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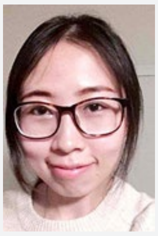
https://www.aivc.org/resource/hepa-filters-improve-vehicle-cabin-air-quality-advantages-and-limitations

Hepa Filters to Improve Vehicle Cabin Air Quality



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Vehicle cabin is one environment challenged by small particles like $PM_{2.5}$. This study investigates the application of HEPA/EPA filter in two-step filtration, for improving vehicle cabin air quality throughout lifetime, considering a balance between space, pressure-drop and filtration performances. It also highlights the importance of extended evaluation scenarios.

Keywords: Pre-filtration; HEPA; vehicle cabin; particulate matter; HVAC

Introduction

Maintaining a good indoor air quality level has received growing attention. One important focus is the airborne particulate matter, especially small particles like $PM_{2.5}$ (particles of aerodynamic diameter less than 2.5 µm) and UFP (ultrafine particles, aerodynamic diameter less than 100 nm). The main protection in vehicle is heating, ventilation, and air-conditioning (HVAC) filter. However, they are mainly limited by loss of efficiency as ageing, and normally lower removal at around 100-300 nm (Xu et al. 2011).

A comprehensive study on the state-of-the-art performance, including field measurements in cars (Wei et al. 2020), development of a model to simulate the air quality (Wei et al. 2022) and the energy use under different air recirculation (Wei et al. 2023) have been carried out.

There is now interest to introduce filters with higher efficiencies, such as HEPA (High-Efficiency Particulate Air) or EPA (Efficient Particulate Air) filters. The dust loading, unlike traditional cabin filters, normally elevates the filtration efficiency. While the limitation is high pressure-drop. Lee and Zhu (2014) studied applying improved filters in vehicles, which showed up to 93% removal of UFP, yet lead to 7% to 22% decrease of the airflow rate.

This study investigates one potential improvement, an EPA/HEPA-filter placed in the engine bay as a pre-filter for the original HVAC-filter. Reduction of $PM_{2.5}$ and UFP were compared through lab and road measurements. Other factors including pressure-drop, and practical installation limitations in the vehicles are investigated.

Methods

The two pre-filter prototypes (P1, P2) have similar design, pleated particle filter made of multi-layer synthetic fibre. P2 (HEPA level) has slightly higher efficiency than P1 (EPA level). The tested vehicle's original HVAC filter is an electrostatically charged multi-layer synthetic filter with activated carbon. The main difference of pre-filters is the media design to achieve much higher efficiencies. P2 was also loaded with ISO 12103-1 A2 Fine Dust (International Organization for Standardization, 2016) and environmental cycle to represent an aged filter status.

Two inter-calibrated GRIMM MiniWRAS (Mini Wide Range Aerosol Spectrometer) model 1.371 were used to measure particle mass and number concentration from 10 nm to 35 µm. Two TSI Portable Test Aerosol Generators (Model 3073) were deployed to generate test dust of NaCl and DEHS (Di-Ethyl-Hexyl-Sebacat).

The prototypes (P1, P2) were installed in a VOLVO XC40 BEV as shown in **Figure 1**, connected to the original HVAC system air inlet. Different scenarios were tested: original HVAC filter alone, and pre-filter (P1 or P2) + original HVAC filter.

Figure 1. Pre-filter prototype installation in an existing production vehicle's thermal compartment.

Results

Clearly the application of pre-filter, either P1 or P2 enhances the removal of particles, as shown in **Table 1.** Similar results were achieved with generated particles. Even after P2 is loaded with dust to represent aged status, the same removal was maintained.

When comparing the removal in different size channels, higher than 97%, up to 99% removal of particles are achieved with P2 + original filter with all particle types. For example, in **Figure 2,** the removal at MPPS is 69% for road particles with HVAC filter only. This enhancement is very important since UFP

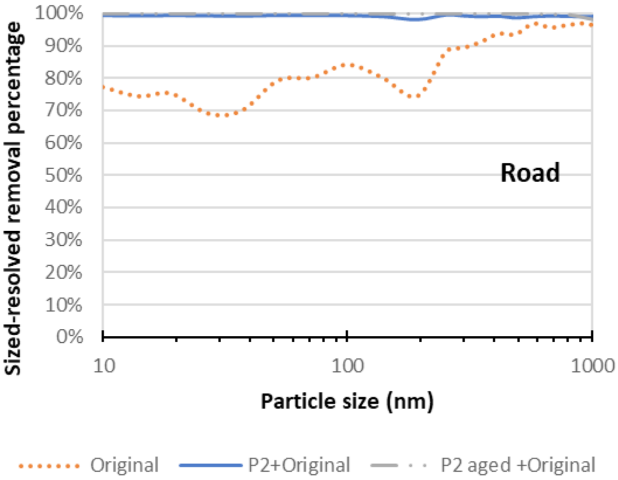

Figure 2. Size-resolved in-cabin removal percentage of particles in the vehicle measurements with road particles. Plotted data are the average of all repetitions. Original: the original HVAC filter alone. Airflow Low level (around 40 L/s), no recirculation. The P2 aged+original line almost overlap with P2+Original line.

Table 1. *Comparison of in-cabin removal percentage of UFP and PM2.5 with different filter combinations. Measurements performed with road particles in Lundby tunnel, Gothenburg, Sweden. Original: the original HVAC filter alone. Airflow Low level (around 40 L/s), no recirculation.*

	Removal percentage of road particles			
	PM2.5		UFP	
	Arithmetic Mean	Standard Deviation	Arithmetic Mean	Standard Deviation
Original	86.8%	3.9%	75.7%	5.9%
P1	97.6%	0	93.1%	0
P2	98.3%	0.5%	98.7%	0.5%
P1 + Original	99.7%	0	96.0%	0
P2 + Original	99.1%	0.7%	99.3%	0.6%

has more potential of entering human body, thus lead to cardiovascular problems.

Conclusions

Two prototypes were tested feasible with regards to achieving better cabin air quality. The vehicle removal of $PM_{2.5}$ was improved from 87% to 99% with both prototypes. The removal of UFP was improved from 76% to above 96% with prototype 1 and 99% with prototype 2. This performance was also maintained with an aged prototype 2. It means that the service interval is possibly mainly dependent on the pressure-drop increase and other aspects like gas adsorption, microbial growth etc., not the particle efficiency.

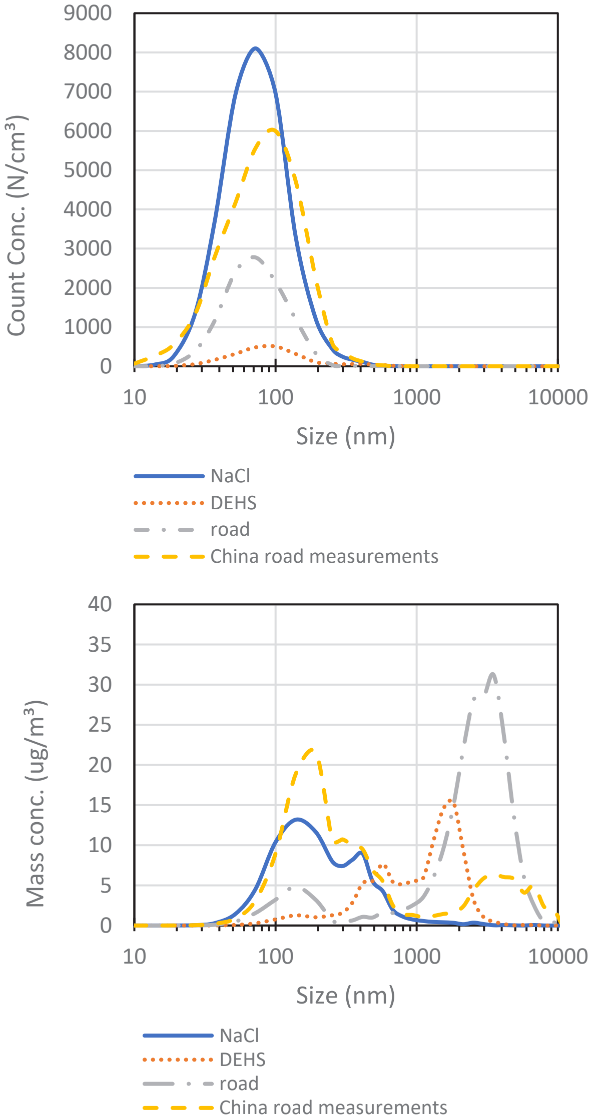

Figure 3. Outside air particle size distribution comparison of both count concentration (N/cm^3) and mass concentration(µg/m^3). Examples of the generated dust of DEHS, NaCl, road air in this study and a previous measurement in China 2019 (Wei et al. 2020) are compared. Four examples all have $PM_{2.5}$ concentration around 100 µg/m^3.

On the other hand, the choice of filter quality in real vehicles would be a complex balance between filtration efficiency, dimension, cost, climate comfort and pressure-drop to reduce the fan power, i.e. the energy consumption and to reduce NVH problems. For example, the application of P1 would give considerable improvement on filtration as well as adding lower pressure-drop than P2. The cost per filter unit is also normally lower for P1 than P2.

Furthermore, the pre-filters with a protection filter had similar performance and slight increase of the pressure-drop; around 10 Pa. It could possibly extend the pre-filter lifetime if space is adequate. The studied pre-filters could also be applied alone to filter particles effectively, which however demands proper design to required gas adsorption.

This study also aimed at contributing to the development of vehicle particle filtration test methods, especially by comparing on road tests and lab tests with generated particles. Different characteristics and behaviours of particles are observed. The same vehicle test setup of original HVAC filter removes 76% of road UFP, while corresponding values for DEHS and NaCl are 78% and 94%. This could be related to the particle characteristics such as size distribution (As shown in **Figure 3**) and particle loss in the ducting (Jeong et al. 2009). This points out the need of further correlating standardized tests with real road conditions, where the latter is the user scenario.

The findings provide inputs to the design of vehicle climate system with good air quality and pressure-drop balance. Relationships among efficiencies, pressure-drop and filter age could be further studied to facilitate the decision on proper filter service interval.

Acknowledgements

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References

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