Reduction of Air Pollution Inside a Vehicle by Using Nano-Particle Filter

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Introduction

It is quite well established now that road users, such as cyclists and especially professional drivers, are exposed to higher levels of air pollution than background or curbside data might suggest, Chan et al (1991), Colwill and Hickman (1980), Kingham et al (1998), Rudolf (1994),Van Wijnen et al. (1995), Taylor and Fergusson (1998). According to the latter source, road users in the center of the roadway are likely to be travelling through a tunnel of the most polluted air and this is the principal reason for their raised relative exposure to pollutants – see Fig. 1.

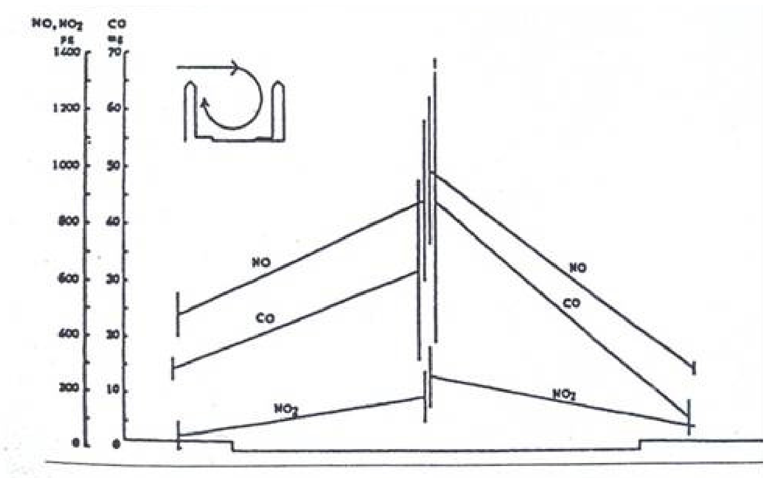


Figure 1: Comparison of differences in CO, NO and NO2 concentrations on the sidewalk and inside a car (Taylor and Fergusson, 1998).

In countries with hot climate conditions, almost the entire vehicle fleet is equipped with air conditioning (AC) systems, and the driver usually makes a decision about the desired method of car ventilation: without AC and opened window, with AC and internal recirculation of air, or with AC and introduction of outdoor air into the car. Recent research works studied the effects of the car ventilation method on air pollution inside a car (Tartakovsky et al., 2006). Significant influence of car ventilation method on the inside air quality was found with relatively high levels of particle concentrations inside a vehicle.

Objectives

The main goal of this study was to assess the possibilities to reduce air pollution by nano-particles inside a vehicle with aid of a special particles filter. The data collected in this research can be used to evaluate exposure levels of professional drivers to air pollution inside a vehicle during driving in urban areas and city centers.

Methodology

The experiments have been performed with 4 vehicles of different makes and types: 3 passenger cars (PC) and one van serving as a shuttle taxi. Main data of these vehicles are summarized in Table 1.

Table 1: Vehicles that have been used in experiments

Vehicle model	Type	Engine type	Engine volume	Production year	Traveled distance, km
Renault Megane	PC	SI	1.6	2005	130000
Citroen C4	PC	SI	1.6	2009	10000
Peugeot 206	PC	SI	1.4	2002	150000
Volkswagen Transporter	Van	CI	2.5	2008	130000

The experiments have been carried out in two Israeli cities: Haifa and Tel-Aviv; both characterized by heavy traffic conditions in city centers and differ in topography: very hilly in the former and flat in the latter. Driving routes in both cities have been selected in collaboration with local transport planning authorities and based on previous road gradient measurements (Tartakovsky et al., 2000) and traffic counts. Average road gradient of two driving routes in Haifa used for experiments with PC and shuttle taxi was found to be about 6% compared with 0.5% at driving route in Tel-Aviv. Experiments with a shuttle taxi have been performed on a real taxi route and in a real-world driving regime with frequent doors opening at taxi stops.

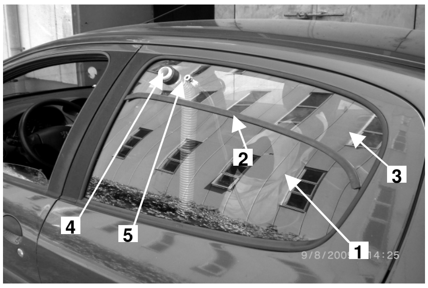
Concentrations of CO, NO, NO_2, and nano-particles PN (particles number) were measured in this study. Average size of nano-particles was assessed as well. Interscan gas analyzers of models 4140, 4540 and 4150 with electrochemical cells served for measurements of CO, NO and NO_2 concentrations, respectively. Nano-particles concentrations and their average size were measured by the Matter Engineering diffusion size classifier (DISC).

All readings of the gas analyzers, and DISC, as well as stop events, were logged at 1 Hz frequency by a Squirrel 1023 and DISC built-in data loggers, and subsequently analyzed after downloading to a computer. Sampling collection was performed in the driver's breathing zone. Experiments were carried out during all working days of the week, from 7 AM till 7 PM.

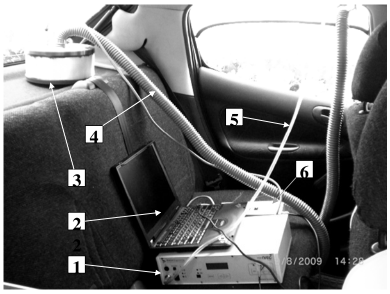
In part of experiments a novel nano-particle filter system (Nanocleaner) developed by the Matter Engineering AG was used, in order to reduce air pollution by particulates inside the vehicle. The Nanocleaner system contains input backpressure monitor, in order to prevent filter clogging. In all experiments with the Nanocleaner, the vehicle's air conditioning (AC) system operated in internal air recirculation mode and a fresh air was supplied inside a vehicle by the Nanocleaner. The filter system installation in the tested vehicle is shown on Fig.2. Filters supplied by the Matter Engineering AG for experiments were designed for use in the PC's, therefore in experiments with the shuttle taxi van two filter systems were used and operated simultaneously.

Comparative noise measurements inside the vehicle were performed with the nano-particle filter system switched on and off. The measurements have been done in proximity of the driver head by sound level meter IEC 651 type d ,Luton SL 4022.

The testing program included measurements outside the vehicle and inside a vehicle at different ventilation modes with the Nanocleaner switched on and off. The following ventilation modes were studied: AC switched on and introduction of outdoor air into the car; AC switched on, internal air recirculation; AC switched off, vent off, window of the driver fully open.



1 – vehicle original window; 2 – seal;
3 – insertion window; 4 – air inlet to nanocleaner;
5 – air inlet to diffusion size classifier



1 – diffusion size classifier; 2 – laptop with DiSC software;
3 – Nanocleaner; 4 – Nanocleaner inlet line;
5 – DiSC sample line; 6 – Nanocleaner control unit.

Figure 2: Nanocleaner installation in tested vehicle.

Results and discussion

Results of nano-particles concentration and size measurements that have been performed with PC in Haifa and Tel-Aviv are presented in Fig. 3. The Figure shows PN concentrations and size, as were observed outside and inside the vehicle, with the Nanocleaner switched on.

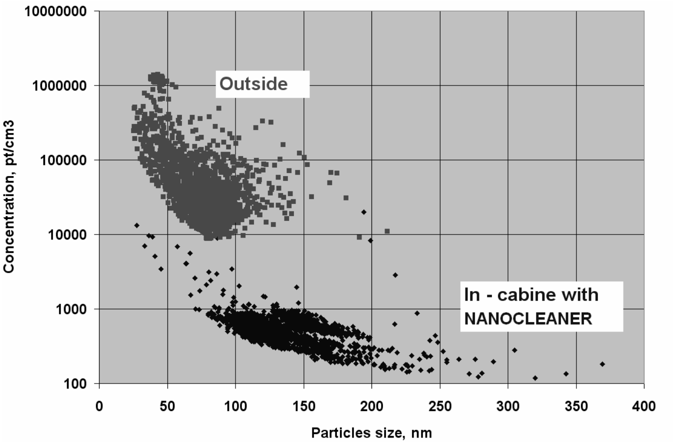


Figure 3: Results of nano-particle measurements outside and inside passenger car.

The experiments results show clearly that the use of the nano-particle filter system allowed significant reduction of up to 95-99% of PN concentrations inside the car, compared with outside readings. The achieved levels of PN concentrations inside the car that were reduced by using the Nanocleaner to values below 250 cm^{-3} are typical for a clean office. Along with this, some minimal time is required, in order to achieve maximal cleaning effect. The experiments on the long Tel-Aviv driving route (route length 15 km) have shown that minimal PN concentrations inside the car (about 230 cm^{-3}) were achieved after about 25 min of filter operation – see Fig. 4.

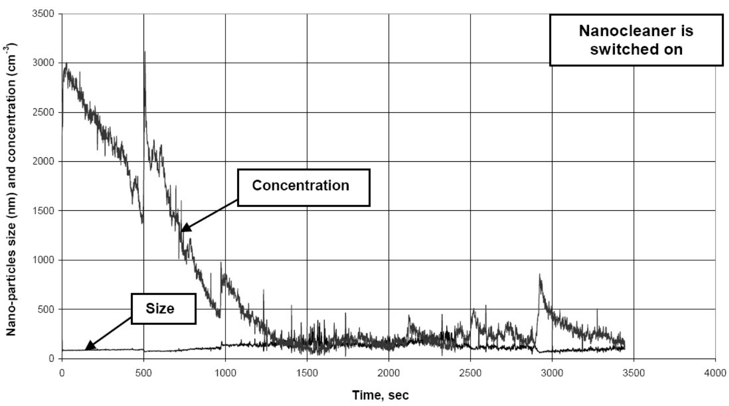


Figure 4: Results of nano-particle measurements inside the car – Tel-Aviv driving route.

Thus, in shorter urban driving trips it will be impossible to achieve a maximal cleaning effect. This was confirmed by the results of experiments on the short Haifa driving route (length of 4.1 km), where time of one driving run usually did not exceed 12-13 min. As a result, minimal PN concentrations that were achieved inside the car in these trips did not fall below 3000 cm^{-3}.

The data in Fig. 3 clearly show that use of nano-particle filter leads to some increase in size of particles measured inside the vehicle, compared with ambient air data. Average nano-particles size outside the vehicle was measured to be 70-80 nm compared with 120-130 nm inside the vehicle after Nanocleaner operation. This result may be explained by increase of the relative contribution of dust particles settled down on seats and other surfaces inside the vehicle and resuspended due to human activities and air movement, as the filter cleans air entering vehicle cabine. Fig.5 shows distribution of nano-particle sizes as was measured outside and inside the vehicle with the Nanocleaner switched on.

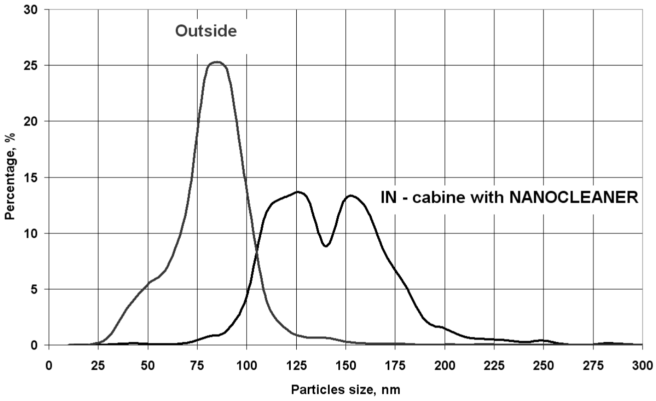


Figure 5: Distribution of nano-particles size inside and outside a vehicle.

Drivers and operators, who took part in the road tests, noted the noise generated by operation of the nano-particles filter. In order to assess this noise level, some preliminary measurements have been performed during experiments with passenger cars. Their results are summarized in Table 2.

Table 2: Noise level inside a car

Operation mode	Noise level, dB
Nanocleaner switched off	66 – 71
Nanocleaner switched on	68 – 73

The measured noise levels with and without nano-particle filter operation indicate some tendency of noise intensification with the Nanocleaner switched on. More detailed study of this issue with frequency analysis of the noise spectrum and development of appropriate noise mitigation measures, if necessary, may be recommended.

As anticipated, no effect of the nano-particle filter system on concentrations of gaseous pollutants was observed.

Results of experiments with the Nanocleaner in the shuttle taxi are shown in Fig. 6. As mentioned above, in these tests two Nanocleaner units were used and operated simultaneously, due to the big volume of the passenger space in this shuttle taxi van. The measured results show a significant influence of the frequent door openings on the cleaning effect. During the major part of the test, PN concentrations did not fall down below 8000 cm^{-3} with a rise back to the almost ambient levels with door opening. It can be assumed that average levels of PN concentrations inside a shuttle taxi may be reduced by appropriate adoption of the filter productivity (filtered air flow rate) to air exchange volume during a shuttle taxi operation.

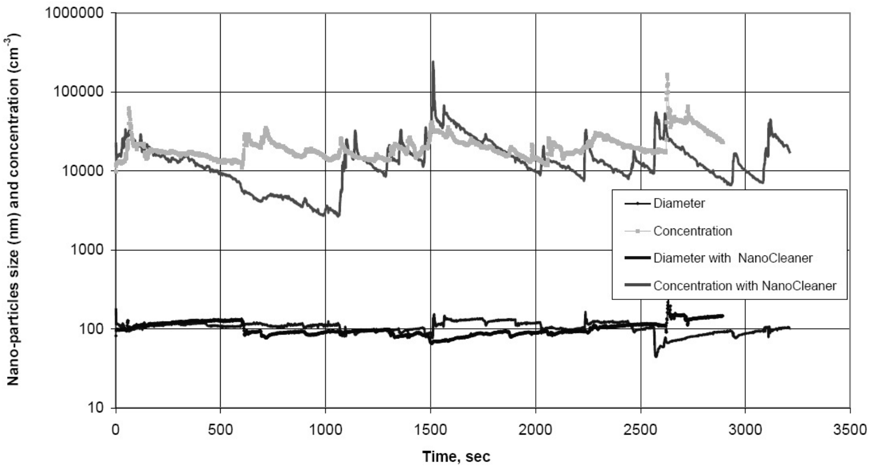


Figure 6: Measurements of nano-particles size and concentrations inside a shuttle taxi.

Conclusions

Results of experiments demonstrated that dedicated nano-particle filter system allows significant reduction up to 99% of particle number concentrations inside a vehicle. Some minimal time is required, in order to achieve maximal cleaning effect. The results of experiments show that minimal PN concentrations inside a car (about 230 cm^{-3}) were achieved after about 25 min of filter operation. Use of nano-particle filter leads to some increase in size of particles measured inside a vehicle compared with ambient air data.

The measured noise levels with and without nano-particle filter operation indicate some tendency of noise intensification with Nanocleaner switched on. A more detailed study with frequency analysis of the noise spectrum and development of appropriate noise mitigation measures, if necessary, may be recommended.

Acknowledgements

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