IMPROVEMENT OF AIR QUALITY IN VEHICLE CABINS BY NANOPARTICLE FILTRATION

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Abstract

A filter system is presented which allows the reduction of the concentration of ultrafine particles in vehicle cabins to very low levels. The original ventilation system is switched to the recirculation mode and all cabin intake air is supplied via a retrofitted filter system. Tests with a variety of different vehicles (from passenger cars to coaches) show the efficiency of the system.

Filters incorporated in present ventilation systems remove large particles, for example pollen, but usually are inefficient for removing very small particles. This is demonstrated by Fig. 1, where the particle number concentration outside and inside a car is plotted during a journey near Zurich. It is obvious that the concentrations inside and outside are more or less identical. All windows were closed during this measurement. Tests with a number of different all cars showed similar results. The filters included in today's ventilation systems usually cannot remove nanoparticles, and so vehicle cabin indoor and outdoor nanoparticle concentrations are more or less identical. The nanocleaner, consisting of a very efficient filter and a high performance blower, allows reduction of the particle concentration in the cabin from several hundreds of thousands or millions per cc. to a few thousand per cc., equivalent to remote woodland, the total exposed dose being reduced by some two orders of magnitude.

***Keywords**: vehicle, ecology, filtration systems, nanoparticles*

1. Introduction

Whereas ambient PM10 concentrations are mainly determined by background particle pollution, the concentration of submicron particles strongly depends on local sources, and may be very high beside busy roads and, in particular, on such roads. This means that people travelling frequently on such roads are exposed to high concentrations of nanoparticles. The exposure may be orders of magnitude higher than at remote areas. A study by S. Fruin [1] shows a 15 times increased concentration inside cars compared to the roadside. Such nanoparticles are now linked to a number of diseases, including heart attacks, cancer, lung diseases and immune system diseases, and are thus considered a serious health problem (2, 3).

Filters incorporated in present ventilation systems remove large particles, for example pollen, but usually are inefficient for removing very small particles. This is demonstrated by Fig. 1, where the particle number concentration outside and inside a car is plotted during a journey in the vicinity of Zurich. It is obvious that the concentrations inside and outside are more or less identical. All windows were closed during this measurement. Tests with a number of different all cars showed similar results.

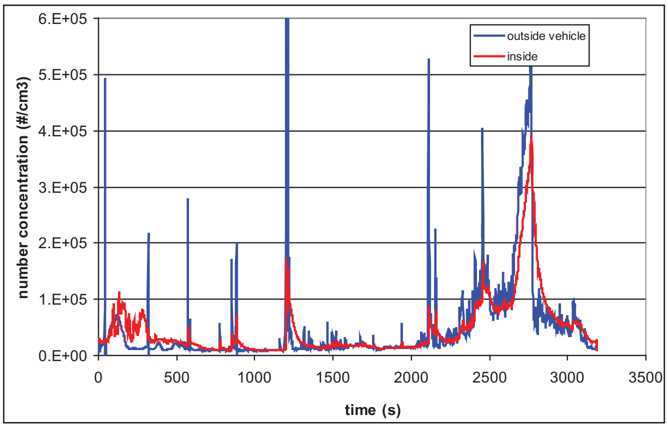

Fig. 1. Number concentration of particles inside and outside a car

Though efficient filters are available to car manufacturers in principle, these are not currently implemented because they cause a higher-pressure drop, requiring stronger blowers. In our approach, we have tried to overcome this problem in part by filtering only partial intake flows, as will be shown below.

2. The nanoparticle filtration system

All of our currently developed prototypes are retrofit systems. The original car ventilation is not modified, but switched to a recirculation mode. No fresh air is drawn from outside via this system. Outside air only enters through an additional filter and a high performance blower. We have tested a large number (some hundreds) of different types of filters. Test parameters were filter efficiency, pressure drop and capacity. A quartz fibre filter proved to be the best one and it is used in our system. Fig. 2 shows the filter efficiency as a function of particle size. In contrast to the filters usually applied in car ventilation systems, this filter has a very high efficiency down to particle sizes of a few nanometres.

A prototype of the system is shown in Fig. 3 and 4. A tube connects an intake location outside the car with the air inlet of the filter system. In the first prototype, the blower is directly at the inlet. To increase the lifetime of the high performance filter it is preceded by a prefilter to remove coarse particles. From there the air reaches the high performance filter. The weight of the system for passenger cars is 1.7kg, the power consumption 40W. A rough estimation of the costs for 1000 units is 400$ per unit.

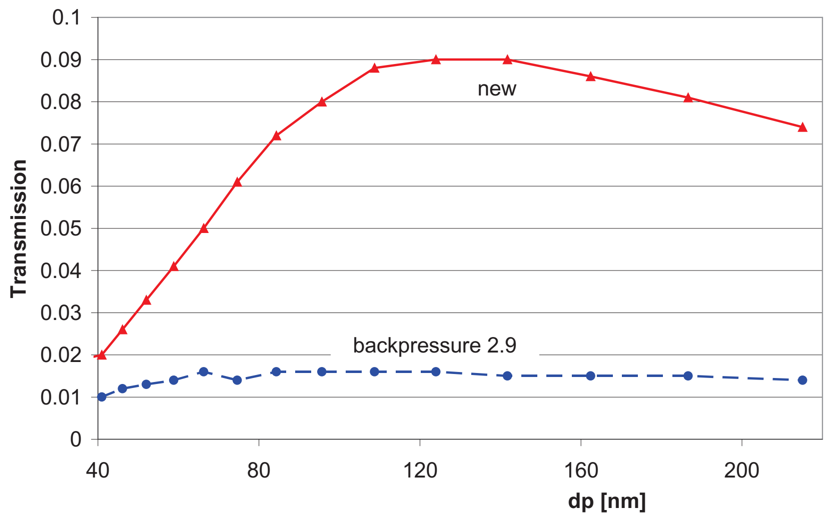

Fig. 2. Filter-efficiency: Transmission as function of particle size for the new filter and for the filter loaded to a pressure drop of 2.9 mbar

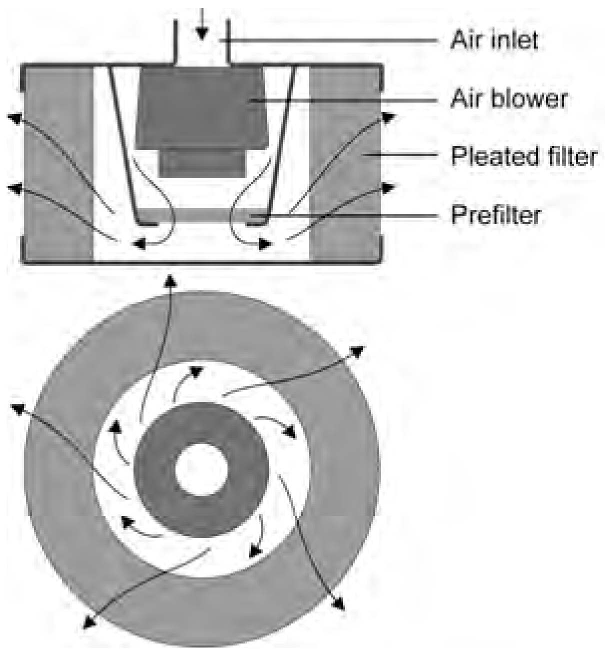

Fig. 3. Setup of the filter with integrated prefilter for course particles and blower

The system is operated at a flow rate of 30 m^3/h (8.3l/s). The blower can handle pressure drops up to 2000 Pa. Importantly, all intake air has a single pass through the filter. The size of the filter is strongly influenced by lifetime demands and by the demands for air intake interchange inside the cabin. To investigate the lifetime experimentally a filter was placed in a road tunnel of the Zurich downtown highway system (Milchbuck Tunnel) together with a particle measurement device for a long term test. Fig. 5 shows the pressure drop of the filter as a function of the length of time of operation in the tunnel.

Based on these results the filter lifetime has been estimated. The particle concentration in the tunnel is about 10 times higher than average road concentrations. This indicates that under typical operating conditions a filter lifetime of about 10,000 h can be expected, before the pressure drop reaches 1000 Pa.

For applications with higher cabin volumes, either several of these filter units can be used in parallel, or larger systems can be devised, as shown in the next section.

Fig. 4. Prototype of the filter system

Main filter, prefilter and blower are included. The system is operated by an external control box, containing the drive electronics for the blower and displays for filter pressure drop and time meter.

Fig. 6 shows one possibility to install the filter system in a passenger car. A number of solutions to place the intake air inlet have been investigated. For most of our tests with passenger cars the filter was simply placed on the back seat, together with sensors to measure the particle concentrations (usually two, one sampling outside air and one cabin air) and a notebook for data acquisition (see Fig. 7). Diffusion Size Classifiers DiSC [4] was used to monitor the particle number concentration. The DiSC is a new instrument, which allows the measurement of particle number concentration.

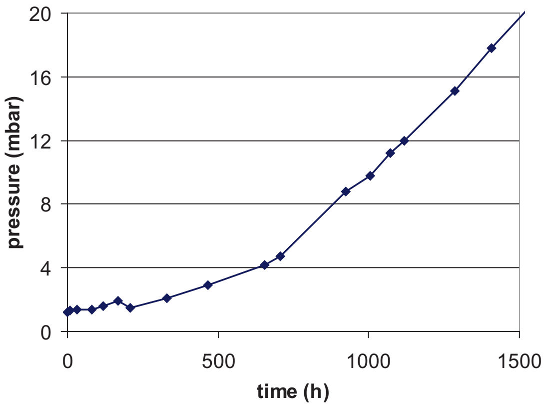

Fig. 5. Filter pressure drop as function of operating time in a highly polluted road tunnel

The DiSC is a new instrument, which allows the measurement of particle number concentration and mean diameter by a very compact, battery operated unit. The absolute accuracy of the instrument is 20%, the reproducibility better than 10%. To make sure that the air exchange remains sufficient, CO_2 concentration in the cabin was also measured using a Li-COR Li-840 CO_2-analyzer.

3. Results

The prototypes have been road-tested for extended periods under an extensive variety of traffic conditions, including high-exposure urban and tunnel situations, in cars with the air conditioning in recirculation mode. On start-up, a rapid particle reduction ('clean-down') of 95-99% within 3 minutes is obtained (Fig. 8). Once cleaned down, the new filter system (air conditioning still in recirculation mode), can maintain a level of nanoparticles in the car at or below 5000 part./cm^3, the equivalent of a typical situation inside a closed office or in woodland, even if external peak counts are (transient) over 1,000,000 part./cm3 or (persistent) over 250,000 part./cm3 for extended periods (a minute or more). The total nanoparticle count inside the car over the journey is typically ~2% of that encountered outside. Fig. 9 shows a typical result. The rapid concentration changes observed outside are hardly visible inside.

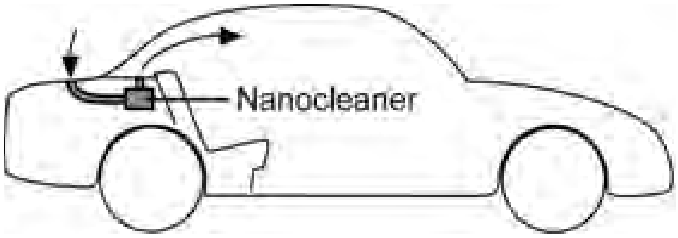

Fig. 6. One possible solution to mount the filter system

Fig. 7. Filter, particle sensor (below notebook) and Notebook for data acquisition

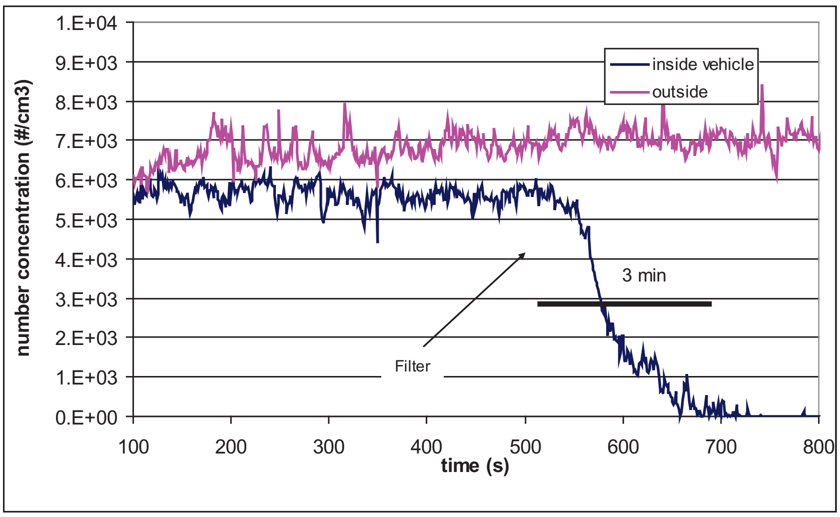

Fig. 8. Particle concentration inside and outside the car (passenger car). After turning the filter on, the inside concentration drops to very low levels over about three minutes

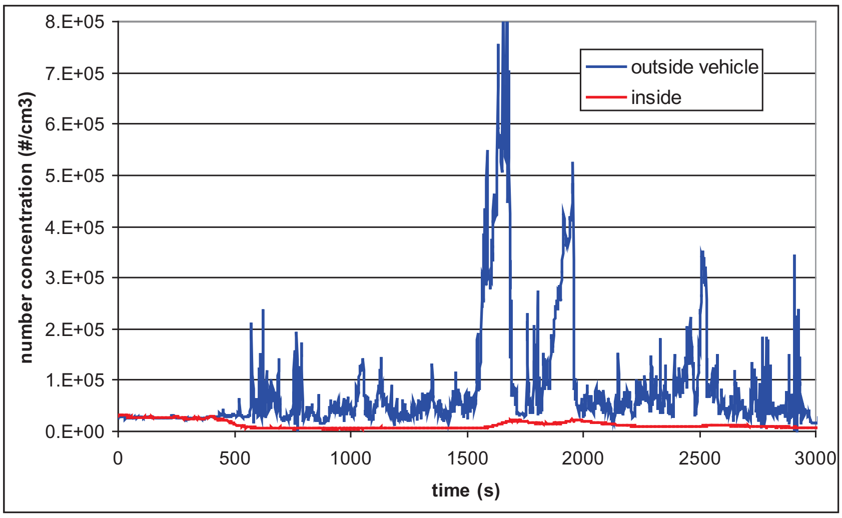

Fig. 9. Particle concentration inside and outside a passenger car with the filter turned on. Even when the external concentration is extremely high, in this example while driving through a tunnel, the indoor concentration remains very low

After tests with a number of passenger cars showed the good performance of the filter system, we started to look at other vehicles with larger cabin volume. Fig. 10 shows two units mounted in a school bus (12 seats). To achieve a sufficient air supply both units were equipped with two blowers, leading to a total air flow of 120 m3/h (33.3l/s). This was sufficient to obtain results comparable to those with the passenger cars. The CO_2 concentration was about 800 ppm, which shows that the airflow is high enough (CO_2 concentrations below 1500 ppm are not critical). Similar results were also obtained for larger buses and coaches, as below.

Another series of test has been performed in a truck. Here initially two of the systems developed for passenger cars have been placed in the truck cabin (Fig. 11). One result of these tests is presented in Fig. 12. Again, the indoor concentration is significantly lower than outside; however, the result is not quite as good as those obtained for the previous cases. Peaks in the outdoor concentration are still visible inside. This indicates that the cabin of the truck investigated is leakier than that of the passenger cars, and so a slightly larger scaled system is needed.

Fig. 10. Two Nanocleaner filter systems, mounted in a school bus

Fig. 11. Nanocleaner placed in a truck cabin. Two units are used for the test measurements

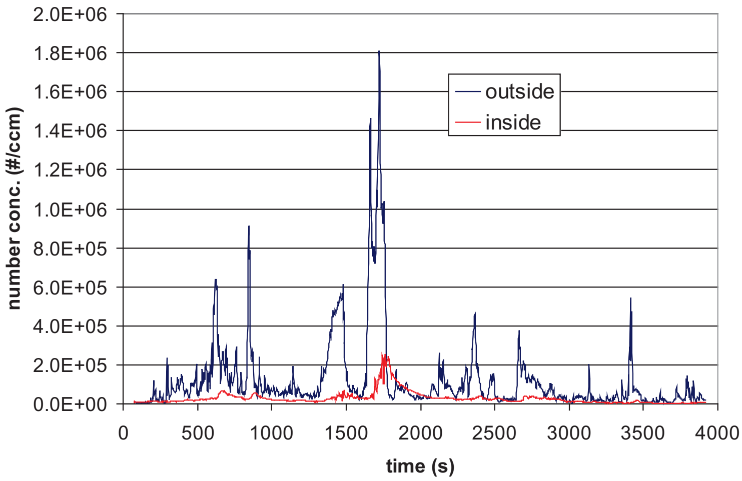

Fig. 12. Particle concentration inside and outside of the truck cabin

A much larger filter system has been installed in the luggage compartment of a 35-seater coach (see Fig. 13). The coach was fitted with three systems each capable of 180m^3/hour (50l/s) airflow, fitted to replace the coach's air conditioning systems, taking air from the luggage compartments, filtering it, and delivering it to the passenger compartment. Again, inside and outside particle concentrations are plotted in Fig. 14.

Fig. 13. Filter system for buses, installed in the luggage compartment

So far, in all applications presented the ventilation system of the vehicle has remained unchanged. As last example we present a case (a BMW 530), where the original filters have been replaced by our high efficiency filter. However, the high performance blower has been used (see Fig. 15) as the sole source of intake air to the cabin. Fig. 16 and 17 show the result with normal filter and with the nanocleaner-filter. Again, the original filter has no significant effect on the particle concentration in the cabin. If it is replaced by the nanocleaner filter, the cabin nanoparticle concentration becomes very low.

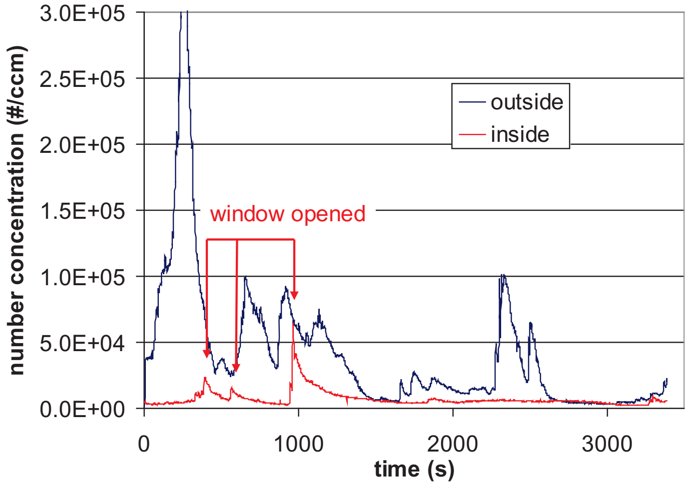

Fig. 14. *Particle concentration inside and outside a coach. Three times, indicated by the red arrows, a window has been opened. Immediately the indoor concentration rises to approach the outdoor concentration and decreases again after the window is closed*

So far, in all applications presented the ventilation system of the vehicle has remained unchanged. As last example we present a case (a BMW 530), where the original filters have been replaced by our high efficiency filter. However, the high performance blower has been used (see Fig. 15) as the sole source of intake air to the cabin. Fig. 16 and 17 show the result with normal filter and with the nanocleaner-filter. Again, the original filter has no significant effect on the particle concentration in the cabin. If it is replaced by the nanocleaner filter, the cabin nanoparticle concentration becomes very low.

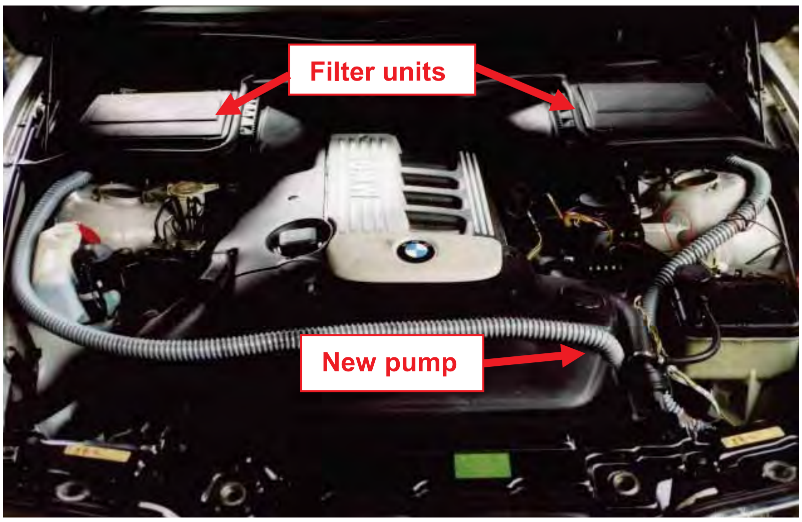

Fig. 15. *The original filter of the BMW 530 has been replaced by high efficiency filters. Air is supplied by a blower, which is also placed in the engine compartment*

4. Conclusion

The filters included in today's ventilation systems usually cannot remove nanoparticles, and so vehicle cabin indoor and outdoor nanoparticle concentrations are more or less identical. The nanocleaner, consisting of a very efficient filter and a high performance blower, allows reduction of the particle concentration in the cabin from several hundreds of thousands or millions per cc. to a few thousand per cc., equivalent to remote woodland, the total exposed dose being reduced by some two orders of magnitude.

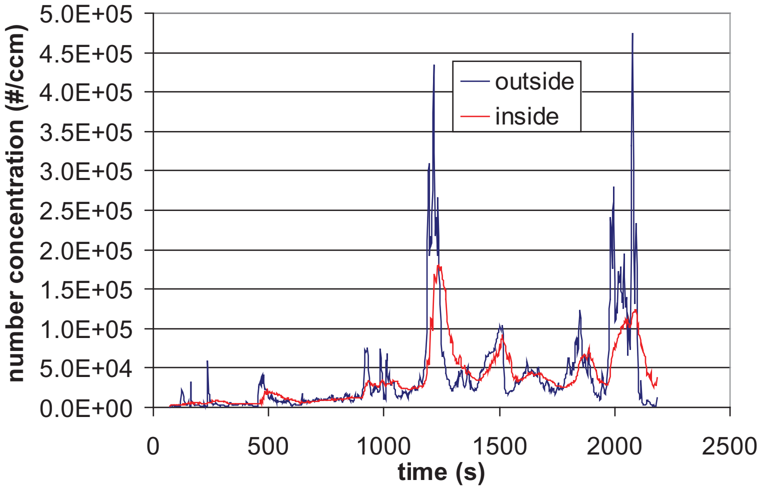

Fig. 16. Results with regular ventilation system

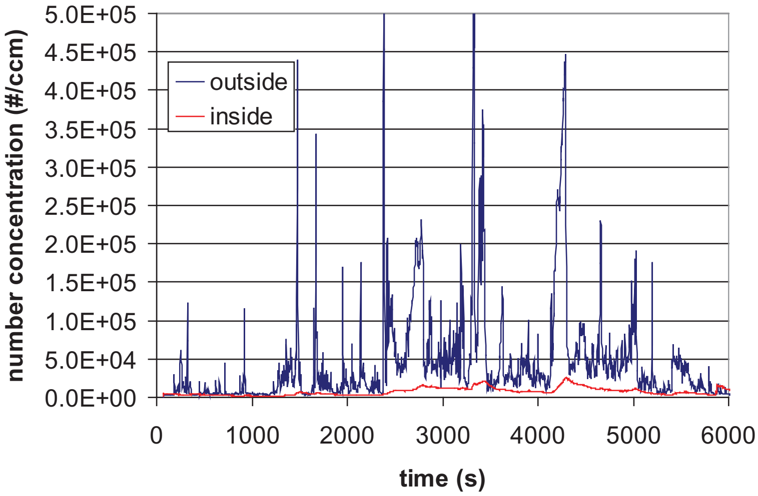

Fig. 17. Results using the nanocleaner filter

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