# Exposure of Particles inside Cars while driving in Road Tunnels

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## Introduction

Air pollution levels in longer road tunnels are several times higher than outdoor air due to the limited dilution by outdoor air in the tunnel and the large emission from the traffic. While driving through tunnels, drivers and passengers are therefore exposed to elevated concentrations in comparison to driving on surface roads, if the vehicle cabin ventilation is the same.

A major bypass highway called “Bypass Stockholm” is being prospected connected the southern and northern parts of Stockholm, Sweden. The main part (18 out of 20 km) of the passing highway will be constructed as a highway road tunnel, which will be Europe’s longest highway tunnel. The air quality inside the tunnel is important because of the exposure of the passengers driving in the tunnel. A project initiated by the Swedish road administration is in progress in order to study the concentrations of pollutants inside vehicles in relation to the tunnel air and also with the aim to come up with guidelines or limit values for tunnel air.

Scandinavia and Sweden experience high concentrations of PM10 in winter and springtime (Norman and Johansson, 2007). The particles are mainly produced by the wear of the road surface by studded winter tyres (Gustafsson et al., 2009). The particles are only emitted into the air during dry conditions. However in longer roadtunnels are the conditions mostly dry and the PM10 might be more than 10 times higher in the road tunnel during the winter season compared to the summer season. For the airquality in road tunnels in Sweden itis therefore of importance to consider both non-exhaust (including road wear) and exhaust generated particles. For exhaust, NOx, particle number and soot may be good indicators.

## Method

Measurement has been performed inside and outside the cabins of private cars while driving through a 5 km long highway tunnel in Stockholm (Södra länken). Measurements of PM10, PM2.5, soot and particle number concentration were made. Two setups of instrument were used simultaneous. One measured at breathing height inside the car cabin and one outside via sample tubings through the right backseat side window. Four different cars have been tested. The cars were tested both with ventilation (i.e. air from outside) and recirculation of the cabin air (if available). All tests were done during daytime March-May 2012 with high traffic density without congestion and the driving speed was between 60-70 km/h. Summary of which cars that were used, the instruments used and what measurements that were made in each car are shown in table 1.

Table 1: Instruments and vehicles used in the study.

| Component | Volvo V70, 2011 | Ford Focus, 2005 | SAAB 95, 2004 | VW LT TDI Van, 2001 |
|---|---|---|---|---|
| PM10, PM2.5 (Lighthouse 3016-IAQ) | √ | √ | √ | √ |
| Soot (Magee Aethelometers AE51) | √ | √ | - | - |
| Particle number (TSI P-Trak 8525) | √ | √ | √ | - |

Concentration of the exhaust related pollution as soot and particle numbers are closely linked to the traffic density and the variation between the different measurements were therefore relatively small. The wear particles measured as PM10 and to some part also PM2.5 shows a seasonal variation with higher concentrations during the winter tyre season and the variation between the different measurements were larger. The variation of the concentration in the tunnel during the study is presented in table 2.

Table 2: Range of concentration in the tunnel during the study.

| Component | Range of concentration[1] |
|---|---|
| PM10, µg/m$^3$ | 350-1500 |
| PM2.5, µg/m$^3$ | 60-170 |
| Soot, µg/m$^3$ | 15-30 |
| Particle number, N/cm$^3$ | 140000-180000 |

[1]The range between the average of each passage.

## Results

Results for PM10 and PM2.5 from measurements in the four different vehicles are presented in figure 1. It shows the concentrations in the cabin air as percent of the concentration in the tunnel air. The Volvo, Saab and Ford concentrations are shown for the conditions with the ventilation running and with recirculation of the cabin. The older VW van did not have the possibility to use recirculation of the cabin air.

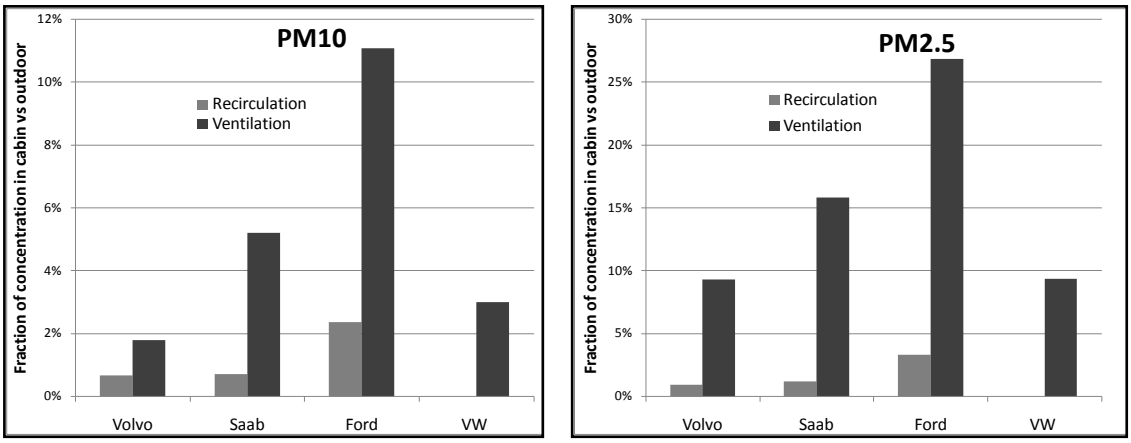


Figure 1: Percentage of the PM10 and PM2.5 concentration in the cabin air compared to the outdoor air for while driving in the tunnel. (The VW van did not have the possibility of recirculation of the air.) Note the different scale for the two figures.

The part of the PM10 and PM2.5 that entered the cabin air through the ventilation system varied significantly between the vehicles. Most of the larger particles are being filtrated and only a few percent of the PM10 entered the cabin. Lowest penetration was found for the most modern car, Volvo V70 with less than 2 % of the PM10 and less than 10% of PM2.5 entering the cabin air while using the ventilation. Surprisingly, the oldest car, the VW van, showed almost as good results as the Volvo, with only 3 % of the PM10 entering the cabin. Both the Ford and the Saab showed higher percentage (more PM entering the cars) for both PM10 and PM2.5 compared to the Volvo.

PM2.5 was found to be less efficiently filtered in all tested cars with the maximum for the Ford where 25-30% entered the cabin air.

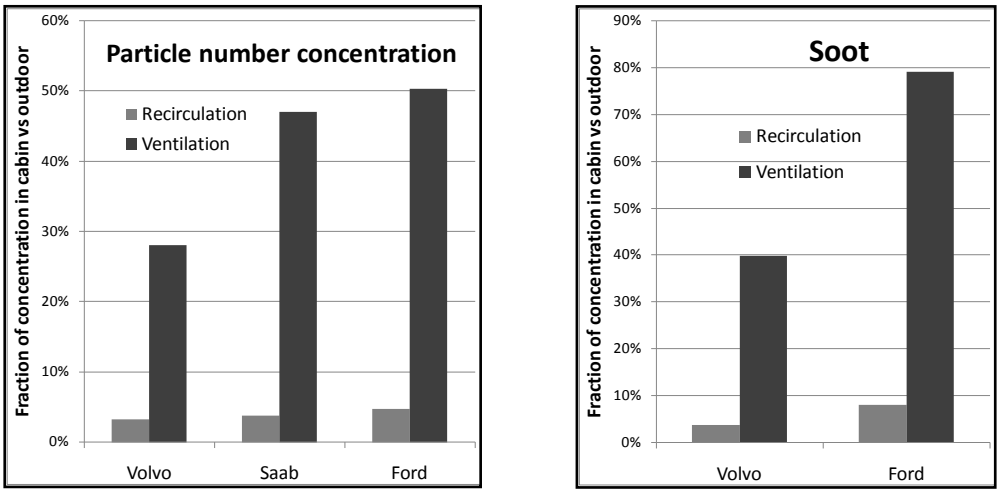


Figure 2: Percentageof the particle number and soot concentration in the cabin air compared to the outdoor air while driving in the tunnel. Note the different scale between the figures.

Results for particle number and soot are presented in figure 2. The relations between the vehicles are following the same pattern as for PM10 and PM2.5 with the lowest percentage of the pollutant entering the Volvo cabin, while highest is seen for the Ford. An important result is that a much larger percentage of both particle number and soot entered the cabin air for all vehicles in comparison to PM10 and PM2.5. Even for the Volvo, with an efficient filter, 40 % of the soot and almost 30 % of the particle number entered the car cabin. For the Ford, up to 80 % of the soot entered the cabin and 50 % of the particle number.

Filter efficiency of cabin filters have been tested by for example by Xu et al., (2012). They found that the lowest efficiency was for particles ranging between 100-500nm in diameter. For both smaller and larger sizes there was an increase in the efficiency observed with best efficiency for particles around 10 µm. The number sizedistribution measured in a tunnel in Stockholm have shown that most particles are found around 20-40 nm in diameter (Gidhagen et al., 2004). Soot particles from car engines are mostly found at sizes of ~100 nm (Virtanen et al., 2004).The wear particles that mostly contribute to PM10 are found at sizes of a few µm (Gustavsson et al., 2007). The results presented from this study in figure 1 and 2 are in line with the study by Xu et al (2012) showing that a large fraction of the soot particles are likely to enter the cabin air.

Recirculation of the cabin air while driving in the tunnel, was found to be very efficient in reducing the concentration inside the cabin. For all cars and all components were a maximum of 10% of the tunnel air concentrations measured in the cabin when using recirculation. The cabin air seems to be passing the filters in the cars also when using the recirculation. This is based on the results that a clear decrease in the cabin concentrations where observed when the recirculation was used.

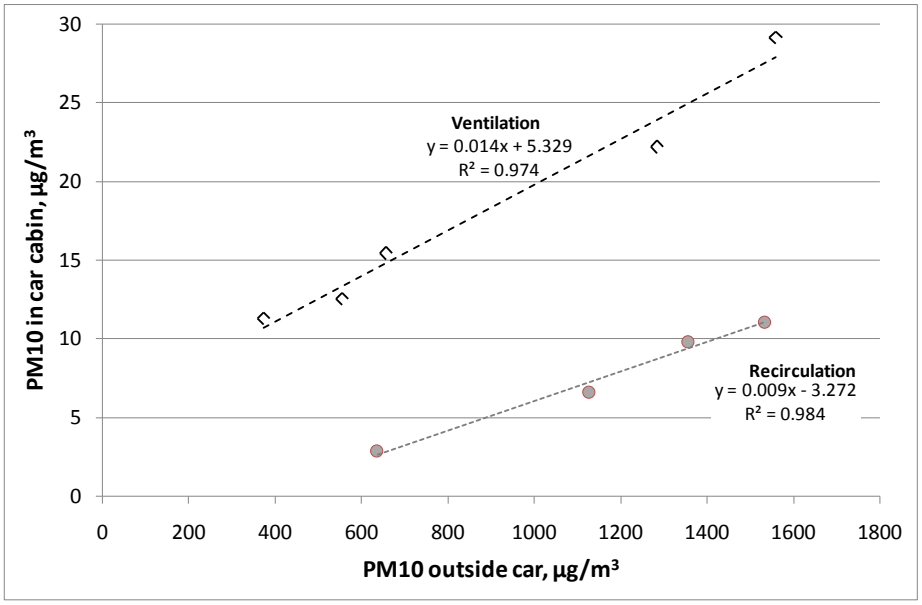


Figure 3: The correlation between the PM10 concentration in the cabin and outside for the Volvo V70.

Several identical passages through the tunnel were done with the Volvo. In total 5 with ventilation and four with recirculation divided into two day with a month in separation. The correlation between the tunnel air and the cabin air concentration are shown in figure 3. This shows that a linear relationship between cabin and outdoor concentrations. This also holds for the concentration when the recirculation was used. The relationships presented in figure 3 are examples that will be used in the future estimation of the exposure in the car while driving in the prospected “Bypass Stockholm”. It will be of large importance for studying the health aspects and for suggesting guidelines or limit values for tunnel air in Sweden.

## Conclusions

The concentrations of pollutants in the tunnel were very high and significantly elevated in a road tunnel in comparison to outdoor air and this has been shown to affect the concentrations inside vehicle cabins.

This study showed that larger particles from road wear (PM10) to a large extent do not enter the vehicle cabins in modern cars due to filtration in the ventilation system. A maximum of ~10% of the PM10 enteredthe cabin air from outside. Small particles, measured as particle number as well as soot entered the cabin air to a much larger extent. As much as 50-80% of the soot concentration outside the cabin was measured in the cabin. Significant differences were found between different vehicles. The most modern car (Volvo V70 from 2011) showed the best filter efficiency for all measured components.

Using the recirculation of the cabin air while driving in the tunnel, was found to be very efficient in reducing the concentration inside the cabin. For all cars and all components were a maximum of 10% of the tunnel air concentrations measured in the cabin when using recirculation.

## Outlook

The project will further be extended also to include nitrogen oxides, $NO_2$ and NO (NOx). Limit values for tunnel air today are based on $NO_2$. The composition of the vehicle fleet (gasoline/diesel) as well as newer engines has changed the $NO/NO_2$ ratio in Sweden over the last years. The relation will also vary depending on the length and ventilation of the different tunnels. NOx might therefore be a better indicator than $NO_2$ for air quality in tunnels. The nitrogen oxides are also not expected to be removed in the ventilation system of the vehicles and might therefore be one of the most important components to use as indicator for vehicle exhaust in tunnel air. But then, the relation between NOx and the toxic components in the

exhaust and in vehicle cabins need to be considered if NOx would be used for regulating tunnel air quality.

The large fraction of soot entering the cabin air shows the importance of continuous monitoring of soot concentration in tunnels in order to make exposure calculations. Today's monitoring in Swedish tunnels is mainly limited to NOx and CO and in some cases also PM10.

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