# PERFORMANCE OF AUTOMOTIVE CABIN AIR FILTERS

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## ABSTRACT

The cabin air filter performance is of prime importance for the air quality in vehicles. New clean filters were tested but also filters loaded with actual traffic contaminants. Both laboratory and field measurements were included in the study. Direct reading instruments and filter sampling was used for the loading rate determinations. The filter performance includes particle filtration efficiency with regards to particle size, filter loading and flow rate as well as filter pressure drop related to filter loading. Test results for these parameters are presented. The results indicate that present car cabin fibre filters could be considerably improved, if restriction in fan power use could be overcome.

## INTRODUCTION

EPA's new Ambient Air Quality Standard for Fine Particulate Matter ($PM_{2.5}$) [1] emphasises the importance of the smaller particle sizes. The standard sets the annual limit at 15 micrograms per cubic meter per day averaged over the whole year, with a 24-hour peak limit of 65 micrograms per cubic meter. Many people spend several hours a week in some kind of vehicle where they are exposed to high levels of different air contaminants. Despite harder regulations on engine exhaust in the future, road traffic will continue to provide a major pollution source, with people exposed in close proximity to the source.

The aim of this work has been to develop a method for measuring the characteristics of cabin air filters and to test a number of actual filters both in laboratory air and in outdoor air in traffic. The test results are applicable for the actual use of filters in cars.

## METHODS

The measurement strategy was based on the practical possibilities of determining the particle filtration efficiency and of loading the filters with actual traffic contaminants. A number of filter media mounted in standardised filter frames with a face area of 0.04 $m^2$ were tested. The suppliers of the filter media were unknown and Volvo had made the technical specifications. We used the laboratory indoor air as the challenge aerosol for the fractional efficiency tests in our laboratory. This provided a more constant aerosol source than what is available in the ambient air.

The particle concentration was measured simultaneously with two different types of instruments. The first instrument was a TSI-3030, which measures an electromobility equivalent diameter between 0.01 - 1.0µm in eight intervals [2]. The second instrument was a PMS LAS-X, which measures an optical diameter between 0.1 - 6.5µm in 16 intervals [3]. Two of each type of instrument was used, with one placed before and one after the filter. To normalise the instruments against each other, the test duct system was also collecting data without a filter before and after each filter was tested. It was therefore not so critical to keep the particle concentration constant during the laboratory testing. Air pressure drop and the filter fractional efficiency measurements were performed at flow rates of 70 L/s, 35 L/s and 105 L/s. The air flow rate through the test system was determined by measuring the dynamic pressure drop across a calibrated measuring duct located after the filter but before the fan. Temperature and humidity was also recorded.

After the measurements in the laboratory, each filter was exposed (loaded) to traffic contaminants. The filters were placed at the suction end of a separate fan system [4]. These systems were placed inside a trailer with open windows, which was specifically furnished for these measurements. The trailer was placed near one exit in one of Stockholm's road tunnels (Soderledstunneln), which has two separate parallel tunnels and is around 1500 m long. Normally there is no ventilation except from the cars' movements and the temperature difference. The flow rate in the tunnel we used had earlier been measured and varies between 200 and 300 $m^3$/s.

The higher concentrations of particles in the tunnel in comparison with outdoor streets made it possible to shorten the time necessary to find the filters' lifetime and pressure-loading curve. The shorter time span still allowed the same composition of contaminants to which a normal car filter is exposed. In this way, the filters could be contaminant-loaded rapidly, under the same conditions for all filters and in a heavy traffic environment. After each loading sequence, the airflow was adjusted back to the nominal 70 L/s and the pressure drop registered together with the loading rate.

Direct reading instruments and filter sampling was used for the loading rate determinations. All cabin air filters were weighed at 25 °C and 50 % RH before loading. After the filters were loaded to an estimated lifetime of one year in a car, the filters were again taken to the laboratory, conditioned for at least one day, and weighed. In this way, the total collected amount on each filter was calculated. This was followed by a new penetration test with particle counters in the laboratory. By measuring before and after loading, the influence of filter loading on the pressure drop relation and on the filtration efficiency was also studied. The efficiency to remove the gases VOC, $NO_2$, NO and $CO_2$ of another group of filters that can filter both gases and particles was also measured in the road tunnel. These measurements and results will be published separately.

## RESULTS

The measuring possibilities were limited by the traffic conditions during the field loading. However, a good set of data on pressure drop at a constant flow rate as related to filter loading in terms of PM10 and TSP could be obtained. The total cabin filter loading measured as an increase of the cabin filter weight, could not be used for estimating filtration efficiency or for ranking filtration performance.

The initial pressure drop varied little between different specimens of the same filter type. The initial pressure drop for the new filters with an airflow rate of 70 L/s was 40 to 80 Pa. The increase of the pressure drop with increasing loading varied considerably between different filter types. A typical increase for a filter loading of up to 3 - 4 g $PM_{10}$ was on the order of 100 Pa, but with large differences between the filters. The increase of the pressure drop up to this loading was close to linear, but at higher loading the pressure drop increased more than linearly. Figure 1 illustrates some typical performances of different filters.

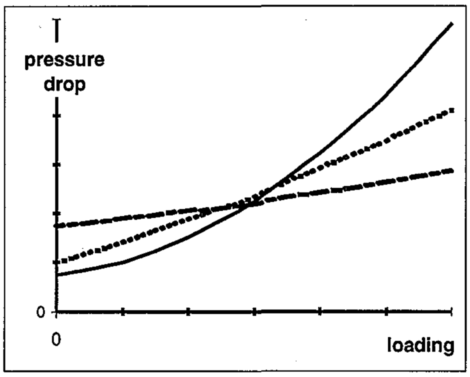


Figure 1. Pressure drop increase with filter loading

As expected, the Most Penetrating Particle Size, MPPS, was around 0,1 - 0,35 µm and the penetration was approximately the same in the whole interval. Unloaded filters of better quality showed a typical penetration of about 55 % in this particle size interval, at an air flow rate of 70 L/s. The differences in penetration are shown for the three air flows in Figure 2, after one of the better filters had been loaded with 6.9g $PM_{10}$.

It is known from filter theory and verified in Figure 2 that, over the smaller and middle sized particle diameter ranges, a lower air flow rate gives a lower penetration. In addition, a loaded filter gives a lower penetration than a new filter.

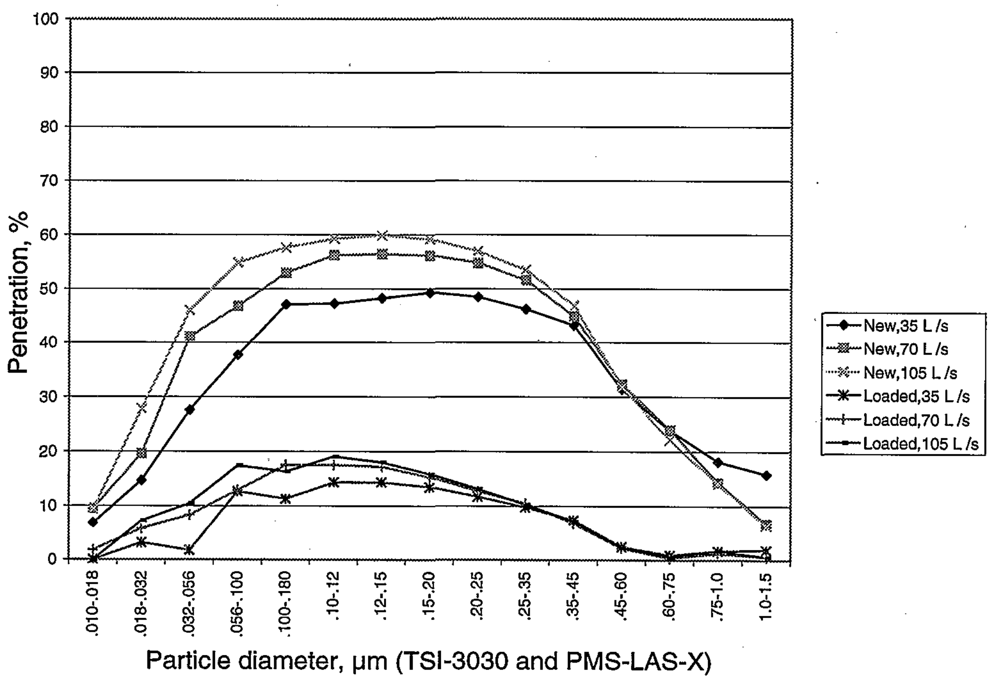


Figure 2. Penetration of different particle sizes at different air flows on a new and loaded filter

The penetration through new filters varied more with the airflow rate than the penetration through loaded filters. In general, for the better filters an increase of the flow rate to 105 L/s increased the pressure drop over the new filter with around 60 % and penetration increased from 55% to 60%. The same amount of decrease (from 70 to 35 L/s) resulted in a decrease in penetration to 35 - 50%, while the pressure drop decreased by around 60%. The results were much less uniform after the loading. The temperature in the lab was 18 - 21 °C and the humidity was 15 - 30% RH during the testing of new filters. During the testing of the loaded filters, the temperature in the lab was 18 - 22 C° and the humidity was 30 - 60% RH.

The spread in penetration between the unloaded filters from the same company was commonly small, which indicates a good test reproducibility, see Figure 3. The number of particles >1.5μm in the laboratory was too little to make a reliable estimation of the penetration of those larger particles.

In Figures 2 and 3, the horizontal axis includes two different types of particle diameters, because of the two different types of instrument principles. The overlap around 0.1 μm between the two instruments is displayed deliberately to show that the penetrations are similar despite the different measuring principles. This makes the results more reliable.

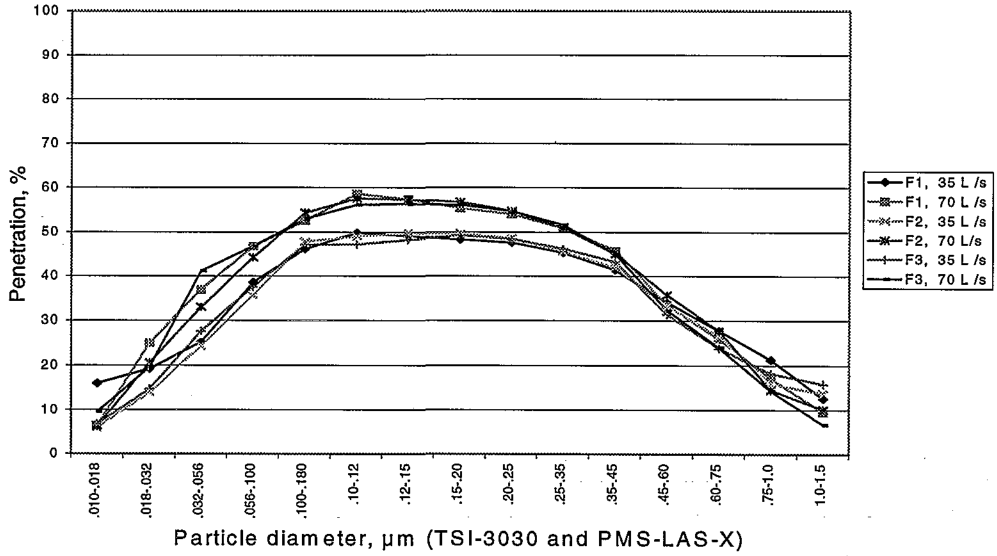


Figure 3. Penetration of different particle sizes at different air flows for three new filters from the same company

Loaded filters showed in general a lower penetration than new unloaded filters. Some filters, probably with electret fibres, showed a higher penetration after loading or at some period during loading. Figure 4 illustrates an overview of the penetration and pressure drop qualities of the fibre filters that were tested. An ideal filter should perform close to the lower, left-hand corner during the whole lifetime of the filter. Today there are no cabin fibre filters with that ability.

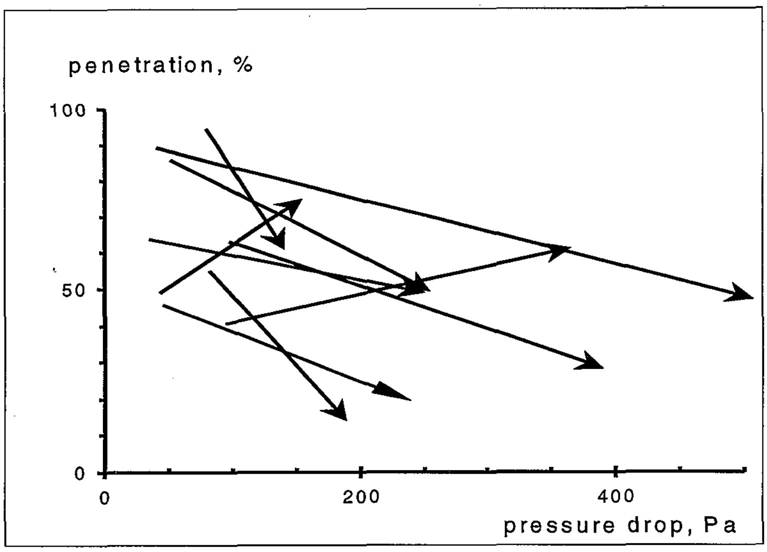


Figure 4. The penetration for the particle size range (0.20 - 0.25μm) versus pressure drop for all the tested filters, unloaded → loaded filters. The lines connect two measured points at the beginning and end of each arrow and only signify the direction of penetration change

## DISCUSSION

Maximum penetration typically occurred for 0.10 - 0.35 μm particles measured with PMS-LAS-X. For each filter, the size of the penetration varied little in this size range. Simplified testing would be possible to perform by measuring for one particle size.

New filters of better quality and 70 L/s showed a penetration of about 50 % in this size range (0.10 - 0.35 μm particles). New filters of worse quality showed a penetration of more than 90% in this size range. This means that the fibre filters in many vehicles today have a marginal effect on particles from vehicle exhaust. Other sources in this size range are atmospheric transformation products of $NO_x$, $SO_2$, and organics including biogenic organics, e.g., terpenes [6].

As a comparison, we also tested a high efficiency filter during the last loading experiments. The penetration for 0.2 - 0.25 μm particles was less than 0.1 % but the pressure drop was as expected also very high. Loaded filters mostly showed a lower penetration but at significantly higher pressure drops. Particle filters with collected contaminants may emit compounds from the collected loading, which give off odours. This may necessitate the use of both gas and particle filter combinations. Gas filter in general is motivated in a heavy traffic environment. That means the pressure drops over the cabin air-filter system becomes even more demanding. Since all our measurements were performed as blind tests, except one high efficiency filter, we had no possibility to include detailed descriptions of the filters, other than through their performances.

The laboratory indoor air as the challenge aerosol had not enough PMS-LAS-X particles >1.5μm, but in practice it can be assumed that a good fibre filter will collect these bigger particles. The same situation exists for the TSI-3030 measurements for particles >0.32μm.

The loading procedure used in the tunnel, with all the filters loaded simultaneously and in a real road traffic environment, is not a representative outdoor environment in any controlled way, but instead provides results in one real city situation.

Contemporary cars are quite airtight, which means that the concentration of contaminants in incoming air has a very large influence on the concentrations of contaminants in the cabin. The air flow rate varies in a car, but a rather normal flow rate of 70 L/s (250 $m^3$/h) gives an air exchange time constant of about 1 minute (60 air changes per hour). The concentration inside the cabin quickly follows the concentration of the incoming air pollution. It therefore makes sense to lower the fan rate when you are travelling in a heavy polluted area or a tunnel, and keep the distance to the vehicle in front of you not only for safety reasons.

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