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Development of a methodology for in-board assessment of the efficiency of air quality filters

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1 Introduction

As large contributor of fine particles, road transport is a major concern for motorist and leads to a continuous improvement of HVAC systems and cabin filters. For the latter, performance evaluation is mainly tested in laboratory according to standards (e.g. ISO/TS 11155-1) (i) with normalized particles which are not representatives of the particles found in urban air and (ii) with the use of optical indicators that make measurement assumptions e.g. a constant particle density.

Thus, there is a lack in the literature about the efficiency of cabin filter in real conditions. Only, few studies concern the determination of the efficiency of a cabin filter in real roadway conditions (Liu et al. 2011), and all of them use optical indicators.

Therefore, the project QABINE 2 (Qualité de l'Air dans les haBItacles eN déplacEment 2) aims to develop a protocol for the evaluation of the filtration efficiency of cabin-filters under real driving conditions near Paris.

Here, the aerosol sampling methodology developed for QABINE 2 is presented with emphasis on describing how the sampling point upstream the filter was designed in order to be representative of the outside air concentrations sucked by HVAC system of the vehicle. Then, the efficiency evaluation of two different filters is performed through two in-field campaigns and almost thirty-seven different tests.

2 Materials/Methods

As defined in standards, the cabin-filter efficiency assessment is evaluated by comparing gravimetric concentrations upstream and downstream of the filter.

Based on previous results, the downstream sampling point of the cabin filter (in cabin) has been placed at the respiratory level of the front-seat passenger to provide also indoor air quality data (Queron, 2017).

Regarding the sampling of particles upstream of the cabin filter, it was performed using a sampling line in the cowl portion (Figure 1).

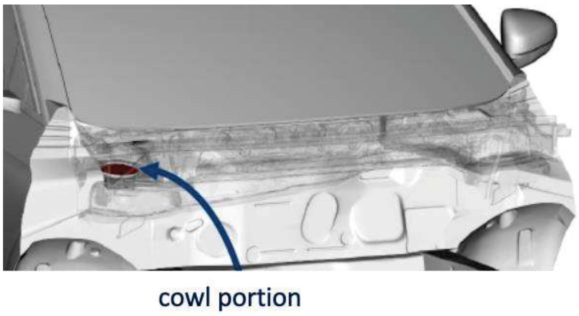

Figure 1: Scheme of a cowl portion through which outside air passes to be filtered and come in passenger cabin.

In order to assess the sampling efficiency of the upstream sampling line, the cowl portion was studied with (i) wind-tunnel tests to know the speed of the air (ii) Computational Fluid Dynamics (CFD) simulations to know the trajectory of the air and, (iii) "Particle Loss Calculator" (PLC) software to estimate particle losses based on the geometry of the line and on the major physical mechanisms to which particles are subject in such situations.

Regarding the in-field tests, the two sampling campaigns were undertaken with a car moving in the Paris area, mainly motorways.

PM_1 and $PM_{2.5}$ were collected during 37 tests by the cascade impactor PM10 Impactor Dekati® equipped with Quartz Filters (Pall®, 25 mm and Whatman®, 47 mm) at a flow rate of 30 L/min for 3 hours. The weighing values were obtained according to the recommendations of NF ISO 15767 and EN 12341. Then the average particulate mass concentrations and the associated filter efficiencies for each test performed were evaluated. During these campaigns, two different filter were tested.

3 Results and Discussion

The inlet sampling line was placed according to the literature, in front of the air flow (Baron and Willeke 2005), thanks to the CFD results of air flow modelling.

The results of the wind tunnel tests showed that (i) the speed of air in the cowl portion depends of the ventilation and (ii) it is stable when the vehicle speed is between 0 and 80 km/h.

All the parameters (sampling line parameters, trajectory and speed of air flow in the cowl portion) have been input into PLC to determine the sampling efficiency of the upstream measurement. The results of the software showed that some parameters have an important influence on the particle losses in the line in our conditions (a high flow rate in the sampling line), e.g. bends in the line. Thus, optimizations of the sampling were done: the impactor was laid on the ground in front of the passenger seat and the glove compartment was removed to make the line as straight as possible and short.

The results of PLC showed a sampling line efficiency above 95% for the particles with an aerodynamic diameter below 1 µm and between 75 and 95% for the particles with an aerodynamic diameter between 1 and 2.5 µm.

Such modifications allow a representative sampling upstream of the filter and in accordance with gravimetric measurements standards.

Once this first phase done, the efficiency of the cabin filter was calculated with the downstream -upstream method during in field-tests near Paris. The protocol has been tested on 2 different cabin filters in real conditions for PM_1 and $PM_{2.5}$. The average filtration efficiency of Filter A is 54% for PM_1 and 58% for $PM_{2.5}$. For Filter B, the average filtration efficiency is 53% for PM_1 and 56% for $PM_{2.5}$.

4 Conclusion

The protocol of QABINE 2 is a first gravimetric protocol to know the real efficiency of a cabin filter. We can also imagine replicating this protocol for the filtering efficiency of gases.

The protocol could be improved: the downstream sampling point could be closer to the cabin filter (but we will not have air quality data at respiratory level), the measurement in cowl portion need to be corrected to calculate the sampling efficiency (there is a sampling line for the upstream sampling point but not downstream the sampling point).

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