particles veh$^{-1}$ km$^{-1}$</td>
<td>1.68E+14</td>
<td>6.18E+12</td>
<td>27.13</td>
<td>0.59</td>
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<td>$\text{PN}_{20-40\text{nm}}$</td>
<td></td>
<td></td>
<td>3.29E+14</td>
<td>6.62E+12</td>
<td>49.64</td>
<td>0.83</td>
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<tr>
<td>$\text{PN}_{40-100\text{nm}}$</td>
<td></td>
<td></td>
<td>9.19E+13</td>
<td>2.22E+12</td>
<td>41.33</td>
<td>0.77</td>
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<tr>
<td>$\text{PN}_{100-400\text{nm}}$</td>
<td></td>
<td></td>
<td>3.85E+13</td>
<td>1.53E+12</td>
<td>25.13</td>
<td>0.55</td>
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<tr>
<td>$\text{PN}_{&gt;7\text{nm}}$</td>
<td>PC</td>
<td></td>
<td>1.16E+14</td>
<td>6.45E+13</td>
<td>1.79</td>
<td></td>
</tr>
<tr>
<td></td>
<td>MD</td>
<td></td>
<td>2.78E+15</td>
<td>5.35E+14</td>
<td>5.19</td>
<td>0.86</td>
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<tr>
<td></td>
<td>HD(Buses)</td>
<td></td>
<td>9.76E+15</td>
<td>1.76E+15</td>
<td>5.56</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total fleet</td>
<td></td>
<td>6.27E+14</td>
<td>1.20E+13</td>
<td>52.06</td>
<td>0.84</td>
</tr>
</tbody>
</table>
RESULTS AND DISCUSSION

- The number EF for the fleet mix: \((6.27 \pm 0.12) \times 10^{14}\) particles veh\(^{-1}\) km\(^{-1}\),

- The number EF for three different vehicle categories:
  - Passenger cars (PC): \((1.16 \pm 0.65) \times 10^{14}\) particles veh\(^{-1}\) km\(^{-1}\)
  - Medium-duty (MD): \((2.78 \pm 0.54) \times 10^{15}\)
  - Heavy-duty (HD) buses: \((9.76 \pm 1.76) \times 10^{15}\)

- The ratios of the EF for PC, MD and HD to that for total vehicle fleet are 0.2, 4.4 and 15.6 respectively, which indicates both diesel vehicle (trucks) and ethanol buses are important sources of PN emission in urban area of Sweden.
Comparison of number EF measured in street canyon/urban road or urban road tunnel

- The results of this study are comparable to the EFs measured on the Stockholm tunnel by Kristession et al. (2004), Ketzel et al. (2003), Jones and Harrison (2006) and Imhof et al. (2005). Figure shows the comparisons.
RESULTS AND DISCUSSION

- There may be many reasons that result in the differences, but at least they can be explained by the different instruments with different lower cut diameters that were used.
- The relatively high particle number EF values measured in this work may in part be a feature of the measurement instrument, but may also be influenced by the fact that a significant proportion of the MD vehicle fleet at Hornsgatan (9%), being diesel fueled vehicles.
- Almost all the public local buses are ethanol fueled vehicles with much higher particle emission. The vehicle fleet emission value for particle number is particularly sensitive to the proportion of public buses.
- So far the emission of ethanol buses is not well known.
Thank you!