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New Filtration Concepts for Cabin Air Filters

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Introduction

The first Cabin Air Filters had been installed in cars in the late sixties of the last century. Filter mats known from air filtration for buildings had been used in a few luxury passenger cars to filter coarse dusts out of the air and to keep the interior clean. Due to the weak filtration performance of these coarse filters, the filtration of the intake air of vehicles never became accepted neither by the automotive industry nor by the car drivers. Developments to design more sophisticated and tailor-made cabin air filters started about 1985 and after several years of investigation and extensive validation test phases the first high efficient Cabin Air Filter (CAF) was introduced to the market in 1988/1989 to improve significantly the air quality in the car interior and to protect the passengers against pollen and other fine dust particles. Freudenberg's micronAir filters, made from a multilayer nonwoven fulfilled all technical requirements of this new application and were from then on successfully adapted to various new vehicle launches. These filters were called "Pollenfilters" or "Dustfilters".

In 1995, combination filters, comprising a particle filter medium and a layer of gas and odor adsorbing granulated activated carbon (GAC), were introduced to the market. In addition to particle removal, combination filters adsorb harmful gases and unpleasant odors from the incoming air.

Today, the ongoing development and optimization of the filter media for CAF is always motivated by the atmospheric pollution situation. Due to periodic variations and regional differences of the air pollution, the development of filter qualities always has to follow these different demands in order to meet the challenges thereof. Depending on the local pollution situation and thus different regional requirements the CAF can be customized by using suitable filter media qualities; filters from worldwide platforms e.g. have to be modified for local demands to meet the lifetime requirements in the different geographic regions at higher/lower pollution levels. The air pollution in South America and Asia is different compared to Europe or USA resulting in filter media characterized by adapted performance levels.

Evaluation of CAF

Requirements for the construction and use of HVAC systems in cars, which influence the function and design of CAF are set in recently introduced regulations like VDI 6032 ("Hygiene standards for ventilation technology in passenger vehicles") [1] and DIN 1946-3 ("Ventilation of passenger cars and commercial vehicles") [2]. These regulations specify the need for the installation of CAF in vehicles not only for fresh air, but in excess they strongly recommend the use of CAF for recirculated air. In order to prevent any possible hygienic irritation to the passengers, VDI 6032 describes the state of the art of ventilation systems for transportation vehicles and postulates various design restrictions which will have an important impact on all future vehicle developments. The CAF installed in the vehicle or the HVAC system are specified by a minimum filter efficiency and a maximum 2-years service interval – in case of a heavily polluted environment the exchange of CAF should be done more often.

Important for filter media used in CAF is DIN EN ISO 846 [3]. The aim of this standard is to determine whether the filter media is inert or if it is a nutritious substance for the growth of microorganisms. The filter media under test is contaminated during two separate examinations with a spore suspension of various fungi and a bacteria cell suspension. After an incubation period of 4 weeks at defined thermal conditions a check follows to examine the intensity of fungal or bacterial growth on the samples. The results are rated into classes of 0-5. Growth intensity ratings of 0-1 for both kinds of microorganisms give a clear indication, that the materials under test can be considered as harmless for the use in HVAC applications. This test method has already been established and accepted for filter materials used for HVAC systems in buildings, described in VDI 6022-1.

Standard test methods for evaluating the CAF performance against particles and gases are described in DIN 71460, part 1 [4] and DIN 71460, part 2 [5]. These test procedures are established to compare the filter performance under standardized laboratory conditions. These DIN tests do not reflect the filter performance under real conditions. New test methods describing the real life situation for this application have to be established for the evaluation of the "realistic" performance of cabin air filters additionally.

Pollution situation and impact on filtration requirements

Filtration requirements for CAF are driven by the nature and the concentration of particles and gaseous substances in the air and their change in the course of time [6, 7].

In the case of particulate emissions:

- A decrease of the total particle emission of approximately 70% is reported between 1990 and 1996. Other sources report a decrease of the total particle emission between 1994 and 2000 by 18 % .This information is based on the established method of recording the total dust emission without differentiation into particle size classes (average concentrations 10 – 250 µg/m³). In order to focus on the particulate emissions, at first the PM10 definition was introduced and in the meantime nearly all immission data measured are based on PM10 pollution data (annual average limit-value for PM10 is 40 µg/m³). On the one hand the total mass of emitted particles is decreasing, but on the other hand the number of particles is strongly increasing as the emitted particles are getting smaller. Due to the fact, that the maximum probability for particle deposition in the lung is proven for 2 µm particles (respirable particles) the need for the determination of PM2,5 emission data was realized. In USA the monitoring of PM2,5 already started and a similar trend can be seen in Europe, in spite of the technological difficulties in measuring the PM2,5 value. One reason for the increase of PM2,5 particles in the atmosphere is due to the number of diesel-engine vehicles which increased in Europe, reaching e.g. 40% of newly registered cars in Germany in 2004. According to the Swiss Federal Office of Environment, Forest and Landscape [8], this results in a reduction of the CO_2 output, but increased the NOx emission by a factor of 3 and the release of the number of fine particles by a factor of 1000.

In the case of gaseous emissions:

- Typical NOx concentration in regions with normal traffic is approx. 70 µg/m³ with peak concentrations of up to 150 µg/m³ - the annual average limit-value is 40 µg/m³.

- On the other hand an approximately 35 % decrease of SO2 emissions from 1994 until 2000 is reported; because of improved incineration processes and the use of low sulphur petrol a further drop is expected (typical concentration in regions with normal traffic is approximately 10-30 µg/m³ – the 24h average limit-value is 125 µg/m³).

- Furthermore an approximately 20% decrease of VOCs' emission between 1994 und 2000 is monitored as a result of traffic emission regulations. A further drop can be expected with the ongoing implementation of the traffic emission regulation EURO 4. Typical concentration (1998) vary between 20 µg/m³ (region with clean air) and 180 µg/m³ (region close to traffic). Most found VOCs are Benzene, Toluene and Xylene.

- From 1990 onwards the Ozone concentration in the atmosphere increased slightly up to approximately 50 µg/m³ (average concentration for regions close to traffic). Peak concentrations of 300µg/m³ of air are not uncommon in the summer months and can lead to smog alarm and health irritations for sensitive human beings.

Figure 1 shows the average air pollution situation in Germany from 1995 until 2002 for some selected particulate and gaseous pollutants [9].

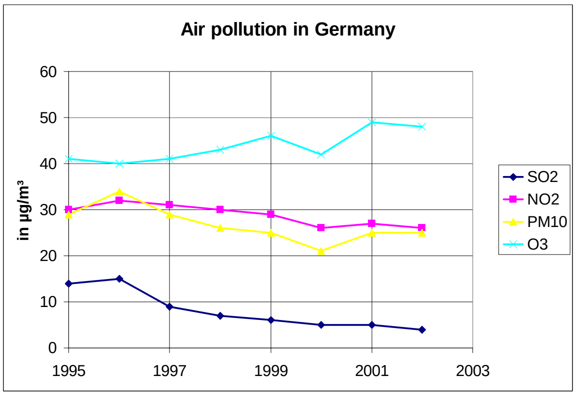

Figure 1: Air pollution in Germany (average values)

Test methods for particle filters

Today's established test methods for the comparison of cabin air filters under lab conditions are described in DIN 71460-1. The efficiency against particles and the dust loading capacity is tested with the synthetic test dusts AC-fine or AC-coarse according to ISO 12103-1. Both test dusts don't reflect the atmospheric situation but they are used to allow reproducible lab test comparisons between different filters at shortest possible test times. The dust concentrations to be set during the DIN test are significantly higher compared to any polluted real atmospheres. Using AC dust for fractional collection efficiency and dust loading capacities result in unrealistic values because of their chemical composition and particle size distribution.
In order to overcome these difficulties and to achieve more realistic filter performance data the CAF can be challenged with atmospheric aerosol, which represents realistic atmospheric conditions and corresponds to a nearly neutralized potential. But this test method is only feasible if the variation of the atmospheric aerosol is known and long term experience for the interpretation of the test results exists. The direct comparison of test results between different test labs in various locations is impossible, but when running the tests on the same test rig and under the assumption that the variation of the atmospheric aerosol is known, these results can provide a good overview about the "realistic" performance of a filter. Filter media which show slightly different efficiencies when tested according to DIN 71460-1, can easily be differentiated when tested against atmospheric aerosol. Thus these measurements are important input variables for ongoing filter media developments.
Another option to simulate the "realistic" efficiency of CAF is the use of Sodium Chloride as test aerosol. This method is a reproducible procedure in accordance with DIN 71460-1 and allows the evaluation of filters in the submicron particle size range between 0,02 – 0,5µm.
Figure 2 shows the fractional collection efficiency with different test aerosols – AC coarse, Sodium Chloride and atmospheric aerosol under comparable conditions.

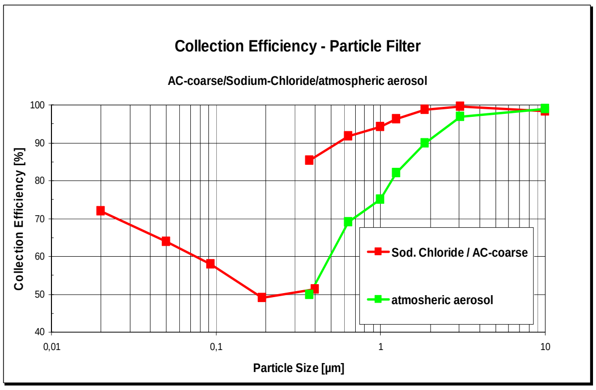

Figure 2: Fractional Collection Efficiency with different aerosols

Test methods for combination filters

Today adsorptive filters are tested according to DIN 71460-2 using n-Butane, Toluene and SO2 as test gases. Alternative gases like NH3 and NOx are possible too. Common for all gases are the high gas concentrations fed into the test rig (80ppm or 30ppm) which are far away from realistic concentrations in the normal atmosphere.

The search for alternative test methods representing the "realistic" adsorptive performance of CAF led us to the modification of the test procedure to run adsorptive tests under low ppm (~10ppm) or ppb concentrations. In all these cases the test method is based on the use of synthetic single gases. Measurements with gas mixtures under ppb concentrations are not state of the art. This leads to the conclusion, that all standard test methods do not necessarily reflect adsorption efficiency under real conditions, i. e. they are not suitable to test the filter according to the ability to improve comfort and wellness in the passenger cabin.

In order to resolve this problem, a method for testing the odor reduction of CAF by olfactometric measurements following DIN 13725 [10] was developed. This method gives additional information about the filter performance and allows for new optimization and development strategies.

Olfactometric measurements are done according to the VDI standard 3882 part 1 [11]. These measurements allow to determine the odor detection threshold. The odor threshold is defined as the odor concentration at which 50% of a defined population perceive an odor. At the threshold the odor concentration c_t of the sample is 1 OU/m^3 (OU: odor unit) by definition.

Four test persons determine the odor threshold of the samples by means of a so-called olfactometer. The olfactometer dilutes the samples to be tested with neutral air, starting at high dilution. Successively, the dilution factor is decreased by factor of 2 in each step until all test persons perceived the odor in two successive dilution steps. Every sample is measured three times. The dilution factor is taken at that point where half of the test persons perceive an odor. From the dilution factor z and the odor threshold concentration c_t, the odor concentration of the sample c_{od} can be calculated:

$$c_{od} = z * c_t \qquad (1)$$

Since odor perception is a logarithmic function of the odor concentration, the odor level is defined as:

$$c_{od,\, dB} = 10 * \lg c_{od} \qquad (2)$$

This means that a change in concentration (dilution) by a factor of 2 corresponding to a $\Delta c_{od,\, dB}$ of 3 dB_{OD} can be perceived by one single individuum. The relative odor level, which is subsequently used, is defined as:

$$c_{od,\, dB,\, rel} = c_{od,\, dB,\, fil} / c_{od,\, dB,\, 0} \qquad (3)$$

where $c_{od,\, dB,\, fil}$ is the odor level after the filter and $c_{od,\, dB,\, 0}$ is the initial odor level of the raw gas before the filter.

Removal of different odors by Freudenberg filter media

Flow-through experiments were performed olfactometrically with defined gases (n-butanol, toluene, n-butylamine, pyridine, acetic acid, ethyl acetate, n-propanethiol), and with real odor mixtures (Diesel exhaust gas, cigarette smoke). A Freudenberg GAC medium, which was developed for application in CAF, was used for filtration. The residence time in the test was adjusted to values, which are typically found in cabin air filtration. Samples were taken before and after the filter element and olfactometrically measured. For all substances, efficient odor reduction was found with the Freudenberg GAC filtration medium (see figure 3). It has to be taken into account that normalization to the initial odor level was done on a logarithmic scale, see eq. (2). This means for example, that the odor level for n-propanethiol (worst case) was reduced by 6 dB_{OD}, corresponding to a dilution factor of 4. Due to an alkaline impregnation of the GAC, odor reduction of acid substances was more efficient than for alkaline or neutral ones (acetic acid vs. ethyl acetate, n-propanethiol, or n-butylamine). In addition to that, complex odor mixtures containing also fine particles as odor carriers like Diesel exhaust gas and cigarette smoke were used in the test. The odor of both mixtures were efficiently reduced by the GAC filtration medium, although the filtration medium did not comprise a particle filter and thus was not able to retain the fine particles in these aerosols. It can be assumed that odor reduction is even higher if a combination filter comprising the GAC medium and an efficient particle filter is applied because odor-carrying particles are removed as well.

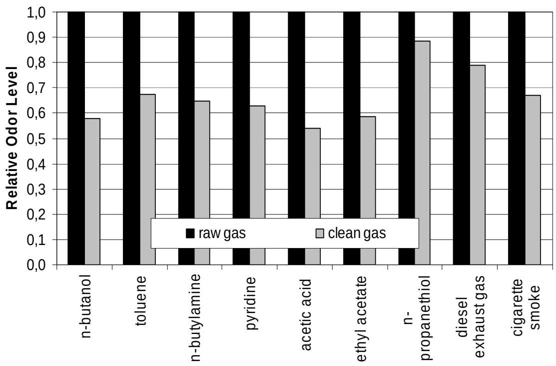

Figure 3: Odor reduction of different gases and real odors by adsorption onto the GAC layer of a Freudenberg filter medium, tested in flow-through experiments.

Particle Filtration Efficiency

There was and still is a trend towards the submicron range in the q0(x) distribution of airborne particles, though dust removal in industry has been greatly improved over the years and the EURO motor regulations for engines resulted in less emission per car.

These submicron particles (indicated by the PM2,5 value) can pass the thorax and get into the alveolar tract of the respiratory system (see figure 5). Part of the very fine particles can be exhaled, but 20-30% remain in the lung for a long period of time and can even enter the blood circulation. As a consequence carcinogenic and inflammatory reactions such as asthma may arise. Additionally these particles are known to be a carrier of odors and toxic substances such as heavy metals and polycyclic aromatic hydrocarbons (PAH).

In the future it is therefore important, that the filtration media has a good fractional collection efficiency in the submicron particle size range. The fractional collection efficiency of a Freudenberg particle filtration medium is shown in figure 4. A large fraction of about 70-80% of submicron particles can be removed by this medium, thus significantly improving comfort and health protection in the car interior.

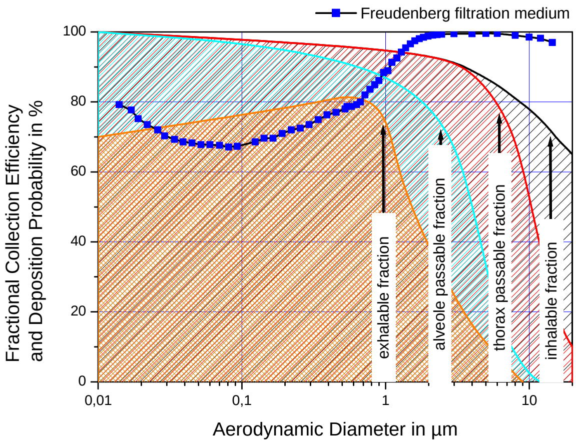

Figure 4: Deposition rate in the human respiratory tract and fractional collection efficiency of a Freudenberg filter media

Summary and Conclusions

The described alternative test methods for CAF are beneficial for close to reality evaluations leading to further characterization of the filter performance and can efficiently be used for media development and optimization. This is especially true when real odor mixtures are used for testing where standard methods like DIN 71460 or other analytical tools fail. The results of our tests clearly indicate, that combination filters comprising a GAC filter medium decrease significantly relevant unpleasant odors in the car interior. GAC has proven to be the best available adsorbent for the reduction of a broad range of different odors. In combination with a particle filter medium, which is highly efficient in the submicron particle range, a filter medium can be designed which is especially suited to meet the requirements resulting from changing atmospheric pollution due to an increasing PM2,5 emission.

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