The Different Standard Test Methods For Cabin Air Filters in Japan, USA And Europe

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1. Development of the Test Standards

Cabin air filters, which are today widely used have been developed from 1985 onwards and came into appearance as particle filters in cars firstly in **Europe** at the end of the eighties. At that point in time, there was no standardized test procedure for these filters.
During the initial development period for cabin air filters in the years 1985-1989 tests were carried out in very different ways. Gravimetric measurements-as still used today in engine air filtration- and particle counting, at that time a new approach to be used in test standards, were the two most frequently used methods. After long discussions it was decided by the working group that particle counting of polydisperse particle size distributions should be applied, thus providing the opportunity, to determine the fractional collection efficiency of the filters to be tested.
Initiated by the German VDA (Association of German Automotive Industry), its sub-organisation FAKRA established a working group in 1989, consisting of members of OEMs, HVAC manufacturers, filter manufacturers as well as independent laboratories and gave it the aim to develop a DIN standard for the test of cabin air particle filters. The Fraunhofer Institute, a well known German research institute was assigned to take the lead to develop a test method and finally design and install a prototype test rig for verification. After various modifications of the test rig this led to the first draft of a standard which was published in 1992, called DIN 71460 part 1. Though this was only a draft, it was used at once by the market participants in Europe for the generation of their specifications.
Whereas the installation of particle filters grew rapidly, the installation of filters against gases was initially limited to upper class and luxury class cars. This was due to the fact, that in the beginning only so called filter blocks, containing up to 900 grams of activated carbon were installed. Their pressure loss was too high for the AC systems of most cars. From 1992 onwards, so called combi filters were developed, which combined particle filtration and the adsorption of gases in one filter element at a pressure loss, which could be handled by most HVAC systems of cars. The first car with a combination filter installed as a standard part was the BMW E38 (7 series) in 1994.
The assignment of the VDA working group was enlarged and the group worked out DIN 71460 part 2, where the gaseous filtration of cabin air filters was standardized. The draft was published in 1993.
The history of cabin air filtration in the **USA** started in 1994, the first car with a cabin air filter was the Ford Contour/Mystique. This car was originally developed as “world car” by Ford in Europe and a particle filter was installed. Other development projects followed. Therefore SAE installed a national working group, which drafted the standard SAE J 1669 part 1 (particle filtration) first and afterwards part 2 (gaseous filtration).

Whereas part 2 of SAE and DIN are identical, there are two major differences in part 1, concerning the test aerosols used and the neutralisation of the test aerosols.
In the mid of the nineties the SAE and DIN standards were drafted and it was decided to work on an ISO standard (ISO/TS 11155 part 1 and part 2) with the aim to have one international standard. The national work at DIN was stopped as it was believed, it would not be too time consuming to achieve a joint solution. This came true for ISO/TS 11155 part 2 (gaseous filtration) but not for part 1 which was strongly influenced by SAE J 1669 part 1.
ISO/TS 11155 part 1 and 2 was drafted in 1999 and round robin tests were performed.
A good reproducibility could be seen when comparing the results of different test labs in gaseous filtration. Therefore today in both standards (ISO, DIN) the gases n-butane, toluene and sulphur dioxide are defined as test gases, with the option of the introduction of other gases, which must be specified in cooperation between the customer and the filter manufacturer. Frequently used as an optional test gas is nitrogen dioxide, sometimes ammoniac and ozone are applied as well.
In the case of the particle filtration round robin test, enormous deviations in the results of different labs could be seen. In the last years, 3 round robin tests were performed in Europe and the USA and the results were exchanged. The discussion about the reason for these deviations is still going on. The major topic of discussion is the neutralisation of the test aerosol which is required at ISO and not allowed at DIN.
As a reaction to the time consuming discussions at ISO and due to the fact, that DIN 71460 is well accepted in all European countries, Brazil, Korea and China it was decided at FAKRA in 2004 to revise and modernise the old drafts from the beginning of the nineties. Finally DIN 71460 part 1 (particle filtration) was officially released in March 2006 and part 2 (gaseous filtration) is to follow still within the year 2006.
In **Japan** the aim of cabin air filtration at first was to clean the air in a cabin, not the external air entering the passenger compartment. The use of these so called air purifiers dates back to the beginning of the eighties. At the end of the eighties the so called “studded tire road dust” was recognised as a problem, which arose from the use of studded tires during the winter time and the filing down of road surfaces by the use of these tires. For the first time cabin air filters, cleaning the intake air of a cabin were used to arrest such relatively coarse dusts. The next step took place in the mid of the nineties when particle filters with higher efficiency were installed for the first time. The use of combi filters started in Japanese cars in about 2000.
May it is because of this history with the frequently changing aims of filtration that no own standard for cabin air filtration exists in Japan even today
During the meeting of **ISO in Milan in October 2005** a group was formed, which is to work on the reasons for the deviation between DIN 71460 part 1 and ISO/TS 11155 part 1 and come to a joint conclusion how to proceed. It is the aim to have one joint standard, the next meeting of the ISO committee is to take place in October 2006.

2. Description of DIN 71460 Part 1

The scope of the standard is the test of air-filters, which are used to clean the air of vehicle cabins from particulate pollutants in external or recirculated air entering the cabin. The results derived from the testing are the pressure loss of a filter at different air flows, the fractional collection efficiency at a given air flow and the dust holding capacity of a filter at a defined increase of the pressure loss, the latter two measured with a defined aerosol.
As test aerosols the dusts A2 and A4 according to ISO 12103-1.1997 were defined. With this selection a vertical test duct became necessary in order to avoid mistakes in the interpretation of

test results deriving from the sedimentation of test dust, which can frequently be observed with horizontal test ducts and test dusts with the particle size distribution like A2 and A4.

Other important parameters

- Air temperature (23 +/- 2°C), Air Humidity (50 +/- 3 %)
- Uniformity of air velocity +/- 10 % from the mean flow velocity
- Flow rate 150 m^3 / h – 680 m^3 / h (tolerance < 3 %) independently from the pressure loss of the filter
- Leak rate < 100 l/ min at a differential pressure of 500 Pa
- Uniform mixture of the test aerosol, no local inhomogenity of concentration and particle size distribution
- Dust feed rate 50 – 100 mg/m^3, 75 mg /m^3 for dust holding capacity measurement
- No neutralisation of the test dust
- Isokinetic sampling +/- 20 %
- Aerosol generator stability +/- 5 % in concentration and particle size distribution
- Aerosol generator upstream concentration min 500 counts per particle counter channel
- Test aerosol uniformity +/- 5% for each channel of the particle counter
- Particle counter for a range of 0,3 µm – 10µm geometrical equivalent diameter or 0,5 µm – 15 µm aerodynamic diameter in at least 6 channels

A sketch of the test rig is given in figure 1.

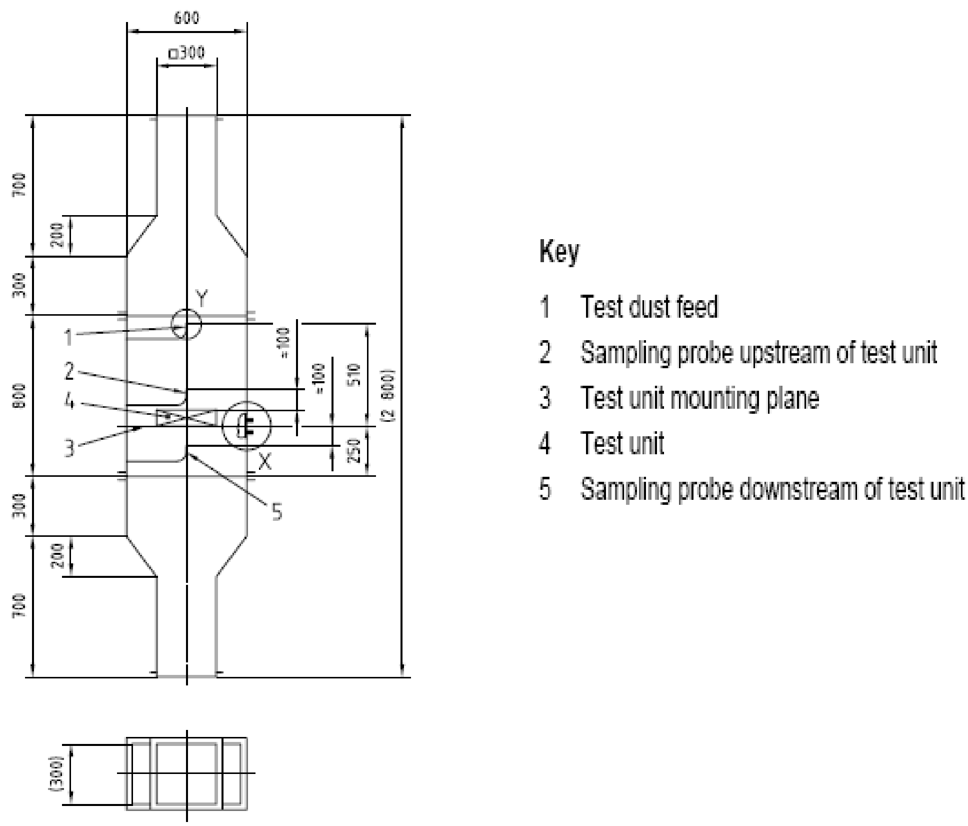


Figure 1: Test rig according to DIN 71460

<u>Performing a Test according to DIN 71460 part 1</u>

Prior to the test, the filter must be conditioned to the temperature and humidity needed for the test. Then it is mounted into an adapter, sealed. properly and installed into the test rig.
The test begins by measuring the pressure loss of a clean filter at 25 %, 50 %, 75 % and 100 % of the air flow rate, which was specified before. The filter pressure loss is calculated by subtracting the tare pressure loss. The result is performed in a table or a graph.
In the next step the fractional collection efficiency is measured at the specified air flow. Particle counting is done alternating 3 times upstream and downstream the filter, then the average of these three recordings is defined as fractional collection efficiency value of every channel of the particle counter used. While performing this test, the pressure loss of the filter is allowed to increase not more than 5 % of the initial pressure loss. The result is performed in a table or a graph.
In the next step the dust holding capacity is determined. A defined quantity of test dust (tolerance of the quantity: 0,1 g) is fed into the test rig at a specified air flow. The dust concentration must be 75 mg/m^3 +/- 5 %. The filter under test must be weighed in new state after each dust increment and when the test is finalized. The increase of the weight is defined as the dust holding capacity of the filter.
The test is finalized, when a specified pressure loss increase (typically 100 – 200 Pa) is reached. During the dust fed several measurements of the dust holding capacity at a defined pressure loss increase together with correlating fractional efficiency values can be taken.

A typical result of a fractional collection efficiency measurement can be taken from figure 2.

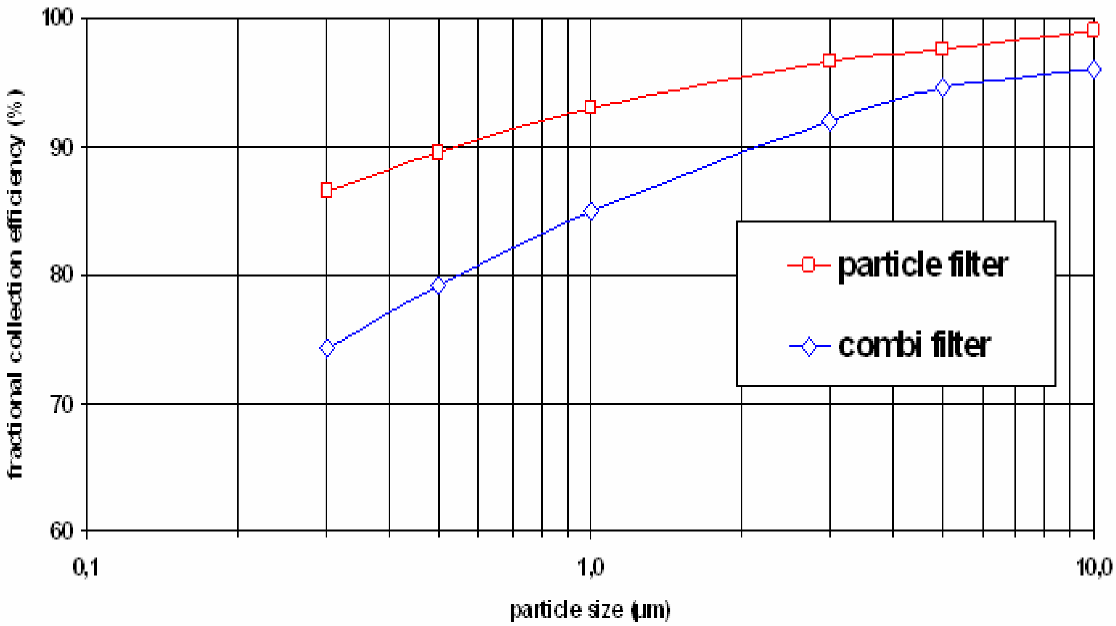


Figure 2: Typical Fractional Collection Efficiency Result

The figure shows a fractional collection efficiency graph for a particle and a combi filters of the same size.

3. Description of DIN 71460 Part 2

The results derived from the testing are in this case the pressure loss of a filter at different air flows, the breakthrough curve, showing the penetration of a filter against a defined gas at different points in time after the start of the test and the capacity measurement which informs on the mass of the gas adsorbed from the air flow in the duct during the test.
In a first approach n-butane, toluene, sulphur dioxide and nitrogen dioxide were chosen as test gases, later on nitrogen dioxide was taken out again.
Generally, today the tests are carried out with the test gases n-butane, toluene and sulphur dioxide, though sulphur dioxide is classified as an optional test gas in DIN 71460 part 2.
The concentration of the gases is 80 ppm for n-butane and toluene and 30 ppm for sulphur dioxide. The selection of the gases and the concentration used resulted from compromises
On the one hand the gases defined for testing should give a representative overview on contaminants in the air, on the other hand problems occurring in on-line testing (e.g. analysers available on the market, laboratory safety regulations, time needed to perform one test) had to be dealt with. Therefore the test gases selected as well as their concentration during testing are compromises of many factors.
The test gas n-butane was selected especially because it is relatively cheap, it is not dangerous, analysers were easily available on the market at the time the standard was worked out and there was a long experience working with it as a test gas. It can be used as a representative for aliphatic organics, but this group does not play a big role in traffic applications. Nevertheless n-butane is today the most frequently used test gas and is widely used in specifications.
Frequently used for analyzing the gases are FIDs (Flame Ionization Detectors), Infrared Spectrometers and Photoacoustic Spectrometers
Shape and dimensions of the test rig are identical to the parameters in DIN 71460, part 1.

Other important parameters which exceed DIN 71469 part 1

- Air temperature (23 +/- 2°C), Air Humidity (50 +/- 2 %)
- Organic contaminants in test air less than 2 ppm TVOC
- Tolerance of gas concentration during test +/- 3 %
- Minimum purity of the test gases 99,5 %
- All parts in contact with the test gases must be chemically resistant and errors due to adsorptive effects on part surfaces must be minimized
- Test rig is to be operated preferably at sub-barometric pressure mode
- Gaseous test contaminants may be supplied directly to the duct, whereas test contaminants which are in liquid state must be volatilized prior to injection into the rig.
- Representative sampling of the single test gases upstream and downstream with a partial flow and providing it to the analyzers
- Sampling frequency in a way that the breakthrough curve is sufficiently well defined, suggested is once every 10 seconds or as frequently as possible for the analyzer used
- Gas analyzers must cover the total range of concentration of the test gases used with a detection limit of 5 % of the test gases
- Experimental determination of lag-time and zero-time

A flow chart for a test rig is shown in figure 3.

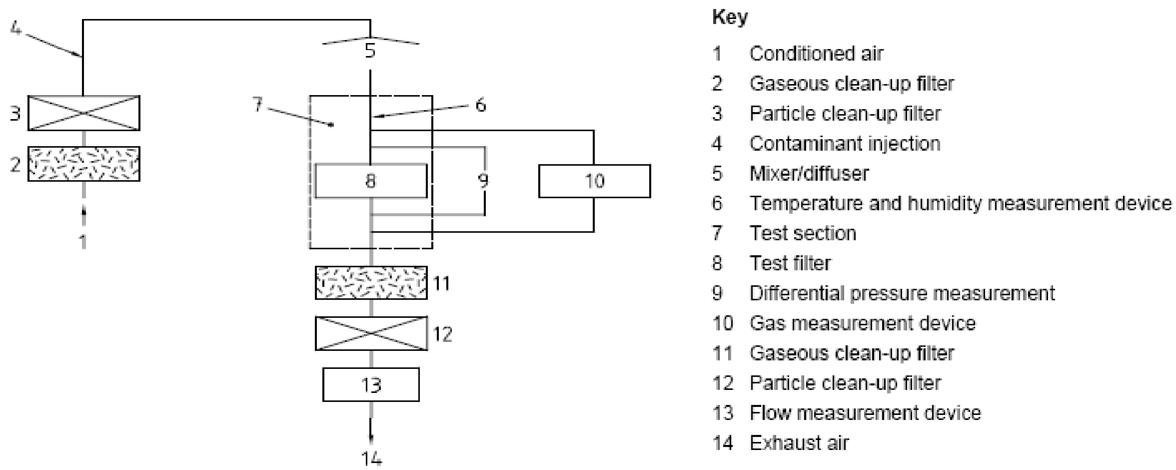


Figure 3: Flow chart for a Test Rig

<u>Performing a Test according to DIN 71460 part 2</u>

The filter must be conditioned prior to starting the test. With the presence of a high water content in the activated carbon the filter has to be dried at first to a residual humidity less than the humidity requested in the standard (50 % at 23°C); lower values in dust holding capacity and higher or lower values in gas adsorption are achieved depending on the actual humidity, if conditioning is not properly done.
The pressure loss is measured according to DIN 71460 part 1.
Before beginning the penetration and capacity measurement it must be made sure that the concentration and total flow of the test gas is within the desired concentration range at the air flow used for the test.
The test is done with constant air flow at the prescribed concentration of the test gas. The penetration measurement is performed with a new and conditioned filter for every test gas specified The concentration upstream and downstream is recorded at the air flow, the temperature and the humidity specified. The test is stopped as soon as the concentration of the test gas down stream has reached 95% of the concentration of the test gas upstream, if a defined breakthrough value was achieved or a defined time frame for the measurement was exceeded.
Finally the capacity of the filter under test is calculated by integrating the penetration curve over the test time.
In figure 4 typical penetration (breakthrough) curves are plotted for the test gases n-butane, toluene and sulphur-dioxide.

From the figure can be taken, that the use of n-butane results in the highest initial breakthrough values compared to toluene and sulphur-dioxide. 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 20 – 30 minutes, whereas it takes hours to finalize capacity measurements with toluene and sulphur – dioxide.

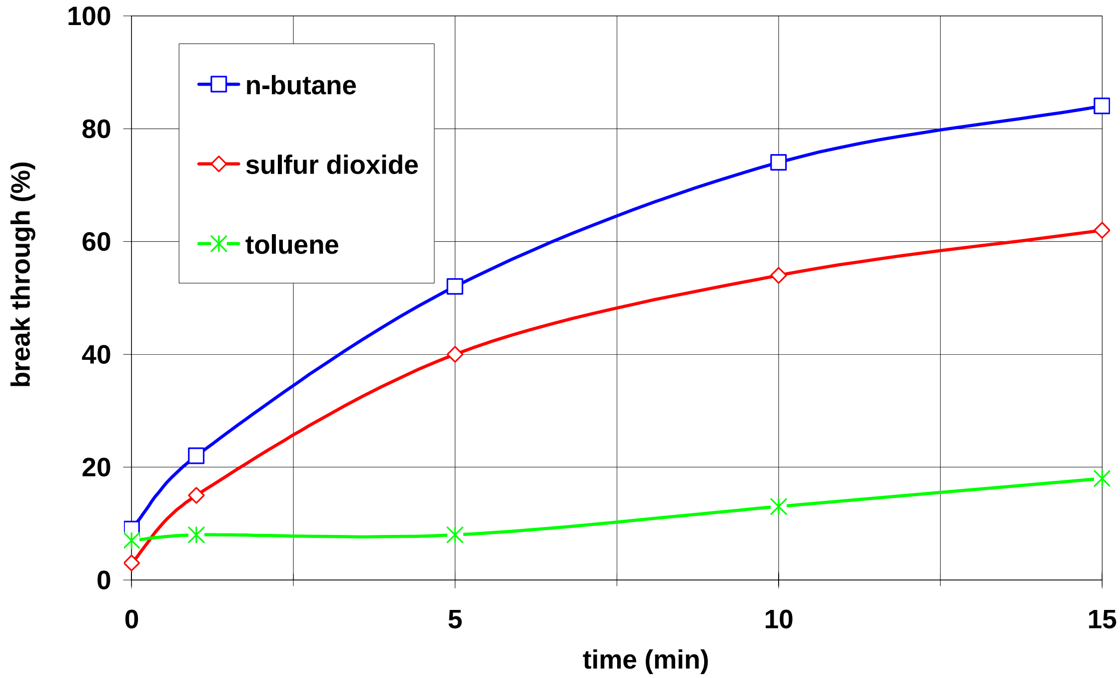


Figure 4: Typical Breakthrough Curves

4. Description of the Japanese Standards

The different standards used in Japan to measure the performance of cabin air filters come from different applications of filtration. The most frequently standards applied are

- JIS B 9908 Air Filter Units for Ventilation(Type 1, Type 3)
- JIS D 1612 Test Methods for Air Cleaners in Automobiles
- JIS B 9901 Method of Test for Performance of Gas Removal Filters
- JEM 1467 Air Cleaners of Household and Similar Use

JIS B 9908 describes a method for the application of particle counting to evaluate the efficiency of a filter. As test aerosol DOP or other particles with the shape of spheres in the range of 0,3 µm can be applied, furthermore the gravimetric arrestance as well as the dust spot efficiency are determined.

JIS D 1612 measures the gravimetric arrestance of a filter, whereas JIS B 9901 evaluates the efficiency of filters against 13 gases, e.g. SO_2, HCl, NH_3, CO.

Finally JEM 1467 is a standard established by the Japanese Electrical Manufacturers' Association. In this standard which can be voluntarily used a filter can be tested against tobacco smoke; wherein, the 3 gases acetic acid, acetaldehyde and ammonia are detected for testing.

However OEMs and HVAC manufacturers in Japan decided to define their own test methods which are modifications of the standards. Therefore there exists no standard which is valid for all Japanese companies

The following figures show sketches of the filter test rigs used and results achieved.

4.1 JIS B 9908 Air Filter Units for Ventilation

A sketch of the test rig (Type 1) can be seen in figure 5.

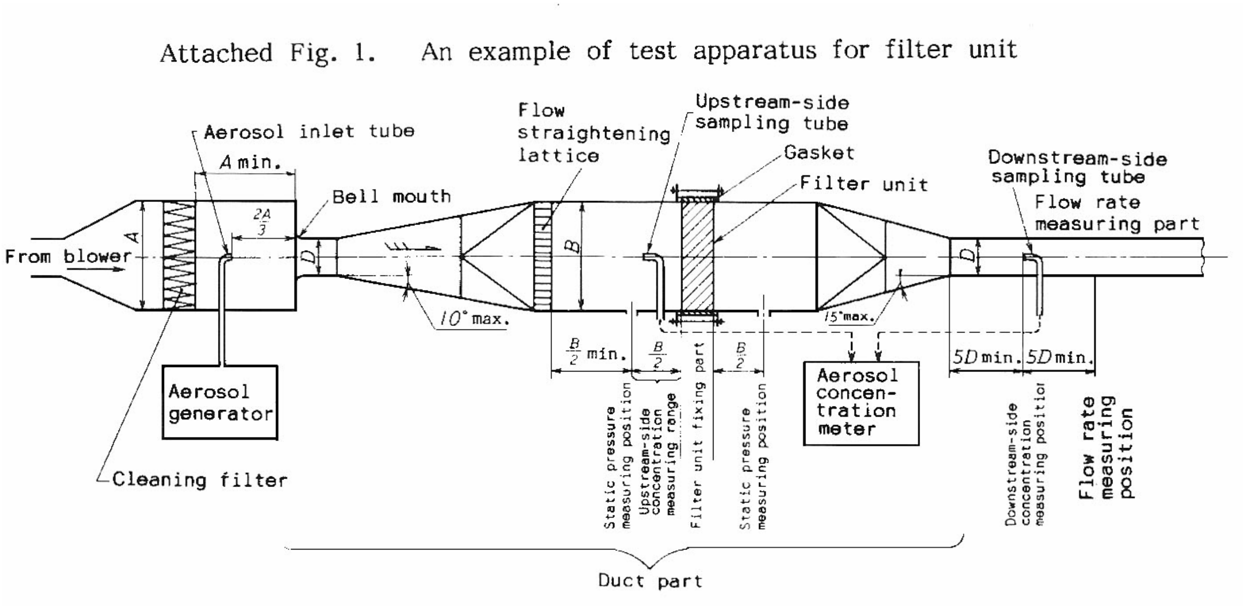


Figure 5: JIS B 9908 Type1 Test duct

Performing a Test according to JIS B 9908 Type1

Measuring the fractional particle collection efficiency is the "Type 1" test. The aerosol generating part of the test rig must be able to supply a polydisperse DOP aerosol, including the 0.3 µm particle diameter. Since 2001 JACA No.37-2001 (Guideline of Substitute Materials for DOP) is in existence. This Guideline determines, that PAO (Polyalphaolefines) have to be used for testing instead of DOP because of the carcinogenity of DOP
In addition to DOP atmospheric airborne dust is frequently used as a test aerosol for the measurement of the filter efficiency.
When using two particle counters simultaneously it must be made sure that the particle counters have the same count performance. After confirming that the aerosol concentration of the upstream side has been stabilized, the upstream and downstream aerosol concentration is measured alternately or simultaneously and the fractional collection efficiency is calculated.

A sketch of the test rig (Type 3) is shown in figure6.

Performing a Test according to JIS B 9908 Type3

Measuring the gravimetric arrestance of a filter is the aim of the "Type 3" test. The test rig is intended to have the construction as exemplified in figure 6.
As test dust JIS No.15 is used, with a dust concentration of 70+/-30 mg/m^3, final pressure loss and filtration velocity can be defined individually.
The mass of the filter unit is weighed with a weighing accuracy 0.1g of its mass.
The arrestance measuring is done at least four times until the defined head loss (pressure loss) has been reached.

The test rig is able to handle different dusts. The results shown in figure 7 come from this test rig.

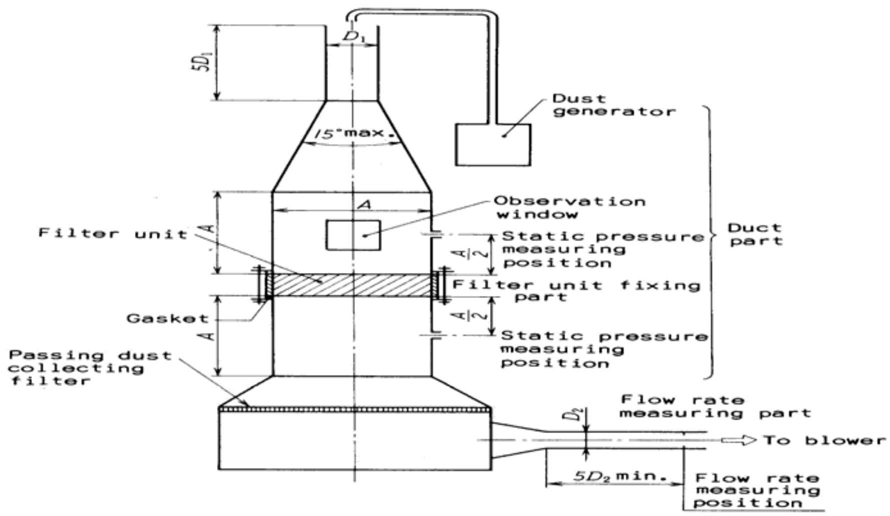
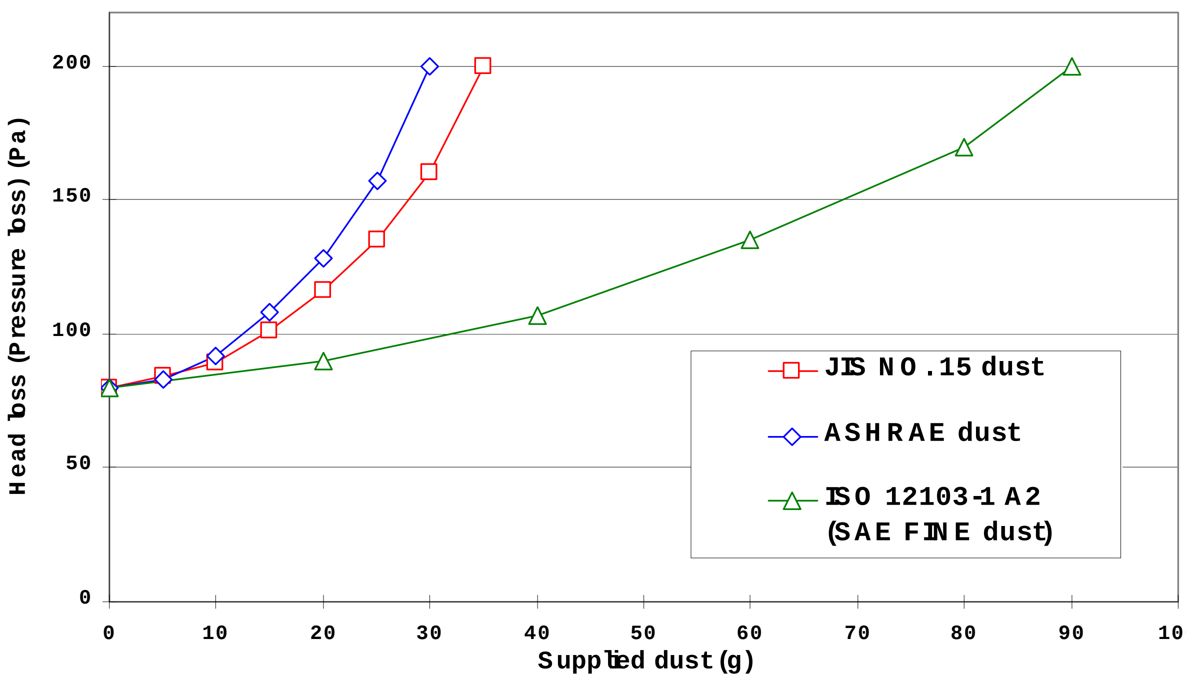


Figure 6: JIS B 9908 Type3 Test Rig

A typical result of a dust feed measurement with different dusts up to a final head loss (pressure loss) of 200 Pa can be taken from figure 7.



(at 3m/s per filter area, filter area 0.09m^3, final pressure loss 200Pa)

Figure 7: Typical Results of JIS B 9908 Type3

Figure 7 shows the different behaviour of the head loss (pressure loss) increase between JIS No. 15 and other test dusts. From our test results can be seen that the dust feed capacity when using

ASHRAE test dust leads to 10 to 15% smaller dust feed capacities compared to JIS No.15 dust and with ISO 12103-1 A2 about three times higher amounts of dust feed capacities compared to JIS No.15 dust can be expected.

4.2 JIS D 1612 Test Methods for Air Cleaners in Automobiles

A sketch of the test rig is shown in figure8.

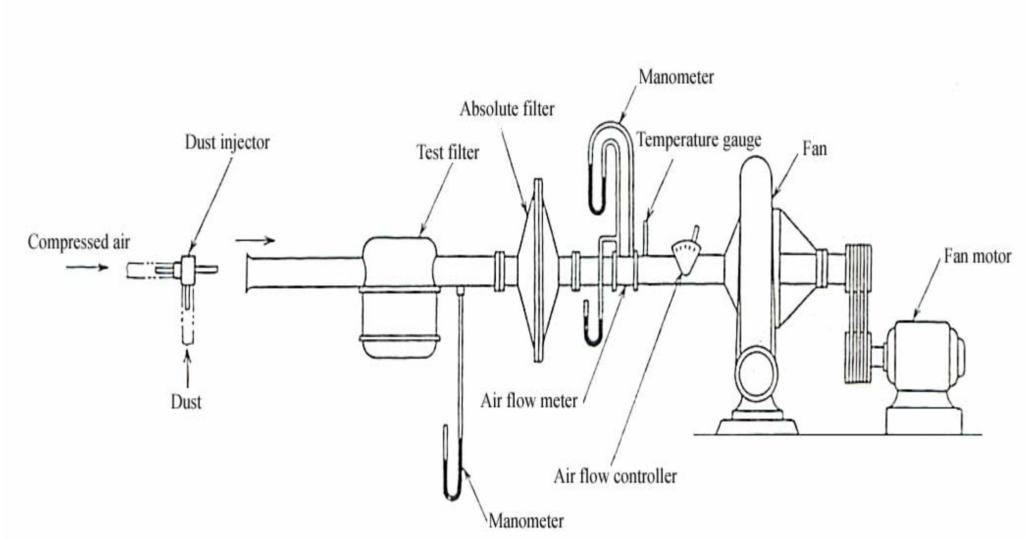


Figure 8: JIS D 1612 Test Rig

Performing a Test according to JIS D 1612

This test method is for engine intake air cleaners. As test dust either JIS No. 7 (coarse) or JIS No.8 (fine) is applied. However, depending upon agreement between the parties concerned (OEMs or HVAC manufacturers on one side, filter manufacturers on the other side), ISO A2 fine dust or A4 coarse dust may be used as special dust as well. The flow rate is defined according to the recommendation of the manufacturer. The dust feed rate is regulated at $1g/m^3$.
The gravimetric arrestance is measured by weighing the absolute filter mass to the nearest 0.01g after the mass has stabilized sufficiently.

4.3 JIS B 9901 Method of Test for Performance of Gas Removal Filters

A sketch of the test rig is shown in figure 9.

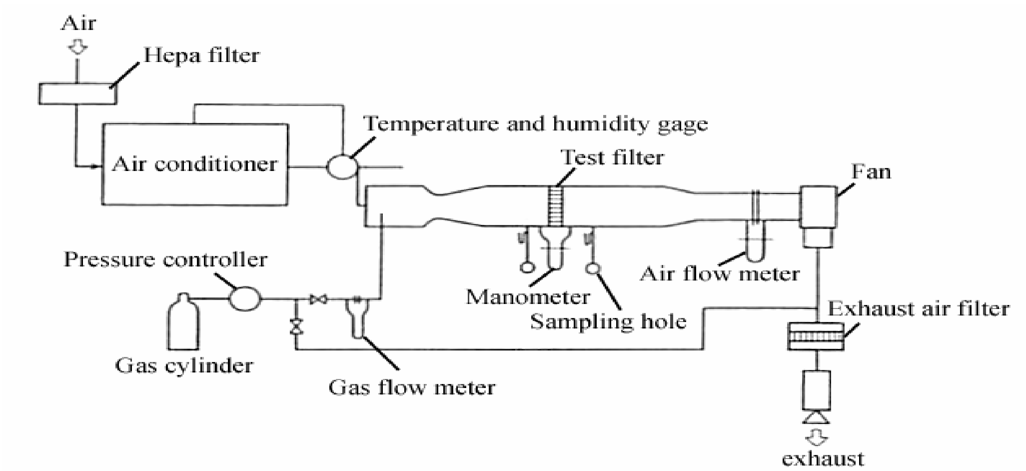


Figure 9: JIS B 9901 Test duct

Performing a test according to JIS B 9901

The filter must be conditioned prior to starting the test**.** The temperature is set to 23 +/- 3°C, the relative humidity: to 55 +/- 10%.The concentration of contaminating dust in the air stream must be kept at 0.15 mg/m^3 or below. The concentration of contaminating gases in the air is not allowed to exceed the environmental reference value established in the Japanese Law for Environmental Pollution Control. The classification and concentration of the test gases is given in figure 10, the tolerance range is not allowed to exceed +/- 10% of the values given in figure 10. The gas concentration is measured 10 minutes after the start of the operation, the air is sucked simultaneously from suction pipes which are located upstream and downstream the filter. The gas concentration is measured with a suitable method (e.g. FTIR) for each gas. The gas removal efficiency is measured three times, the average value thereof indicates the efficiency of the filter.

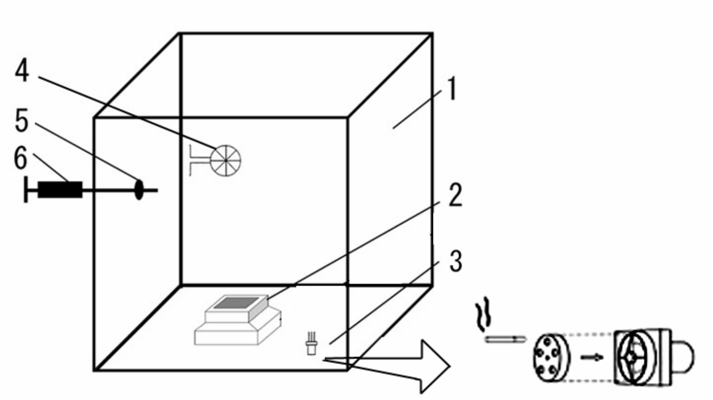
Classification of test gas	Concentration of test gas (ppm)	
	When gas-removal efficiency is tested	When gas removing capacity is tested
Sulfur dioxide SO_2	0.5	20
Hydorogen chloride HCl	10	100
Ammonia NH_3	10	100
Carbon monoxide CO	50	1000
Nitrogen oxides NO_x	0.5	10
Chlorine Cl	1	10
Ozone O_3	0.5	-
Toluene $C_6H_5CH_3$	3	1000
Acetone CH_3 $COCH_3$	50	1000
Formaldehyde HCHO	1	10
n-Butane CH_3 $(CH_2)_2CH_3$	50	1000

Hydrogen sulfide H_2S	1	20
Fluorine compound HF	0.02	0.2

Figure 10: Classification and Concentration of Test Gases

4.4 JEM 1467 Air Cleaners of Household and Similar Use

A sketch of the test chamber is given in figure 11.



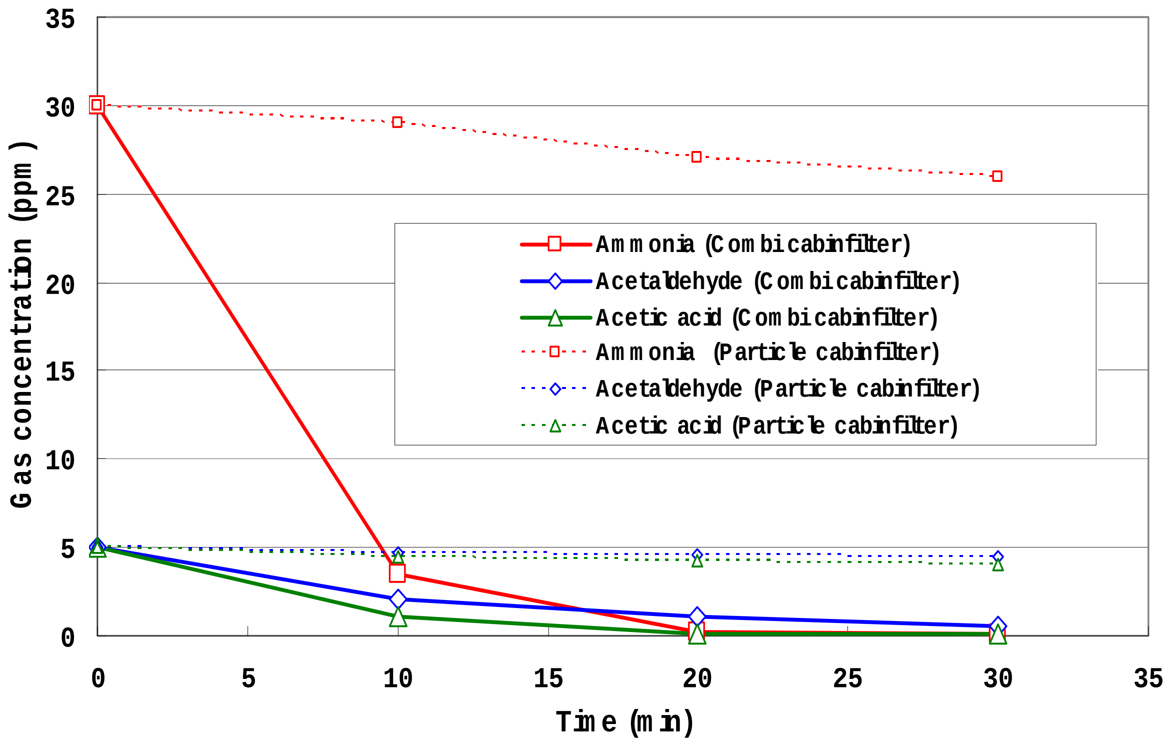
Key:
1 $1m^3$ chamber box (1m x 1m x 1m)
2 Air purifier
3 Cigarette smoke generator
4 Agitator (mixing fan)
5 Gas sampling hole and Gas injecting hole
6 Gas detector tube and gas aspirator

Figure 11: JEM 1467 $1m^3$ Test Chamber

Performing a test according to JEM 1467

To perform the test, the gas in the chamber is smoke generated by a cigarette smoke generator with 5 cigarettes.
The concentrations of 3 gases are measured by detector tube which is for ammonia gas, acetaldehyde gas, and acetic acid gas. While measuring the acetaldehyde gas, the ammonia gas detector tube must be serially connected in front of the acetaldehyde gas detector tube through a gum tube so that the ammonia gas does not influence the acetaldehyde detector.
The fan power of the agitator (mixing fan) must be able to maintain an air flow $0.7m^3$/min to keep an even gas concentration in the chamber. Measuring the initial gas concentration starts after the cigarettes are completely burnt out and an additional time interval of 2 to 5 minutes.
Ammonia and acetaldehyde are measured simultaneously and before acetic acid is measured.
After this the air purifier is operated for 30 minutes and then the gas concentration is measured in the same way as before.
Each OEM and HVAC manufacturer has generated an own method by applying different gases (Toluene, n-Butane, SO_2, NO_2, Formaldehyde, Acetaldehyde, Methyl mercaptan, and so on) instead of cigarette smoke. Instead of an air purifier alone car air conditioner systems including a cabin air filter are tested in the chamber. Additionally the operating time may be shortened.

A typical result of JEM 1467 measurement using a cabin air filter can be taken from figure 12.



(at 1.5m/s per filter area)

Figure 12: Typical Results of JEM 1467

Five cigarettes were burnt out naturally, and their smoke was circulated through the filter with the aim to be adsorbed in the filter. The decrease of the concentration of three gases was observed from the point in time the cigarettes were burned out until 30 minutes later. The three curves above show the decrease of ammonia, acetaldehyde and acetic acid measured in the $1m^3$ chamber.

5. Conclusion

In Europe, Japan and USA different standards were generated for the evaluation of cabin air filters which originate from the different development. The aim of further standardization work should be, to create one standard valid word wide. This would help all people involved in this highly globally acting industry by providing OEMs and HVAC manufacturers world wide comparable filter performance data.