Effects of various car ventilation settings on size distribution and lung deposition of ultrafine particles

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Abstract

The objective of this study was to find the effects various air ventilation settings may have on ultrafine particle burden inside the passenger cabin of an operating car. To examine the effects in an actual real life situation, a highway tunnel system was chosen to serve as an particle laden environment for the sampling campaign. The data obtained were then applied to a lung deposition model, to observe which effects the different ventilation settings have on passengers sitting inside the car. Our observations suggest the usage of the recirculating air setting when driving through poorly ventilated systems to reduce the inhalation burden of ultrafine particles on car passengers.

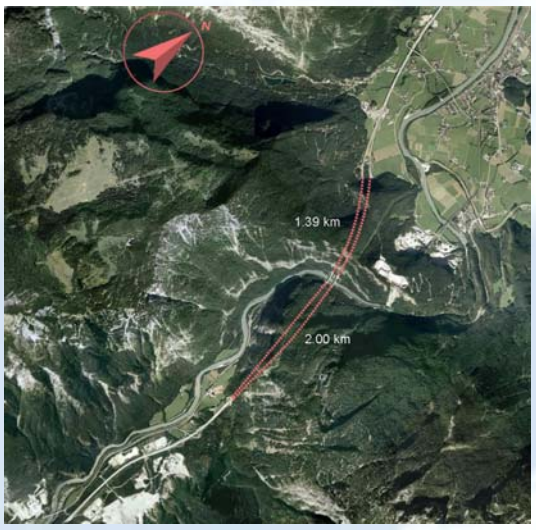

Fig. 1: Aerial view of the investigation site, a highway tunnel system (Ofenauer Tunnel 1.4 km , Hiefler Tunnel 2.0 km). Modified after Google Earth.

Introduction

The primary objectives of this study were (i) to examine the particle size distribution of particle burden entering a car, and (ii) the effects various ventilation settings have on this particle load as and in further consequence on lung deposition. The measurements were taken while driving through a 3.4 km long highway tunnel system consisting of two separate sections.

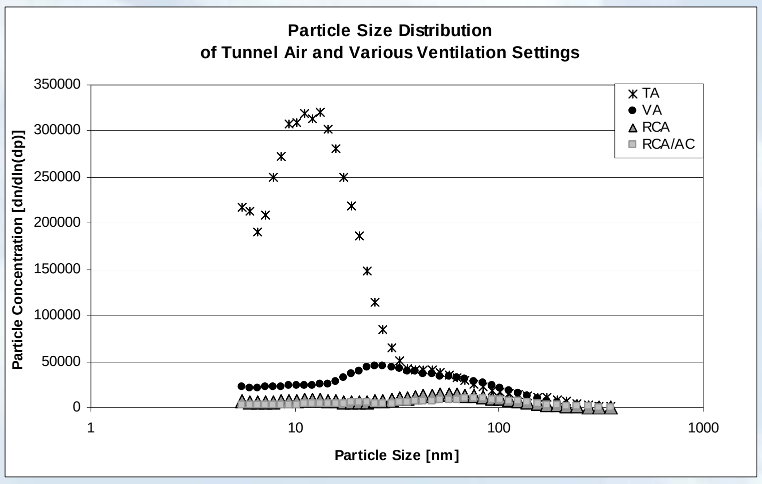

Fig. 2: Differences in particle size distributions during of various ventilation settings. TA (tunnel air), VA (unfiltered ventilated air), RCA (re-circulated air), RCA/AC (re-circulated air with AC on)

Methods

Measurements took place on several days during the week and on weekends. The sampling campaign involved a BMW (330 D Touring), operating at three different ventilation settings: (1) air from outside ventilated into the cabin [VA], (2) recirculating air within the cabin [RCA] and (3) recirculating air with air-condition [RCA/AC]. In addition, the tunnel air [TA] was sampled as a reference to determine the filter efficiency of the built-in ventilation system particle filter. A tunnel air scan was used as a reference value.

For all measurements, a Scanning Mobility Particle Sizer (SMPS) was used to monitor the particle size inventory ranging from 5.5 nm to 350 nm in total. The SMPS is a mobile continuous nano-particle counter, which combines a CPC and a DMA.

A stochastic lung model originally developed by Koblinger and Hofmann (1990) and Hofmann and Koblinger (1990) was applied to the sampled data to model the fate of inhaled particles. In this model, the geometry of the airways along the path of an inhaled particle is selected randomly using the most resent version of the Monte Carlo code IDEAL, whereas deposition probabilities are computed by deterministic formulae.

Results

Although the BMW 330 D Touring is fitted with a pollen filter, its user manual does not provide any filtering efficiency for a given particle size range below 10 µm. This investigation found a significant reduction of nano-particles transported into the passenger cabin. Using the ventilation system to rout air into the passenger cabin (VA setting) shows a strong filtering effect compared to the particle load of the ambient air. This could be observed for all investigations performed during the rides through the tunnel systems. An even better particle reduction inside the passenger cabin is obtained by applying the re-circulated air (RCA) setting.

The RCA setting reduces the amount of ultrafine particles by about 5 times compared to the amount of the VA setting, particularly in the size range of 5–40 nm. This factor decreases with particle size to a factor of 2 at the larger end of the sampled size range. Applying the RCA/AC reduces the particle burden by another 50% compared to RCA setting in the same size range. This difference also decreases with particle size and is almost non-existent at a particle size around 100 nm. This can be attributed to the ever increasing filter efficiency of the built-in pollen filter at a higher particle size range

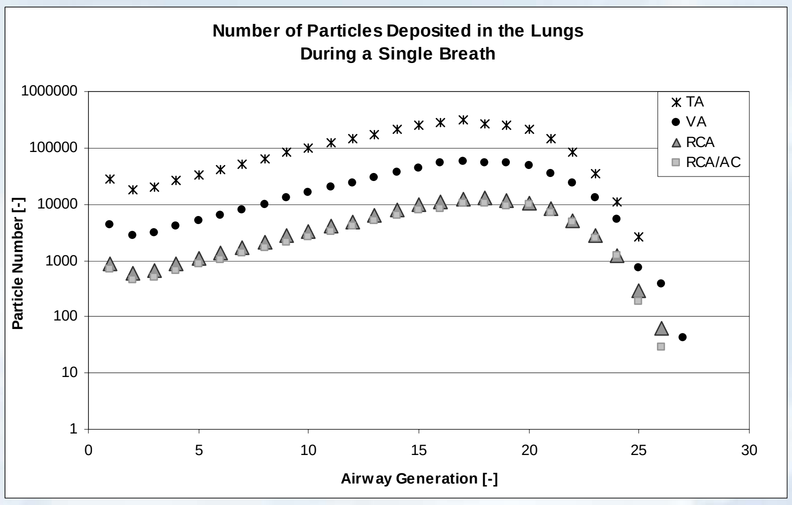

Fig. 3: Difference in the number of particles deposited in the lungs during a single breath for different ventilation settings. Model simulation based on the Monte Carlo code IDEAL

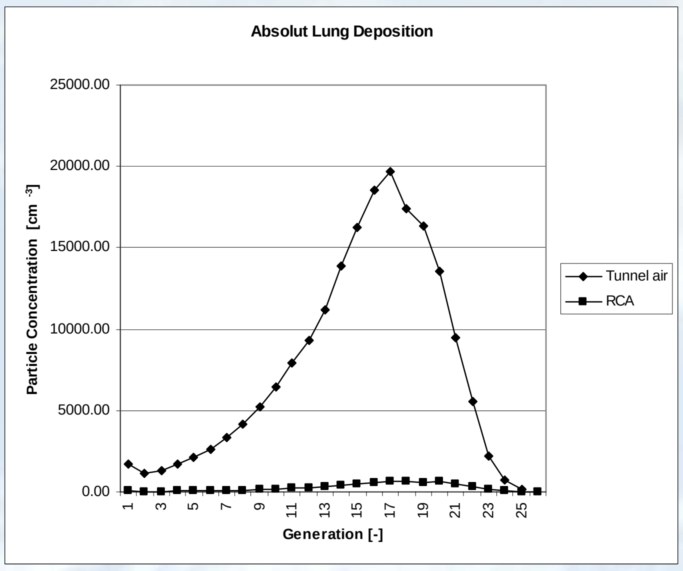

Fig. 4: Modelling total particle deposition in the lung using the Monte Carlo code IDEAL, Plotted tunnel air (TA) and re-circled air (RCA)

Conclusion

While it is clear that the reduction in particle concentration in the VA and RCA setting is a result of fewer aerosols entering the passenger cabin of the car, the RCA/AC setting does influence the particle concentration in some other way. It is likely that condensation and coagulation processes take place, as changes in temperature and humidity result from the air-conditioning system (Ashgarian, 2004). The apparent drop in the particle burden starting at around 300 nm is caused by the fact, that fresh vehicle exhaust contain relatively few particles in this size range (Imhof et al., 2005).

Applying the data to the lung deposition model reveals a deposition peak past the 15th generation (alveolar region of the lung) for all ventilation settings. This alveolar deposition is common for predominantly hydrophobic particles such as urban traffic exhausts. It has been proposed that alveolar deposition is associated with increased cardio-circulatory problems, as the immune system is the primary organ to remove entrapped particles (Donaldson et al., 1988).

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