Recent Trends In Air Filter Testing

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Contents

1. Introduction

1.1. History

Since the early days of mankind (or at least shortly thereafter) air has been filtered. During archaic ages people protected themselves against uncomfortable dust concentrations in the respired air by breathing through textile cloths. But not before the insight, that dust is not only a nuisance but can also affect health seriously about two hundred years ago, have people bothered more intense about the evaluation of efficiency of various filtration methods and filtration devices. Especially in mining environments the often fatal effects of high dust concentrations have been discovered quite early. Therefore it is not surprising that a scientific approach to these phenomena has first been applied in the mining industry. Surprising is, however, that even far into the first half of the last century the problem of the so-called dust pneumonia was still common amongst miners, as efficient and applicable methods of personal respiratory protection have already been available. This was possible only by the use of simple evaluation and test methods.

Early test methods were more or less exclusively based on gravimetric and visual evaluation to provide a measurable quantity for filtration efficiency. Since the middle of the last century the use of optical test systems for efficiency testing increased. First, particle concentrations have been measured collectively by applying photometers, later particle counting devices became available, which where able to detect single particles and classify them according to their size in real time. Today this is reliably feasible in a size range from some nanometers up to some hundred microns. Therefore air filters can be evaluated in particle size ranges, which according to physiological knowledge are of highest health related relevance. Accordingly filters today can be designed and provided for most diverse applications and requirements.

Since several decades the industry also attends the gaseous contaminants in the air, which are handled with adsorption, catalysis or classical chemical methods. The recent developments in semiconductor industry have put especially this aspect, under the term „Airborne Molecular Contaminants"(short AMCs), into focus.

1.2. Requirements and industrial Developments

Under the permanent interaction between ever more precise requirements and new applications in the markets on the one hand and improved metrological options on the other the test codes and standards also change and become increasingly diverse. In addition the global markets request harmonized international standards. It can be observed that the development of test codes often cannot keep pace with the velocity of the melting of the markets. One of the reasons for that is that national strategic market interests often dominate the discussion and applicable mechanisms of settlement are not in place.

2. General Ventilation of Buildings

Relating to the methodology of air filter testing there are no significant conflicts in these markets. Currently the international community is quite homogeneous regarding the selection of test substances as well as the applied test procedures and devices. For example dust holding capacity tests are worldwide performed using very similar test dusts (ASHRAE–dust). Efficiencies on higher performance filters are determined all over the globe with particle counting methods. Filters are classified according to their particle collection efficiencies, often averaged over an assumed life cycle of the products. With respect to the filter classes and the classification systems there are significant differences however. As the test certificates, which are usually not easy to understand for the layman, are established and rooted in their corresponding markets since many years and have a long history there, it is not at all easy to make radical changes in this field. In addition there is always the problem that potential new codes are not accepted by the markets and will not be applied. One just needs to think about the System of International Units (SI), which was released and recommended for general use already in 1972, and which, up to this day, has not become the standard system of units in the USA.

With respect to air filter testing we have the situation that the still largest market in the US is governed by ASHRAE standards and in the European sphere mainly the so-called EN 779 is in use. A Swedish initiative one and a half year ago to propose the EN 779 as a basis for a future ISO document has exemplified the problems typically inherent in international harmonization. As the US and others did of course not want to adopt EN 779 unaltered a lot of change items were collected at first. The subsequent international discussion finally led to the point where all aspects of both existing standards are more or less questioned and the basis of consensus is smaller than ever.

The current target is to publish an ISO committee draft until the end of 2006 under the title ISO/CD 21220. Realistic judgment however makes a publication in 2008 more likely. In the following chapters it will be tried to explain the status quo and to outline the possible trends.

2.1. USA (ASHRAE 52.2)

Following the ASHRAE 52.2 standard filters are classified according to a number called MERV (Minimum Efficiency Reporting Value). From all fractional collection efficiencies during the complete test the lowest value for each particle size is taken and these values are combined to a so-called "Composite Minimum Efficiency". This minimum fractional collection efficiency is split into three particle size classes (0,3-0,5 µm, 0,5 – 1 µm and 1 – 3 µm). The standard contains a MERV table according to which the filter can be assigned to one of 16 MERV classes.

Efficiencies are measured using a potassium chloride aerosol. Dust loading is performed using dust according to ASHRAE 52.76 up to a final pressure drop of 375 Pa. Possible discharging effects are not especially addressed. The nominal airflow is at 3375 m³/h very similar to EN 779.

For review versions of the standard and for new international test codes ASHRAE has investigated the possibilities to replace ASHRAE 52.76 dust. The fact, that this dust does not represent the filter challenge in real world applications, the problem that it is not easy to reproduce and the difficult handling will lead to a new loading dust in the future, probably ISO 12103-1 A2 or something similar. The efficiency test with potassium chloride will be maintained on the other side of the Atlantic as the classification of low class filters (coarse filters according to EN 779) will be difficult using DEHS.

2.2. Europe (EN 779:2002)

In Europe products for standard ventilation applications are divided into two main groups: coarse filters (G-classes) and fine filters (F-classes). Both types are tested according to EN 779. Coarse filters go from G1 to G4 as fine filters cover the range from F5 through F9. Filters with even higher efficiencies are termed HEPA and ULPA products but will not be discussed here in detail.

Coarse filters are only exposed to test dust and are loaded in several stages to a final pressure drop of 250 Pa and at each loading stage the gravimetric penetration and retention are determined. These retentions are averaged weighted by the mass increases and this average arrestance is used for classification. Other characteristic properties like the dust holding capacity are, similar as in the American standard, not considered for classification purposes.

For the fine dust filters (F5 to F9), contrary to ASHRAE, the Europeans have defined a "mean efficiency", which is intended to represent the average efficiency during filter life. This average efficiency however is specified at only one specific particle size of 0.4 µm. That number is calculated from all efficiencies at 0.4 µm during the dust loading cycles and the individual values are weighted with the mass increments of each loading stage. In the standard there is a classification table, which defines the filter grades according to this average efficiency.

The efficiency is tested with DEHS (Di-bisethylhexylsebacate). This substance and a closely related material called DOP have a long tradition in filter testing. Due to the perfect spherical shape of the particles (droplets) the size classification of optical particle counters, which are usually calibrated using monodisperse latex spheres, is very accurate (the Mie-theory uses this special solution for spherical particles of the Raleigh equation). Size classification errors due to form factors does not occur. Furthermore, aerosols with DEHS are easy, cheap and reproducible to generate.

Dust loading is also performed with ASHRAE 52.76 dust up to a final pressure drop of 450 Pa at airflow of 3400 m³/h, if not otherwise specified. Table 1 summarizes and shows the main differences between the current versions of the standards and the potential or probable new ISO-norm from a today's view.

Table 1: Summary of differences in the current standards and a potential future international test code

Item	ASHRAE 52.2	EN 779:2002	Future ISO-Standard
Efficiency Aerosol	KCl	DEHS	KCl or DEHS
Loading Dust	ASHRAE 52-76	ASHRAE 52.76	ISO 12103-1 A2
Final Pressure Drop	375 Pa	250 (G), 450 (F)	Open issue, maybe no loading
Classification	MERV (Minimum Efficiency Reporting Value	Yes, two main categories: G (coarse filters) und F (fine filters)	No classification defined, will be the sole responsibility of national bodies
Classification	Based on minimum efficiency during the filter life and considers all particle sizes	Based on mean efficiency during filter life and considers only 0.4 µm particles	Only initial efficiency after "conditioning" considered. Particle size or range not clear yet
Discharging of synthetic Media	No	Yes, but not sufficiently specified	Alternatives: diesel soot, humid air, ionized air etc.
Shedding Test	No	No	Unclear
Airflow	3375 m³/h	3400 m³/h	3600 m³/h

Although the classification systems of ASHRAE and EN 779 show significant differences both standards are very similar regarding the test procedure. If the same final pressure drop would be defined and the same efficiency aerosol would be used the tests would be performed absolutely identical. As the classification shall not be part of a new ISO test standard anyway, the community was quite close to a general consensus. By questioning many of the items in the existing documents discussions arose which have made an early reasonable agreement very unlikely. From our point of view it would have been much more beneficial, to harmonize the few issues in the current codes and use this basis to create a common document, which could have been subsequently reviewed, adapted and maintained, instead of questioning everything what was done in the past and start from zero. The test certificates could have been designed to allow classification according to MERV as well as EN 779 classes. Over time there could have been a correlation system established which would have even allowed harmonizing the classification system without confusing the regional markets. Unfortunately the trend does not go in that direction.

Considering the current state of discussions about two years from now a document will be published describing a testing procedure not even containing a loading test and therefore using a classification system which will not have much in common with today's filter characterization. The technical consequences may not even be a serious issue for the filtration industry, but for the markets they will cause a lot of confusion. One just has to consider the specification sheets and RFQs for public buildings and industrial environments. It should also not be forgotten that both standards have served us well in the past and that huge experience and data pools have been created on their basis.

As already explained above there is a reasonable discussion going on right now about what efficiency aerosol and what loading dust are most appropriate. To further illustrate that question in table 2 the pros and cons of each item are summarized.

Table 2: Advantages and disadvantages of several testing substances

	Advantages	Disadvantages
Efficiency Aerosol KCl	Solid Particles (Real World Relevance?!) Relatively simple Handling, Relatively stable under humidity fluctuations compared to other salts, Homogeneous shape, no critical influence of shape factors etc.	Electro statically charged aerosol with significantly higher charge density than atmospheric aerosol, Strong interaction with charged media Not a good representative for natural aerosol,
Efficiency Aerosol DEHS	Spherical particles, Homogeneous, Electro statically neutral, if used pure,	Liquid droplets, Not representative for atmospheric aerosol,
Loading Dust ASHRAE	Many years of experience and large data pool, Short loading time at relatively low dust concentrations,	Differences between different manufacturers, Difficult handling, Special dispersing equipment required, Agglomeration, Not representative for atmospheric aerosol,
Loading Dust ISO A2	Easy to disperse, Less Agglomeration, Simple handling,	Not representative for atmospheric aerosol, Filters show up to three times higher capacities, resulting in longer loading durations or requiring higher dust concentrations,

2.3. Adsorptive Filters in General Ventilation

Initially these products showed up in the market only for special applications. In the meanwhile a general interest of the industry in the reduction of harmful substances or in the improvement of comfort by using adsorptive filters can be observed. Since about one year ago there is a working group in CEN (Commission European de Normalisation, responsible for EN-standards), which deals exclusively with gas phase filtration. As the basic test procedures are very similar to the tests in automotive cabin air applications described below the first draft of a test standard will be very similar to DIN 71460-2 and ISO/TS 11 155-2 with regards to the procedures and methods. An agreement to use these documents as a basis for a working draft has already been achieved. The challenging agents for performance evaluation however will be different from the ones used in automotive industry. Which gases will be used indeed cannot yet be foreseen.

3. Automotive

3.1. Cabin Air Filtration

It was already during the late eighties when the FAKRA of the VDA had begun to develop a test standard for the „pollen filters“, which had just recently appeared. Novel to this standard was the fact, that for the first time it was tried in a filter test code to use particle counting techniques, enabling the labs to determine the efficiency as a function of particle size.

In the early nineties the work on a second part of that standard was started describing the evaluation of adsorptive filters and gas phase filtration.

Both parts remained in the state of drafts for a long time as in 1995 the work on harmonized ISO documents was initiated. The perspective to have an international code available in the near future made the national efforts seem unreasonable. With respect to the second part of the norm this hope proved to be true, but as far as particle filtration was concerned the separating differences in „testing philosophies" were much more significant. That first part of the ISO 11 155 draft was strongly influenced by the SAE J1669-1 document, which the US experts had defined before.

Against the end of the nineties both parts were published as technical specifications ISO/TS 11 155-1 and –2 for general use. In the European market place, which is still by far the largest in the world for these products, part one of the specification did not find its way to general use. Up to this day the discussions circle around two issues: In ISO/TS the only possible efficiency aerosol is KCl, whereas in the German draft NaCl as well as dusts according to ISO 12103 – 1 are allowed and can be negotiated between manufacturer and customer. The second main difference is that the ISO-procedure requires the neutralization of the test aerosol and the German document forbids neutralization.

Several round robin tests, which should have helped with the decisions, did not provide unanimous results, so the discussions linger on. The ISO-specification has been extended unaltered during the last review process. FAKRA has begun to further develop its own document DIN 71 460-1 and make it a finished and released standard which will be published this year. This test procedure is still the most widely used particle standard and will probably remain in that position.

Regarding the two adsorption test codes (DIN 71460-2 and ISO/TS 11 155), they are basically identical and therefore do not cause any controversial discussions. However they are sometimes criticized from a general point of view. The argument is focused on the following aspects:

- The concentrations of the testing agents are unrealistically high (they have been selected that way to reduce testing time and costs)
- The testing substances are not very relevant for real world applications (especially butane and toluene)
- As the main goal of the filters is the improvement of comfort in the passenger compartment the odor reducing performance is not sufficiently considered.

For these reasons several projects have recently been initiated to deal more directly with the odor reduction performance of these products.

If and how the findings of these project will influence the standardization of filter testing cannot be predicted, as there are no results available yet.

3.2. Engine Air Intake Filters

Engine air intake filters are tested according to ISO 5011. This standard describes a gravimetric test procedure. Initiated by the US experts in SAE an ISO-draft is about to be published transferring the methods and techniques from cabin air filtration to engine air intake filters. Therefore these products will be specified in the near future based on fractional collection efficiencies. There are still some issues of the proposal under discussion but the general trend is clear.

3.3. Further Automotive Air Filters

Taking the automotive industry as a whole it must be observed that the air filtration applications around road vehicles have increased and are still increasing. Besides filters for the crankcase ventilation and transmission filters a whole new range of filter systems in the vehicle has developed. This is mainly due to the so-called OBD II-standard and driven by the trend to zero emission vehicles. A multitude of sensors on the cars, which can be very sensitive to contamination (with particles and gases) and in many cases have to be protected, require specific air filters. Today there are 30 to 40 different filter applications around the automobile to be found. The technological performance requirements of the majority of these products are usually more straightforward and are often but vaguely defined. The definition of performance profiles does not yet follow standardized filter tests but are negotiated between automotive engineers and their suppliers.

4. Aviation

4.1. General

Aviation industry is by its own standards an extremely sensitive market. The potential loss of prestige and reputation for aircraft manufacturers as well as airlines, enormous financial risks in cases of accidents and the „larger than life“ public visibility have led to that markets own technical safety rules. With respect to the evaluation of air filters for the passenger cabin existing test standards are used to define and specify the basic performance of the products, but often the products are investigated during the development and design stage under conditions, which sometimes appear to be exotic.

4.2. Passenger Cabin

Air filters used for the ventilation systems of the passenger cabin in modern aircrafts show relatively serious general performance requirements. In the latest airbus generations of planes for example filters are used that reach filter classes of H12 to H14 (better than 99% to 99,995% at the point of their lowest efficiency in the delivery state). The products are tested according to EN 1822 or BS 4400 (sodium flame test).

Exceeding these more general requirements obvious safety issues of air transportation are often points of interest. The challenges of international terrorism or potential pandemic global diseases of course show their impact especially in this application. The filters are tested for their efficiency against bacteria and viruses. The importance of microbiological threads will even gain momentum in this market. Also the use of gas phase filters is currently investigated and the first products are implemented and optimized for that use.

5. Clean Rooms

Some years ago the critical impact of gaseous airborne contamination on some production processes in the semiconductor industry was realized. Since then this industry has increasingly focused on filter products being capable of removing gaseous contaminants from the ambient air of sensitive processes. Even traces of some substances can show a serious disturbing potential. Several working groups have been established to encounter the problem with standardized test procedures. They concentrate mainly on the selection of appropriate test substances and test methods and also to develop filter classification systems.

Regarding the multitude of test substances this application seems highly diverse and complex. The identified unwanted air components can originate from ambient air, from processes or from the products themselves. As already low-level concentrations can cause significant problems the testing and evaluation can be strenuous and challenging. Hence it is difficult to predict how future guidelines and standards will be structured.

6. Conclusions

Basic trends in air filter testing have to be discussed for particle and for gas phase filters separately. With respect to particle filtration testing the procedures are long established and generally accepted. Current activities in that field deal with details like neutralization of aerosols, dusts or filters and filter media. The pros and cons of various test substances for diverse filter applications are also discussed.

The latest issue regarding the so-called fine dust emissions did not, from our point of view, influence filter testing and there is no indication that this may change in the near future.

As far as gas phase filtration is concerned there will be a lot of movement and activity, as the products still have to penetrate the various markets by and by. Requirements and specifications for a large part still have to be defined and the appropriate test methods have to be selected. The automotive cabin air market has technically progressed quite far. However, as far as human comfort is concerned, there is the need to implement olfactory evaluation into air filter testing and to develop its beneficial use in filter design. In general it has to be said that the wide spread use of these methods is still blocked by the inconsistency of the human nose as a detector and the related poor reproducibility of results with these methods, which can only be overcome by excessive efforts with large test panels and the like. Therefore the technical progress in the years to come will concentrate on the testing of adsorptive filters and gas phase filters.