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## **Recent Developments in Cabin Air Filtration**

**Dr.-Ing. Heinz Reinhardt  
Freudenberg Vliesstoffe KG  
69465 Weinheim, Germany**

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## **Abstract**

The filtration of inlet air into passenger compartments of vehicles has been known since the late eighties in Europe, when predominantly particle filters were installed. Later on there has been a shift on emphasis to the so called “combination filters” which are capable of reducing the particulate and gaseous pollutants at the same time. The reasons for this trend are the increasing health and wellness demands of car owners. The contamination level of our air is different from place to place and has changed over the last years. The arresstance of fine dust particles, VOCs, NO<sub>x</sub> and ozone increase in importance. The paper deals with the performance of new filter materials and introduces olfactometry as a new tool to characterize and specify the real life performance of filters and provide end user focused information in addition to the methods currently used.

## **Introduction**

The installation of cabin air filters (CAF) in vehicles has begun in Europe at the end of the eighties with the premium class vehicles. The idea gained ground very quickly because of the increasing demand for health and comfort related issues. In the

subsequent years cabin air filters have been introduced to all vehicle classes. Initially the manufacturers used only particle filters with the exception of one company which installed additionally so called activated carbon blocks, the aim of which was to adsorb gaseous components.

The purpose of the installation of particle filters was to protect the passengers from harmful dusts originated by industry, traffic and nature, thus it was a product driven by health awareness. The protection of the components of the HVAC systems was an additional goal.

## **Combination Filters**

The installation of activated carbon blocks shows that from early on it was the intention to adsorb gases which are perceived as harmful and unpleasant to passengers. However the concept of the activated carbon blocks could not be transferred to all vehicle classes as they built up too high pressure losses in the HVAC systems.

Therefore the so called “combination filters” or “combi-filters” came into use from 1996 onwards. Combi-filters can capture particles and adsorb gases in one filter element, thus increasing the health and comfort aspect.

Looking at adsorption, the primary goal of combi-filters is the “peak-shaving” of gaseous components by using an

activated carbon layer with the aim to keep their level below the passengers' threshold value of perception.

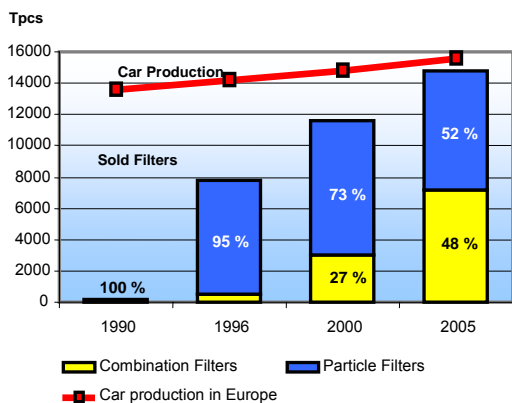


Figure 1: Market development in Europe

Figure 1 gives an overview of the OEM market development for cabin air filters in passenger cars built in Europe (without Russia) in the period from 1990 to 2005. The number of cars built can be taken from the upper line. It increased from a yearly production of less than 14 mio cars in 1990 to about 15.6 mio cars in 2005. Additionally the number of cars equipped with cabin air filters can be taken from the columns for the years 1990, 1996, 2000 and 2005.

Whereas in 1990 less than 0.5 mio filters were installed, this number increased from about 8 mio filters in 1996 to 11.5 mio filters in 2000 and 14.8 mio filters in 2005. The share of combi-filters increased from 5 % in 1996 to 27 % in 2000 and amounts to about 48 % in 2005. Taking into account the aftermarket, the share of combi-filters is even higher as there are companies installing particle filters in OEM only but using combination filters additionally in the aftermarket.

Despite of the growth of combi-filters experienced in this period of time it can be said, that particle filters will not be substituted completely due to technical as well as commercial reasons. The overall installation rate of cabin air filters in Europe is > 90 % for 2005.

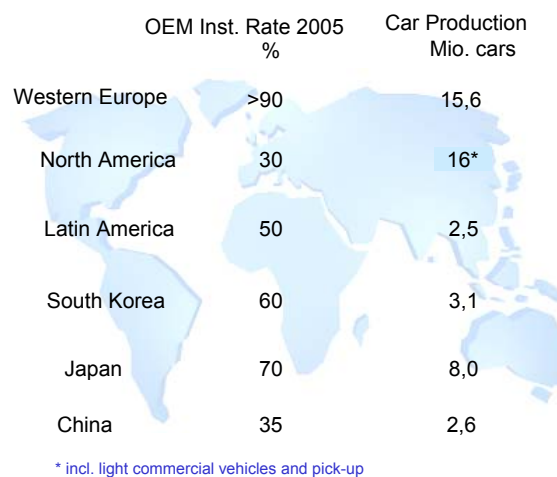


Figure 2: OEM installation rate of CAF world-wide

Figure 2 shows the OEM installation rate of cabin air filters (particle filters and combi-filters) in different regions of the world for the year 2005. It can be seen that cabin air filters are in different stage of their life cycle in the major car producing regions of the world. The installation rate in Europe is the highest with slight differences in the different countries followed by Japan and Korea and the lowest in the USA. The value of cabin air filters should increase based on the world-wide socio-cultural trends like rising health awareness of people, increased comfort demands and the continuing growth of allergies.

Looking at the installation rate between particle and combi-filters, the share of combi-filters is the highest in Europe today followed by Japan, only minor but growing installation rates can be found in Korea and the USA. Vehicle manufacturers in Latin America and

China follow closely the trend of their respective parent companies.

### 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, their changes in the local region and over time.

The source of particles is either naturally occurring (pollen, micro-organisms, dust from the soil and marine environment) or man-made (industry, traffic, household), their concentration is typically in the range of  $< 20 \mu\text{g}/\text{m}^3$  to  $> 200 \mu\text{g}/\text{m}^3$  and their particle sizes vary between  $< 100 \text{ nm}$  and  $> 100 \mu\text{m}$ . Typical atmospheric particle contaminant sizes are illustrated in figure 3.

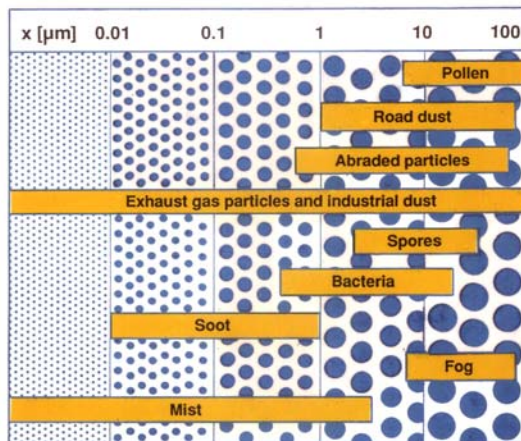


Figure 3: Typical atmospheric particle contamination sizes

In Europe the concentration of total dust in the atmosphere has diminished, but the concentration of the fine dust particles, with their main source of man-made particles from combustion processes, has increased in many densely populated areas. Many cities have problems to adhere to the new

EU threshold limit values for the concentration of fine dust  $< 2.5 \mu\text{m}$  /1/. The most likely area of deposition of the different particle sizes in the human respiratory tract can be taken from figure 4. Whereas particles  $> 5 \mu\text{m}$  stay in the area of the upper respiratory tract, particles  $< 2 - 3 \mu\text{m}$  penetrate deeply into the lungs and can be arrested there

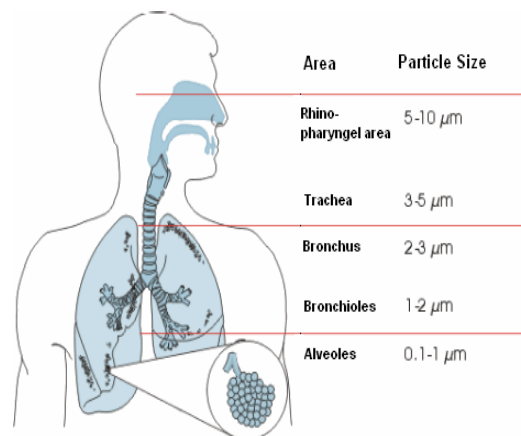


Figure 4: Most likely areas of particle deposition

The particle sizes  $< 2.5 \mu\text{m}$  are important for the total population from the health awareness point of view, additionally problems caused by relatively big pollens ( $> 5 \mu\text{m}$ ) can arise for sufferers from pollen allergies and respiratory ailments.

The main sources of the gas contaminants are naturally occurring and man-made combustion processes from industries, household and traffic; VOCs,  $\text{SO}_2$  and  $\text{NO}_x$  are the main components, VOCs and  $\text{NO}_x$  are precursors of photo-oxidants, especially ozone. Other important emitted gases are acetaldehyde and  $\text{NH}_3$ .

The development of the immission values is different in the different world regions; they have to be taken into

account when developing new filter materials.

Generally it can be said for Europe and the USA that the overall concentration levels for dust and gases have decreased, whereas the concentration levels of fine dust particles, NO<sub>x</sub> and ozone have increased or stayed stable. This means that there is a need for CAF to increase the filtration performance for fine dust particles and the ability to adsorb NO<sub>x</sub> and ozone. The adsorption performance of VOCs by the filter stays important as they are poisonous and carriers of odours, especially in combination with SO<sub>2</sub> (sulphur-organic compounds).

### Measuring the Performance of Cabin Air Filters

Cabin air filters are not safety items and there is no governmental standard for their required performance. However, according to recently introduced regulations like VDI 6032 /2/ and DIN 1946-3 /3/ the filtration of fresh air is specified and for recirculated air the use of cabin air filters is strongly recommended. Both regulations will be important for all future development projects. The CAF are specified by a minimum performance and a service interval of max. 2 years. This should be reduced in cases of a heavily polluted environment.

The performance of cabin air filters is defined individually by every OEM for every development project. The world-wide existing standards to measure the performance of CAF are not identical. They specify a test method but not a performance needed.

In Europe, cabin air filters are tested in most cases according to DIN 71460 part 1 for particle filters /4/ and DIN 71460 part 2 for adsorption /5/. In the

USA ISO/TS 11155 part 1 is used for particle filters and part 2 for adsorption measurements /6/. While the measurements of adsorption characteristics are identical there are differences in the way the performance of particle filters is measured.

### Results of Particle Filter Testing

In figure 5 a typical result of an initial fractional collection efficiency measurement according to DIN 71460 part 1 is shown for a particle filter and for a combination filter of the same geometry.

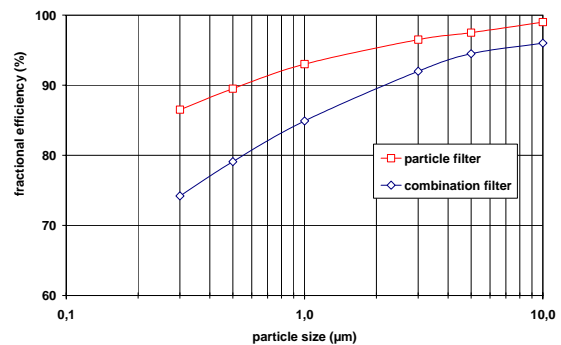


Figure 5: Typical fractional collection efficiencies with test dust A2 (SAE fine)

Typically the particle efficiency values for combination filters are below the efficiency values for particle filters. The limited power output of the blower leads to a limited tolerable filter pressure drop. For a combi-filter the pressure drop consists of the pressure drop of the particle filter material plus the pressure drop of the activated carbon layer. In order to keep the overall filter pressure drop low the particle filter material of a combi-filter thus has a lower particle filtering efficiency. Additionally, the filter area in a combi-filter is lower because of the additional carbon layer which leads to a higher thickness of the whole filter

material. Additionally the pleat pitch spacing is wider.

The reduction of filter area leads to a higher filtration velocity through the filter material and thus to a reduced fractional collection efficiency. Typically 20 – 40 % less filtering surface is used in a combi-filter compared to a particle filter; therefore combination filters show higher initial pressure losses and lower dust holding capacity compared to particle filters with identical geometry.

### Results of Adsorption Tests

The adsorption performance of filters is tested at concentrations of 80 ppm (n-butane, toluene) and 30 ppm (SO<sub>2</sub>). The test is conducted with each individual challenge gas, mixtures of different gases are not measured. The performance criteria for the filter are characterized by the breakthrough values initially and e.g. after 1, 2 and 5 minutes as well as the capacity of the filter element for the gas tested. The capacity of a filter is defined as the mass of the gas adsorbed at 95 % breakthrough value of the challenge gas. Typical breakthrough graphs for n-butane, SO<sub>2</sub> and toluene can be found in figure 6. The measurement in this case was stopped after 15 minutes for each gas.

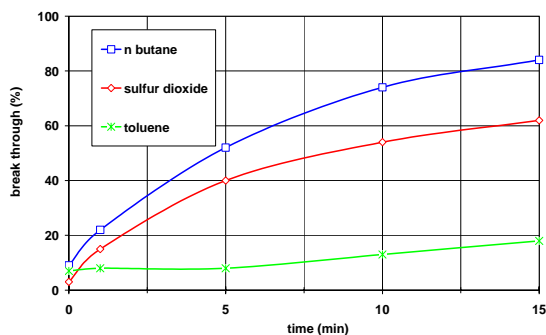


Figure 6: Typical breakthrough graphs

It can be seen that the use of n-butane results in the highest initial breakthrough values compared to SO<sub>2</sub> and toluene. The time to reach the capacity is the lowest for n-butane; normally the capacity (i.e. the 95 % breakthrough value against n-butane) is reached after up to 30 minutes, whereas it takes hours to finalize capacity measurements with toluene and SO<sub>2</sub>. This is one reason why n-butane is the preferred and the most frequently used test gas.

Figure 7 and figure 8 present another test result with n-butane as the test gas. The test was carried out in the course of the development of a filter material with improved kinetic behaviour by using a newly developed activated carbon.

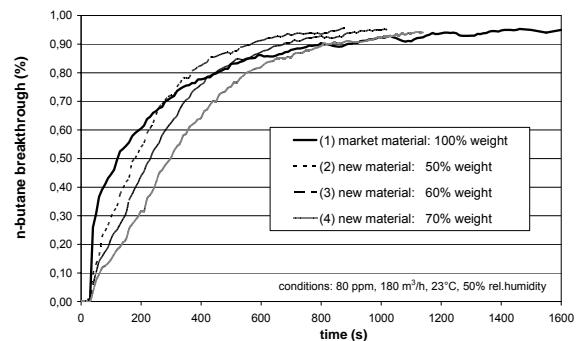


Figure 7: Original plots: adsorption of n-butane of different media

Figure 7 includes the original plots of a filter material from the market (1) and the newly developed materials (2) – (4). Materials (2) – (4) differ from material (1) in the activated carbon used and the weight of the activated carbon layer. Compared to the filter material from the market (1), about 50% of the weight of the activated carbon is installed in material (2), material (3) provides about 60 % weight compared to material (1) and material (4) uses 70 % compared to material (1). Figure 7 shows that the

time-frame necessary to complete the tests varies between 800 sec. and 1600 sec.

The interpretation of the plots in figure 7 is given in figure 8. It can be seen that the kinetic behaviour of all three new materials measured with the breakthrough values (left side of the graph) initially, after 1 min. and 5 min. is better than the respective values of the existing material (1). The breakthrough values of the new materials decrease with increasing weight initially as well as after 1 min and after 5 min. The capacity increases with increasing weight of the new filter materials and the same capacity is reached with 70% activated carbon weight, compared to the existing material (1). Compared to the existing material, the respective pressure loss at 180 m<sup>3</sup>/h is 85 % for (2), 95 % for (3) and 135 % for (4).

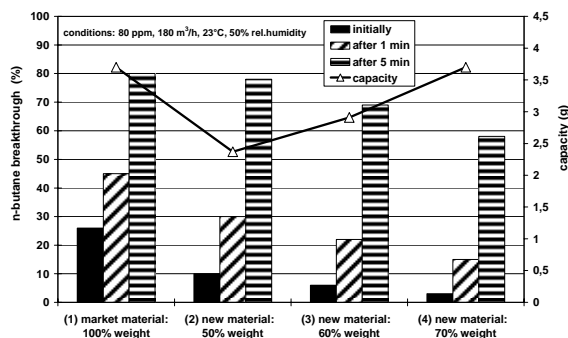


Figure 8: Breakthrough and capacity values of different media

The results of such measurements can be used to find optimized activated carbons (e.g. other granule sizes and carbons of different base materials) or activated carbons with different impregnations. Reaching specified results with lower weight of the activated carbon layer means a decrease of the thickness of the material, providing the option to install

higher filtration surfaces and thus to increase the performance of the filter.

## Development in Cabin Air Filter Testing

The test methods used today are suited for the standardized comparison of the filter performance and for development reasons. They are necessary to be performed but they do not reflect the filter performance under real life conditions, i.e. their use alone is not suitable to test the filter in regard to the ability to improve comfort and wellness in the passenger cabin. This is especially true for the test of adsorptive filters. That is why we searched for alternative test methods with the aim to give more information to development engineers, marketing people and to end users.

A new tool for testing the odour reduction of CAF by using the methodology of olfactometric measurements was developed. Using this tool an objective result of subjective odour perception can be achieved. It gives additional end user related information about the filter performance and allows for new optimization and development strategies. It can be combined with the evaluation of samples from the laboratory and from the field and can be applied for the solution of problems like

- odour removal efficiency against different odours (Diesel, cigarettes) and odour mixtures
- desorption of odour
- evaluation of different adsorbents and equipment against odours

## Olfactometry – A New Tool in CAF Testing

Olfactometric measurements are performed according to DIN EN 13725 /7/ and VDI Guideline 3882 part 1 /8/. Their objective is to determine the odour detection threshold which is defined as the odour concentration where 50 % of a defined population represented by a test panel of 4 persons perceive an odour. The odour concentration  $c_t$  of the sample at the threshold is  $1 \text{ OU/m}^3$  (OU: odour unit) by definition. A so called olfactometer is used which dilutes the odour of the sample to be tested with neutral air in a defined way, starting with high dilution rates. Stepwise, the dilution is decreased by a factor of 2 until all 4 test persons of a test panel perceive the odour in two successive dilution steps. Every sample is measured three times to guarantee the statistical confidence. The dilution factor at the point where 50 % of the test panel perceive an odour is regarded as the threshold.

From this dilution factor  $z$  and the odour threshold concentration  $c_t$  the odour concentration of the sample  $c_{OD}$  can be calculated

$$C_{OD} = z * c_t \quad (1)$$

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

$$C_{OD,dB} = 10 * \log c_{OD} \quad (2)$$

This means that a change in concentration (dilution) by a factor of 2, corresponding to a  $\Delta C_{OD,dB}$  of 3 dB<sub>OD</sub> can be perceived by an individual.

## Results of Olfactometric Measurements

We have performed olfactometric measurements systematically for several years. After setting up reproducible measuring methods we have used this measuring technique to evaluate active air treatment processes such as UV irradiation or UV photocatalysis for the reduction of cigarette odour and to compare their long-time efficiency versus the use of combination filters alone /9/.

The use of Diesel odours in order to improve the real life related evaluations of combi-filters was another direction as olfactometry is the only method for the evaluation of mixtures of odours. By using olfactometry for the evaluation of Diesel odours with its more than 1000 different chemical components, differences in the quality of combi-filters can be detected which cannot be seen when using the DIN/ISO measurements only. Results from such measurements can be taken from figures 9 to 11.

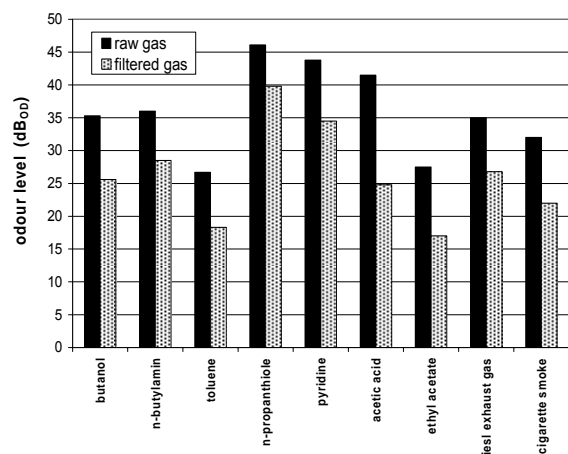


Figure 9: Odour reduction with activated carbon

Figure 9 shows the odour reduction by adsorption on one of our activated

carbon materials for different gases and odour mixtures. It can be seen that the raw gas odour levels for the substances tested are perceived differently from substance to substance and a varying but efficient odour reduction can be achieved for all substances tested. As the activated carbon material is impregnated with alkaline, the odour reduction of acid substances was more efficient than for alkaline or neutral substances. Additionally Diesel odours and cigarette smoke as representatives of complex odour mixtures were reduced efficiently, e.g. Diesel odours from 35 dB<sub>OD</sub> to 28 dB<sub>OD</sub>, which corresponds to an 80 % reduction.

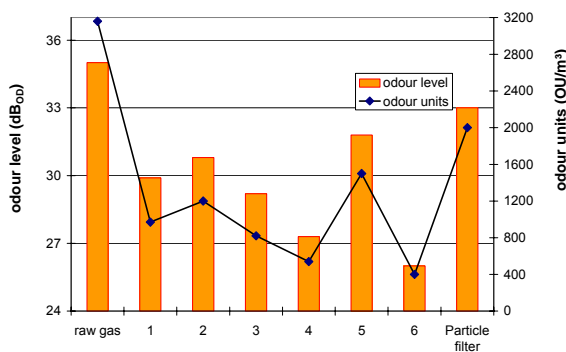


Figure 10: Olfactometric evaluation of new filter elements

In figure 10 results from Diesel odour measurements with new combination filters can be found. On the left axis of ordinates the logarithmic odour level is displayed, on the right axis of ordinates the linear odour units can be found. The columns represent the odour level values, the drawn line the odour units for the alternatives tested. The first column on the left represents the Diesel odour level without filter, the column on the right hand side the Diesel odour level when using a highly efficient particle filter only.

Reductions from 35 dB<sub>OD</sub> to values between 32 dB<sub>OD</sub> and 26 dB<sub>OD</sub>, corresponding to an odour reduction of 50 % to 87 %, are achieved. The method is well suited to show differences and to evaluate the quality of different filters under test.

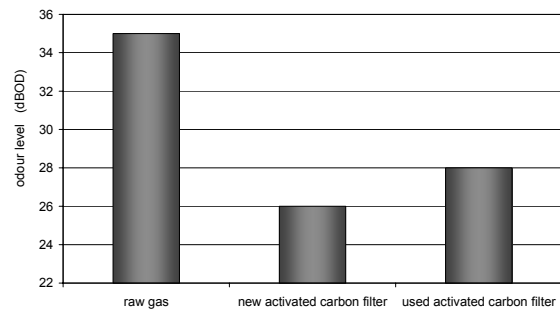


Figure 11: Odour reduction of new and used filters

Finally in figure 11 the efficiency of the most efficient filter from figure 10 is shown at the end of its lifetime, given by the final pressure loss of the particle filter material used. It can be seen that the filter loses only 2 dB<sub>OD</sub> of its efficiency, corresponding to an odour reduction of still nearly 80%.

## Conclusion

Combination filters decrease significantly the level of particulate and gaseous contamination and odours in the compartment of cars.

Today, standardized methods of measurements are used to evaluate their performance. Using these methods is necessary e.g. for the development of new filter materials but should be supplemented by further reality related and end user focused measurement. An additional tool to achieve reality related results which can be communicated easily to end users is olfactometry.

Olfactometry should be used systematically for the evaluation of combination filters in addition to the standardized tests.

## References

- /1/ Richtlinie 1999/30/EU Council of 22.04.1999  
AB1. L 163 of 29.06.1999
- /2/ VDI 6032  
Hygiene standards for ventilation technology in passenger vehicles  
Verein Deutscher Ingenieure  
Düsseldorf, 2004
- /3/ DIN 1946-3:  
Ventilation systems – part 3: Ventilation of passenger cars and commercial vehicles  
Beuth Verlag Berlin, April 2003 (draft)
- /4/ DIN 71460 – 1  
Road vehicles – Air filters for passenger compartments - Part 1: Test for particulate filtration  
Beuth Verlag Berlin, May 2003 (draft)
- /5/ DIN 71460 – 2  
Road vehicles – Air filters for passenger compartments – Part 2: Test for gaseous filtration  
Beuth Verlag Berlin, February 2003 (draft)
- /6/ ISO/TS 11155 part 1, part 2  
Road vehicles – Air filters for passenger compartments  
Part 1: Test for particulate filtration  
Part 2: Test for gaseous filtration  
2001/2002 (draft)
- /7/ DIN 13725  
Air Quality – Determination of odour concentration by dynamic olfactometry  
German Version EN 13725: 2003  
Beuth Verlag Berlin, 2003
- /8/ VDI 3882, part 1  
Olfactometry, Determination of Odour Intensity  
Verein Deutscher Ingenieure  
Düsseldorf, 1992
- /9/ Schmitt, Borris, Klausnitzer, Jähnke  
Olfactometry – A new tool for the assessment of cabin air filter performance