Publication Series Viledon

Air filter classification in the light of rising energy costs

Dr.-Ing. Thomas Caesar,
Freudenberg Filtration Technologies KG

Paper presented at
Filtrex 2008
Cologne (Germany)

Freudenberg
Filtration Technologies

Introduction

In the context of increasing energy prices and the imperative of reducing CO_2 emissions, the energy consumption caused by air filters has become the focus of attention. In an average industrial plant approximately 10% of the total energy is consumed by fans in HVAC systems whereof 10–50% is related to the pressure loss of filters, depending on the size and the design of the HVAC units. Hence, a reduction of the pressure loss of air filter systems can be a significant contribution to save energy and to reduce carbon dioxide emissions, when used in conjunction with variable speed drives. At the same time, there is an increasing demand for higher air cleanliness on the market employing higher efficient filters which counterproductively give a larger contribution to the overall pressure drop of an air handling unit.

Currently, air filters are classified only by their particle collection efficiency, e.g. according to the European standard EN 779 (average particle collection efficiency) or according to the American standard ASHRAE 52.2 (minimum efficiency reporting values). The aim of our investigations is to present a method of air filter classification which incorporates both aspects – the particle collection efficiency and the energy efficient operation.

The energy consumption of air filters can be calculated as a function of the volume flow rate, the time of operation, the efficiency of the fan and the average pressure drop. As a first step, laboratory results derived with different test dusts are compared with real life performance data. From this evaluation, it can be shown that a loading with AC Fine dust (ISO A2 dust) can be used to simulate the real life behaviour of air filters and to determine the average pressure drop in a standardized laboratory test method. The pressure drop and the particle collection efficiency are related to each other by defining a key energy performance number. On the basis of this key number an energy-efficiency-classification scheme is derived, which can be used to rank filters according their energy efficient performance.

Background of Air Filter Classification

Typically, to separate fine particles from the air stream in HVAC systems, nonwovens or paper like filter media made of synthetic-organic or mineral (e.g. glass) fibres are used. Mostly, these filter media are converted into 3-dimensional elements, such as pocket filters or pleated cassette filters. The ability of filter media to capture particles from the air stream and hence the particle removal efficiency is based on mechanical effects (inertia forces, interception, gravity and diffusion effects) and the electrostatic interaction between particles and filter fibres.
Especially the efficiency related to the mechanical collection effects strongly depends on the diameter and the density of the fibres. Smaller fibre diameters and denser fibres arrangements typically lead to higher fractional collection efficiencies, but also to a higher air flow resistance and hence higher energy consumption in operation. In contrast to mechanical filters which solely rely on mechanical mechanism to capture particles, electret filters collect particles by means of a combination of mechanical and electrostatic mechanism. Since the electrostatic forces interact over longer distances compared to mechanical effects, electrostatic charging of fibres increases the efficiency and therefore media require lower fibre matrix density to reach high collection efficiencies. As a result, electret media typically have a lower air flow resistance and lower pressure drop at a given particle collection efficiency compared to pure mechanical filters.

The relation between the pressure drop $\overline{\Delta p}$ and the fractional collection efficiency *T(x)* of a filter medium can be expressed by a quality factor (see Equation (1)) often designated as α- or 100γ-value [1].

$$\alpha = \frac{-\log(1 - T(x))}{\Delta p} \cdot 100\,\mathrm{Pa} \tag{1}$$

Even though electret filters and filter media have proved their performance in real life operation for many decades, concerns exist on potential electrostatic charge decay. In order to retain the stability of the electrostatic charge and to keep a potential decay to a minimum, materials used as electret filters therefore need to have high electrical resistance. Many of the polymeric materials offer such properties. Polypropylene (PP) is the most popular one, others include polybutylene terephthalate (PBT), polytetrafluoroethene (PTFE), and polycarbonate (PC).

Besides the flow resistance of the filter medium, the overall pressure drop of a filter element is also related to its 3-dimensional structure. Depending on the filter design and the quality of converting, the contribution of the 3-dimensional flow field to the overall pressure drop of a filter element can be up to 80% [2]. As the filter accumulates dust in operation, the pressure drop increases until it reaches a defined final pressure drop and the filter has to be replaced. Modern HVAC systems are typically designed with frequency controlled variable speed drives which give a constant air flow rate. Hence, with increasing pressure drop, the energy consumption of the fan increases. The pressure drop evolution as a function of the time of operation strongly depends on the type of filter medium, the filter design and the quality of converting.

There have been and there are still ongoing industry-wide discussions on how to develop a laboratory test standard that reflects the real field performance of air filters. In Europe, EN 779 [3] defines a filter classification scheme based on the average collection efficiency for 0.4 µm particles. The average collection efficiency is calculated from the efficiency values measured during the course of loading the filter with synthetic ASHRAE test dust. In North America, the test standard ASHRAE 52.2 [4] is used to test and classify air filters. The classification scheme in this test standard is based on so-called Minimum Efficiency Rating Values (MERV), which are measured for different particle size ranges during the course of dust loading.
In the test regime of both mentioned standards, the pressure drop evolution during the course of dust loading is measured as well, but is not incorporated into the classification scheme. Air filters are purely classified by their ability to capture dust particles with no regard at all

to energy efficient operation. In the light of rising energy cost, classification systems are required which allow users to compare and select filters not only based on the particle collection efficiency, but also with regard to the filters' energy consumption and the total life cycle cost.
Both standards mentioned above also try to evaluate the potential charge decay of electret filters by e.g. chemical treatment of filter media samples. The laboratory test methods described in these standards are known to reveal results for the efficiency, which are far below the values recorded in real life operation. Hence, current test standards used in the industry do not pay sufficient credit to the benefits of synthetic filter media, especially in terms of energy efficiency. There is a strong need to develop test methods which describe the performance of electret filters more realistically, in terms of particulate and energy efficient operation.

Evaluation of the Energy Consumption

The energy consumption of an air filter system is given by Equation (2) [6].

$$E = \frac{\dot{V} \cdot \overline{\Delta p} \cdot t}{\eta \cdot 1000} \text{ where } \overline{\Delta p} = \frac{1}{t}\int \Delta p(t)dt \tag{2}$$

In Equation (2), E is the energy consumption in kWh, $\dot{V}$ is the volume flow rate in m^3/s, t is the operation time in hours, and $\overline{\Delta p}$ is the average pressure drop in Pa. The electrical efficiency η of the fan is related to its design. State-of-the-art fans can reach efficiency values of up to 85 %, with a typical value of 70 %. The operation time of a typical HVAC system during one year is assumed to be 6.000 h (24 h per day, 5 days per week and 50 weeks per year). Provided that the volume flow rate and the efficiency of the fan are constant, the only variable parameter is the average pressure drop.
During operation, air filters in HVAC systems are continuously loaded with atmospheric dust, which leads to an increase of the pressure drop. The response and development of the filter's pressure drop depends closely on the design of the filter, the concentration and composition of the atmospheric dust, and the environmental and process conditions involved. Depending on the location of the filter in the HVAC system (first stage without pre-filtration or second stage with pre-filtration) and the quality of pre-filtration, filters are typically replaced by new filters after one to two years of operation either when they reach their final pressure drop or due to hygienic aspects.
Hence, to define an energy efficiency classification scheme, the first issue is to find a laboratory test method which is suitable for predicting the average pressure drop of air filters during the first year of operation.
In an intensive study, the response of the pressure drop of air filters to different synthetic test dusts has been compared to real life performance data. In Figure 1, the pressure drop of a rigid filter of class F7 to EN 779 is plotted as a function of the stored mass of different test dusts and atmospheric dust. The data obtained from a loading with synthetic AC Fine (ISO A2) test dust and ASHRAE dust in an EN 779 test rig are compared to data obtained from a real life application where filters are operated with ambient air and loaded with atmospheric dust. While the curve for the loading with ASHRAE dust significantly deviates from the real life data, the curve for AC Fine reflects closely the real life behaviour of the filter element.

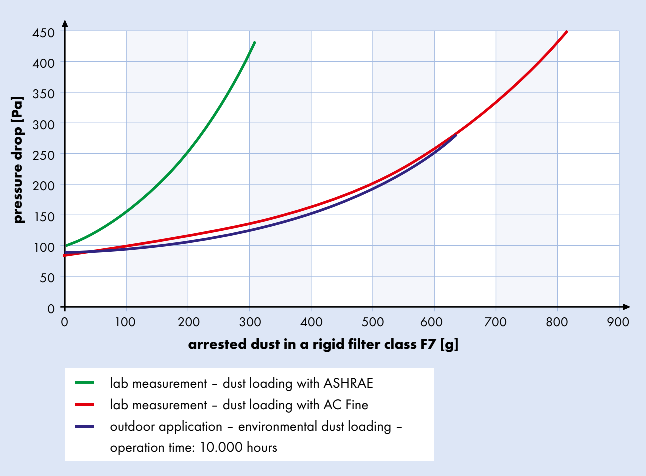

Figure 1: Comparison of pressure drop behaviour for a rigid filter class F7 with AC Fine, ASHRAE and environmental dust loading at 3400 m^3/h

The test result for a pocket filter of class F8 (Figure 2) shows the same characteristic, that the response to AC Fine dust loading and to the real life application is almost identical. Hence, to calculate the average pressure drop, the behaviour of the filters in real life applications can be simulated in good agreement by a laboratory test with AC Fine dust loading.

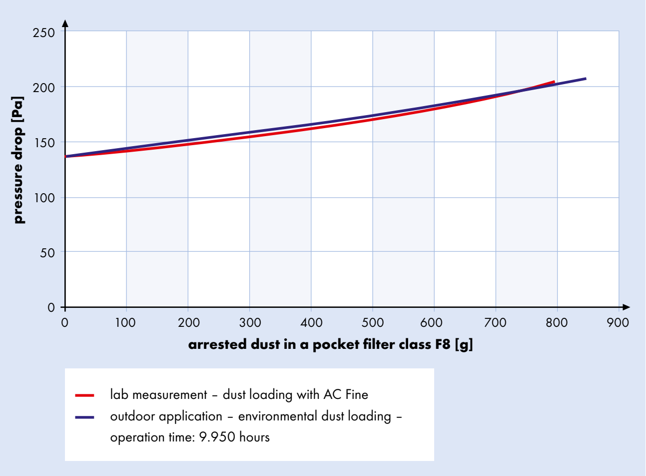

Figure 2: Comparison of pressure drop behaviour for a pocket filter class F8 with AC Fine and environmental dust loading at 3400 m^3/h

Based on the results shown above, in the classification scheme presented here, AC Fine (ISO A2) is used as a synthetic loading dust to predict the average pressure drop $\overline{\Delta p}$ in a laboratory test method. According to the Umweltbundesamt (German Federal Environment Agency) [5], the average fine dust concentration in ambient air in Germany is 40 $\mu g/m^3$. At a constant volume flow rate of 3.400 m^3/h and an operation time of 6.000 hours, the total mass of environmental dust delivered to a filter within one year is approximately 800 g. Therefore, in our method, this value is also chosen for the loading with AC Fine dust to predict the average pressure drop. During the course of dust loading, the pressure drop is measured and the average pressure drop is then calculated using Equation (3).

$$\overline{\Delta p}_{A2,800g} \equiv \frac{1}{800\,g}\int_{0}^{800g} \Delta p(m_{A2}) \cdot dm_{A2} \tag{3}$$

In Equation (3) m_{A2} is the mass of AC Fine dust stored in the filter.

The method described above is fully suitable and evaluated for filters which are exposed in the first filter stage to atmospheric dust. In real life, filters operated in the second filter stage are loaded with less and much finer dust compared to the first stage. Nevertheless, to simplify the method, we use the same procedure for filters typically operated in the second filter stage (filter classes F8 and above to EN 779), but loading the filter only with 200 g of AC Fine test dust. Further investigations are ongoing to improve the method for these filter classes.

Proposed Energy Efficiency Classification

The pressure drop and the particle collection efficiency of a filter can be related to each other by defining a key energy performance number (kep number) as given in Equation (4).

$$kep = \frac{-\log(1-T)}{\overline{\Delta p} - C} \cdot 100\,\mathrm{Pa} \tag{4}$$

Compared to the definition in Equation (1) often used to describe the relation between pressure drop and efficiency in the development of filter media, the definition of the kep number in equation (4) additionally incorporates the empirical constant C. This constant was introduced to better reflect the real performance data of 3-dimensional filter elements and is needed to derive a more realistic classification scheme. Here, this empirical constant is set to C = 22 Pa.
In our classification scheme the efficiency $T = \overline{T}_{EN\ 779}$ (0.4 µm) is defined as the average efficiency according to EN 779 for a particle size of 0.4 µm measured at 3.400 m³/h. The average pressure drop $\overline{\Delta p}$ is derived from the loading with AC Fine (ISO A2) dust as defined in Equation (3) at 3.400 m³/h.

At a given flow rate, large kep numbers indicate an energy efficient operation, since they relate to a lower pressure drop at a given collection efficiency compared to lower kep numbers. Hence, this number can be used to classify filters in accordance with their energy efficiency. In total, we define five energy efficiency classes at a flow rate of 3.400 m³/h, which are derived from an evaluation of commercially available filters (see table below).

kep number @ 3400 m³/h	energy efficiency class
kep ≥ 1	1
1 > kep ≥ 0.8	2
0.8 > kep ≥ 0.7	3
0.7 > kep ≥ 0.6	4
kep < 0.6	5

An energy efficiency class of "1" indicates an energy efficient air filter consuming less energy during operation compared to a filter with energy efficiency class "5", for example. In Figure 3 the lines of constant kep numbers are shown, defining the different energy efficiency classes. In the diagram, the average pressure drop corresponding to one year of operation is plotted as a function of the average efficiency according to EN 779.

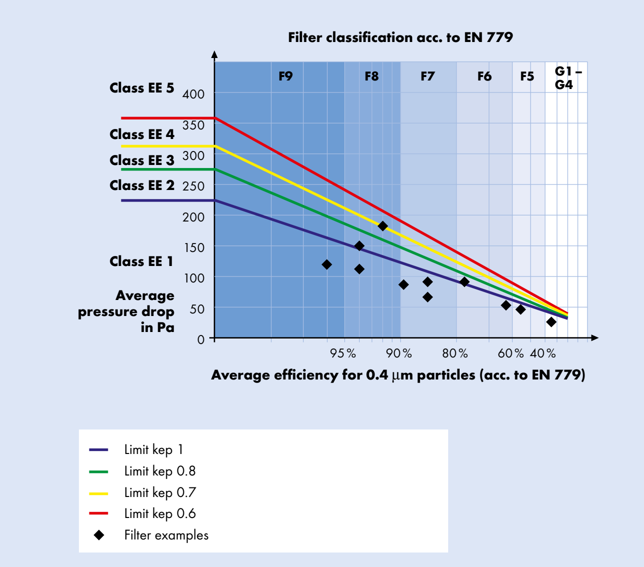

Figure 3: Energy efficiency classification scheme. The lines show the average pressure drop at constant kep numbers as a function of the average efficiency according to EN 779. The dots show example values for different filter elements.

Small absolute differences of the average pressure drop (e.g. 20 Pa) for low particle efficiency filters (e.g. F5 filter with an average pressure drop of 40 Pa at 3.400 m³/h) lead to larger relative differences compared to high efficiency filters (e.g. F9 filter with an average pressure drop of 140 Pa at 3.400 m³/h). Therefore in Figure 3, radial lines are given in the diagram, which stand for constant kep numbers and allow for varying a broader pressure drop range for air filters with higher particle efficiency.

Conclusion

An energy-efficiency classification scheme for air filters is developed for typical air handling units for HVAC application. A volume flow rate of 3.400 m^3/h per filter and an operation time of one year (6.000 hours) are chosen as standard conditions for a typically used filter element. Based on the average outdoor fine dust concentration (40 $\mu g/m^3$), an air filter is typically loaded with 800 g of environmental dust per year.

Our investigation revealed that filter loadings with AC Fine dust reproduces well the pressure drop behaviour of air filters when exposed to environmental dust, which could also be confirmed for different filter designs (pocket and cassette). These findings facilitate the simulation of the real life behaviour in the laboratory. The filter evaluation is carried out by first measuring the pressure drop during the loading of 800 g AC Fine dust (200 g for filters typically used in the second filter stage). In a second test with ASHRAE dust loading, the average fractional efficiency for 0.4 µm particles is measured according to EN 779. The energy efficiency classification is based on a key energy performance number (kep number). This number describes the relation between the pressure drop and the average collection efficiency for 0.4 µm particles according to EN 779. The filter's particle collection efficiency is a major factor in this classification scheme; for more particulate efficient filters (higher filter classes to EN 779), wider energy efficiency class limits are defined compared to less particulate efficient filters.

Based on the kep number an energy efficiency classification scheme with five classes from "1" to "5" is developed, where the energy efficiency class "1" marks the lowest energy consuming air filter. In combination with the collection efficiency class to EN 779, this classification scheme allows the quick comparison of different filters according to their energy consumption.

References

[1]
Chen, Chun-Wan; S. Huang; C. Chiang, et al. *Filter Quality of Pleated Filter Cartridges*. Ann. Occup. Hyg., Vol. 52, No.3, pp.207–212, 2008.

[2]
Caesar, T.; Schroth, T. *The influence of pleat geometry on the pressure drop in deep-pleated cassette filters.*
Filtration + Separation, 39(9): p. 49 – 54, November 2002.

[3]
EN 779: 2002. *Particulate air filters for general ventilation.*

[4]
ANSI/ASHRAE Standard 52.2-2007. *Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size.*

[5]
Umweltbundesamt. *Hintergrundpapier zum Thema Staub/Feinstaub (PM).* Germany, 2005. http://www.umweltbundesamt.de/uba-info-presse/hintergrund/feinstaub.pdf

[6]
Goodfellow, Howard; Tähti, Esko. *Industrial Ventilation*. Academic Press, 2001.

[7]
Mayer, M.; Caesar, T.; Klaus, J. *Energy efficiency classification of air filters.* Proc. 10th World Filt. Cong., Vol. 3, p. 313 – 317, April, 14 – 18, 2008. Leipzig, Germany.

Freudenberg Filtration Technologies KG
69465 Weinheim / Germany
Phone +49 (0) 621 80-6106 | Fax +49 (0) 621 88-6106
info@freudenberg-filter.com | www.viledon-filter.com

Freudenberg