Particle Shedding in HVAC Filters

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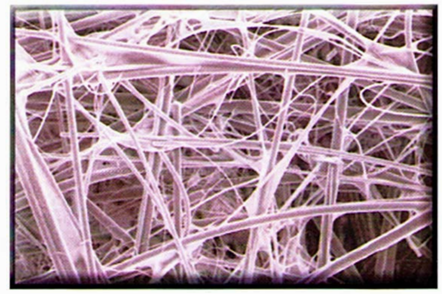
1. Background

There is an increase in public awareness of potentially adverse effects of lung penetrating fine particulate and fibrous airborne matter. A growing body of independent scientific research work is available and the general public has become more aware of the dangers caused by shedding of fibers and particles from HVAC filters. Although this effect is not considered and quantified when HVAC filters are classified and measured as per the current US[1] or European standards[2] for general HVAC air filters, it is widely known and understood.

Quantitative results of shedding of HVAC air filters are published by many authors. Measurement methods of shedding are discussed in international standardization committees and considered to be taken up in corresponding standards for HVAC air filters.



Picture 1: Glass fiber paper filter medium. Binder to interlink and stabilize individual fibers is clearly visible. M. Baraket, Swiss Federal Technical University, ETH, Zürich; 1992

2. Definitions

Under the general term "shedding," three separate aspects of adverse filter behavior are summarized in EN779-2002[3]: particle bounce, shedding of fibers and re-entrainment of particles. Some or all of these phenomena are likely to occur during the life cycle of an installed HVAC air filter depending on its design and the operating conditions.

Subject	Shedding from HVAC Particle Filters		
General Term	Shedding		
Sub-terms	Fiber Shedding	Particle Bounce	Particle Re-entrainment
Definition	Loss of fibers of filter medium to the airflow.	Locus of particles that impinge on the filter structure without being retained.	Primarily retained particles that are subsequently lost to the airflow.
Explanation Comment	Fibers or bits of fibers, originally part of the filter medium, which become loosened during the operating life of the filter, finally dislodged into the air stream.	When particles collide with filter medium fibers, the adhesive forces are not strong enough to retain them, and the particles are discharged into the air stream. When this occurs the filter will exhibit lower than expected efficiency for particles of this size.	Previously collected particles to be dislodged and finally discharged into the air stream again due to: • changes in operating conditions • increased velocities through the interstices of the media as clogging proceeds • relative movements of fibers within the filter medium. When this occurs the filter can, over short periods, exhibit a "negative efficiency." *(More particles discharged downstream than present upstream.)*

The above table shows a hierarchy in which shedding comprises all potential "losses" downstream of the filter. The table provides a quick overview of the three aspects of the term "shedding".

3. The various forms of Shedding

3.1 Fiber Shedding

Some filter media either contain and / or generate during use some loose fibers or fractions of fibers. During filter operation this loose material can be emitted into the air stream. The extent of such fiber shedding depends on the integrity of the media fiber structure and its rigidity and stability in the face of varying dust burdens and air velocities throughout the operating life of the filter. If the individual fibers of the filter medium are, for example, interlinked among each other (e.g. glass fiber paper filter medium with a binder **[Picture 1]** or synthetic filter medium with thermally bonded fibers) and / or the filter medium is well stabilized and can't move in the air stream when air is passing (e.g. rigid filters with pleated paper medium) fiber shedding can be reduced significantly, optimally to a near zero level. However, with a traditional filter design (glass fiber fleece filter medium pocket filters) operated under normal and especially under adverse conditions (variable air flow, frequent starts & stops), the effect can be noticeable.

The quantity or mass of fibers that shed from such filters normally remains low compared with the total amount of dust penetrating through a filter and compared with the fibers normally contained in atmospheric air. However, the fiber shedding can't be ignored because of the potential health risk of glass fibers. It is a widely accepted fact that the health risk of glass fibers is much greater than the risk of environmental dust particles of equivalent mass or number.

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Recent research work of Reichert and Ohde, FHTW Berlin[4,5], has clearly shown the significance of fiber shedding for glass fiber pocket filters. According to these publications, a typical glass fiber bag filter sheds in constant operation between 1 and 18 fibers per m^3 of air, which means – at a filter unit air flow of 2500 cfm – between 4,200 and 75,600 fibers per hour. For standard HVAC applications this is not reason for concern. However, for critical applications such as hospitals and pharmaceutical industry it is of increased health concern and should be carefully considered. As a consequence, only filter designs that do not shed fibers should be used for final filter stages in these critical application areas.

Summary:

The fiber shedding effect is more pronounced for Fine Dust Filters (MERV 9 and higher) rather than for Coarse Dust Filters (MERV 1 to MERV 8). It is also more pronounced for fleece type glass fiber filter media than for synthetic fiber filter media and more pronounced for bag filters than for rigid filters. For final filter stages in critical application areas, only filter designs that do not shed fibers should be used.

3.2 Particle bounce

In an ideal filtration process each particle would be permanently arrested at the first collision with a filtering surface, such as a filter fiber or an already captured particle. For small particles and low air velocities, the energy of adhesion greatly exceeds the kinetic energy of the airborne particle in the air stream and once captured, such particles are therefore unlikely to be dislodged again. As particle size and air velocity increase, this is progressively less so and the likelihood of dislodging increases. Larger particles have a greater chance to be bounced off of a fiber instead of being captured by it. However, the particles normally loose enough energy to be captured in a subsequent collision with a fiber. If no contact with a fiber follows, this particle will be shed, i.e. bounced off. This results in a corresponding reduction of apparent efficiency for particles in that size range.

The efficiency reduction due to particle bounce will be greater for higher air velocities and for bigger particle sizes. It is also true for dust that is completely dry and has no tendency to stick to a fiber (e.g. dry sand, compared to oil droplets, soot or wet salt particles).

In scientific research work, investigators[6] have found a significant reduction in filter efficiency in the particle size range 2 to 8 µm which is most probably caused by this particle bounce effect. If a tackifier is applied to the filter fibre, a significant reduction of the particle bounce effect can be achieved [**Figure 1**].[7]

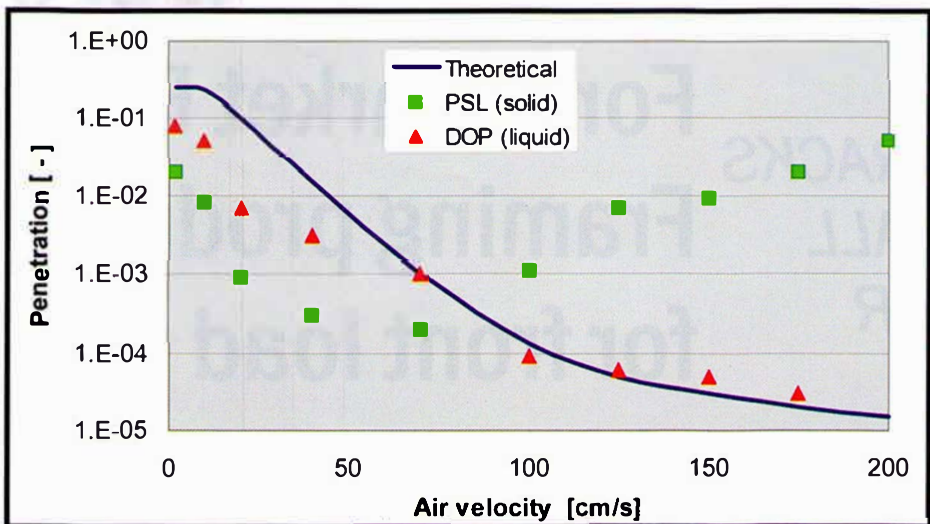

Figure 1: Experimental compared with predicted theoretical filter penetration for solid (PSL) and liquid (DOP) 2.0 µm particles according to [7]. Bouncing-off effect increases penetration of solid particles for higher air velocities.

A measurement method to quantify the "bouncing off" type of shedding is defined in Annex E of ASHRAE Standard 52.2-1999.[8] EN779-2002, yet neither provides methods for measuring particle size efficiencies for solid particles nor for particle sizes above 3.0 µm and therefore does not consider (that is ignores) the "bouncing off" effect in its test results and in filter classification.

Summary:

The particle bounce effect is much more pronounced for Coarse Dust Filters (MERV 1 to MERV 8) rather than for Fine Dust Filters (MERV 9 and higher) and also more pronounced for higher air velocities, bigger particle diameters and dry particulate matter.

3.3 Re-entrainment of particles

The particle re-entrainments effect, also known as "blow-off" or "unloading" effect, becomes relevant as the quantity of the separated dust in the filter medium increases[9], due to the following reasons:

a) An incoming particle may impact on an already captured particle and re-entrain it into the air stream.

b) The air velocity in the channels through the filter medium will increase because of the space occupied by the already captured particles. Furthermore the filter medium – if not stabilized by inter-fiber bonding - may become compressed by the increased resistance to airflow thereby causing even further increase in velocity in the air channels. The resulting increased fluid drag on deposited particles may re-entrain some of them.

c) But by far the strongest source for particle re-entrainment is movement of the filter medium during operation. This may cause movements among fibers of the filter medium and thus a rearrangement of dust held in the filter medium structure which leads to an immediate re-entrainment of dust.

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Circumstances that amplify this effect are:

(i) Fibers with little surface roughness

(ii) Dry dust with little adherence to the fiber (rather than wet, oily, sticky dust, forming a dust cake)

(iii) Filter designs that allow free movement of the filter medium. For example, bag filters show an average bag movement of the pocket ends of 4 to 8 mm with a typical frequency of about 20 s^{-1}. Comparative measurements of two different designs of fully loaded filters – glass fiber pocket filters and pleated paper media rigid filters - showed differences of particle re-entrainment of a factor of 500 [**Figure 2**][4,5].

Figure 2:
Measurement of 0.5 µm particle re-entrainment of 2 MERV 13 filters, loaded with ISO fine dust up to 2" w.g. Air flow 2000 cfm.
☐ 8 bag pocket filter with class fiber fleece medium
◊ 4-V mini-pleated compact filter with glass fiber paper medium.
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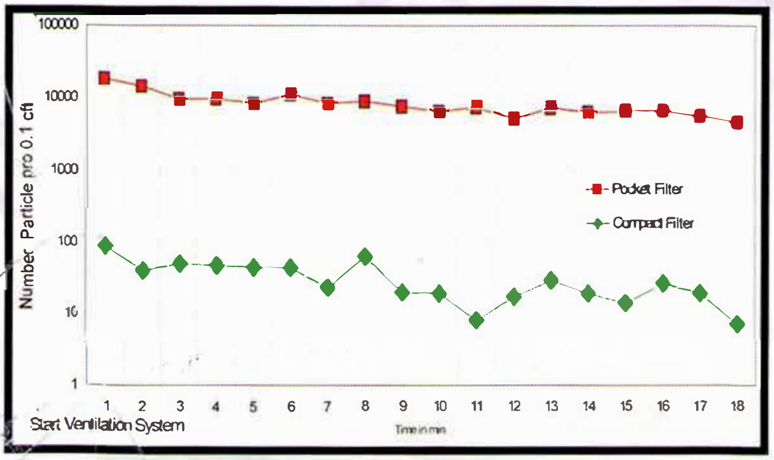

(iv) Filter medium designs that allow free movement of the fibers within the filter medium (e.g. glass fleece media). By using synthetic or glass fiber medium with interlinked fibers [**Picture 1**], shedding can be significantly reduced.

The possibility of filter media movements are related to the design of the filter but also to its mode of operation in the HVAC system. Particle re-entrainment can be triggered by:

(i) Air flow through the filter combined with periodic (e.g. daily) start / stop operation of the air conditioning system. This effect has been quantified by measurements[10] and proved to be relevant. For example, one start / stop operation with a loaded filter may result in at sudden particle release, equal to approximately 2 hours of service without filter.

(ii) Varying airflow rates (VAV AC systems)[10,11].

(iii) Mechanical vibrations within the AC unit[4].

Summary:

The **particle re-entrainments effect**, is relevant for Coarse Dust Filters and for Fine Dust Filters but it is more dependant on the design and the mode of operation of a filter than to its MERV number. Filters with binder less fleece medium, designed as unstable, floppy bags, frequent start / stop operation and variable air flow cause significantly more particle re-entrainment then rigid filters with pleated and stabilized medium which contains a binder.

To reduce the particle re-entrainment, bag filters should not be excessively loaded with dust and changed relatively frequently. For AC systems with frequent start / stop operation or variable air flow, it is recommended to use rigid filters as final filter stage.

4. The "shedding topic" in present and future standardization

As it was stated above, the current standards in the US standard ASHRAE 52.2-1999 and its European counterpart EN779-2002 do not properly consider and quantify the three sorts of shedding for measuring and classifying HVAC filters. One might argue that if in the current US standard the subeffect of particle bounce is considered, however the aspects of particle re-entrainments and fiber shedding are certainly not. Therefore, the efficiency / particle size curves provided in these standards do not reflect all shedding effects discussed above and therefore they do not reflect the behavior of these filters under real life conditions. Also the gravimetric arrestance curves presented in standardized test reports reflect shedding components only partly, if at all, because the ASHRAE loading test dust presently used has a soot content that has a humidity dependent tendency to stick to fibers [**Figure 3**].

On the other hand, the writers of these standards on both sides of the Atlantic were well aware of the adverse effects that shedding may have on the performance determination of filters. This can be seen in:

EN779-2002, clause 10.4.2, where it is written that "any drop in the value of the arrestance or resistance during the course of a filter loading test should be taken as an indication that shedding may have occurred."

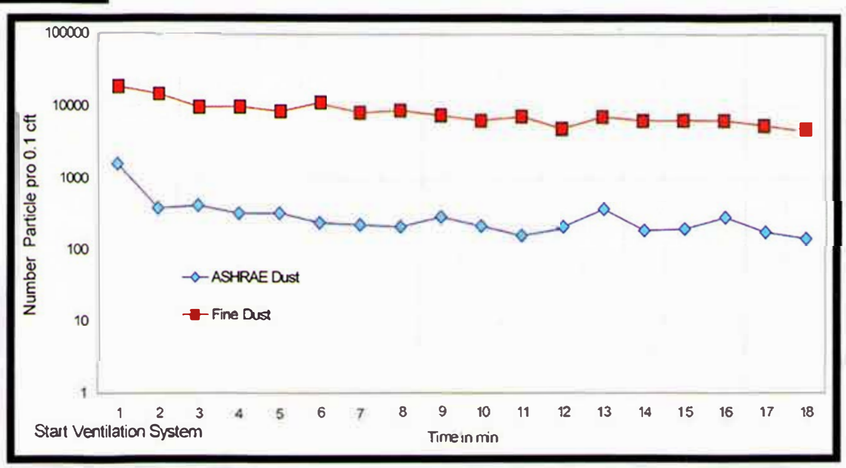

Figure 3:
Measurement of 0.5 µm particle re-entrainment of 2 identical MERV 9 filters, loaded with different test dusts up to 2" w.g. Air flow 2000 cfm.
◊ ASHRAE test dust
☐ ISO Fine test dust
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ASHRAE 52.2-1999, clause 10.7.3 and EN779-2002, clause 10.4.3, where methods are described for adjusting efficiency measurement for loading test dust migration (that is, re-entrainment shedding). But instead of including this adverse effect of shedding in the efficiency results, the current standards provides means and methods to compensate for and hence exclude the particle re-entrainment and fiber shedding effects from the standardized measurement results.

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It should be pointed out that meaningful measurements of particle shedding and re-entrainment are not easy to perform. The reasons for that are many. Among them, the reproducibility of the measurement configuration and that the particle counter sampling systems are not readily adaptable to measuring short-term "bursts" of particles.

For future revisions of the mentioned standards, consideration should be given to develop and establish measurement methods that detect, quantify and report significant "shedding" or "re-entrainment" of particles or fibers. If such shedding effects are relevant for a specific grade of filter and have the potential to significantly reduce its separation performance, it should also be considered to find means to downgrade (that is, down-classify) a filter that sheds significantly more than others.

For standardization bodies and filter manufacturers, to deal with shedding may first look very unattractive and difficult because it complicates their lives and reduces the efficiency values of the filters that may be reported in the test reports and promotional literature. But over the long run, it may give them the satisfaction of having taken action to avoid product liability issues and make their filters more effective – and this is it what quality is all about!

What finally counts is the real life behavior of a filter in its operational situation. Users of filters will become more and more aware of the possibility that filters may shed by corresponding scientific publications, by their practical experiences and through carrying out in-plant diagnostic air sampling tests (e.g. per Eurovent 4/10: 2004 or in future by a corresponding ASHRAE document). Therefore, it is recommended to include relevant shedding effects in future standards for filter performance measurements and classifications.

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