This is the ninth in a multi-part series on air filtration.

THE POWER OF THE UNKNOWN PARAMETERS

Iyad Al-Attar addresses the important parameters that need to be factored in while selecting filters. He also draws our attention to several unanswered questions on the subject, which hopefully, posterity will answer.

The human race has always endeavoured to better itself. The advancement in civilisation has largely been the result of mankind studying failures to achieve success and learning more about diseases to seek curative measures to lead healthier and longer lives. In fact, the history of humanity is full of great lessons we have learnt.

On a tangential, but relevant note, in October 1707, the English Admiral, Clowdisely Schovell, miscalculated his position in the Atlantic Ocean, leading to his fleet of ships colliding into the rocks of Silly isles, a series of islands off the southwest coast of England, claiming two thousand lives. Given the crude measurements professional seamen had to rely on at the time to estimate their average speed and, consequentially, their position, the miscalculation of the Admiral can be understood. The methods available at the time to measure longitude lacked precision, and in the case of Clowdisely Schovell, perhaps, the underlying reasons of the disaster could be identified[1]. The analogy becomes clear if we superimpose the Admiral's disastrous mistake to the field of air filtration and ask: what do we know that is critically important, but we are unable to measure? As a corollary to it, what do we know that is critically important, but we seem to overlook?

To answer these seemingly rhetorical questions, it is important to realise that the performance of a dust-loaded filter is not well-established beyond any reasonable doubt, and there is yet so much left to be discovered. Frankly, no one can claim today that they know everything in the field of air filtration that needs to be known. Perhaps, future discoveries will help rectify our past mistakes, and also, hopefully, our ongoing endeavours to improve filter design, manufacturing and operation of air filters will bear fruit.

HOW EFFICIENT IS YOUR AIR FILTER?

To answer the question, let's go back to the most addressed performance characteristic of air filters – filter efficiency. The overall efficiency of a filter hinges on the efficient functioning of the single fibre of each capture mechanism[2]. In this context, the most important mechanisms considered are diffusion, interception and inertial impaction[3]. Illustrations of interception and diffusion capture mechanism in air filtration are shown in Figure

In gas filtration, it is common to assume that each mechanism acts independently of the rest. However, it is a more complex and dynamic process. When absolute filters are assessed, the effect of the impaction mechanism is usually omitted, as diffusion and interception are the two dominant mechanisms around the Most Penetrating Particle Size range (MPPS). Filtration efficiency, in general, is a function of particle size, particle shape, filtration velocity and, frequently, particle charge, which makes the comprehensive evaluation of air filter efficiency a tedious task.

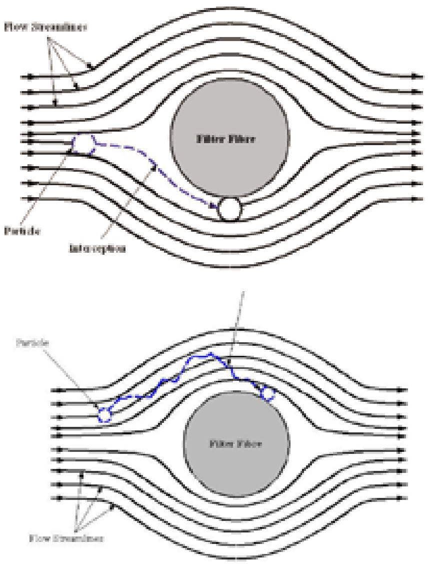

Figure 1: Illustrations of interception and diffusion capture mechanisms in air filtration

To better understand the dominance regions, the MPPS has to be defined. For particles of 1 µm and smaller, complex interactions between Brownian diffusion and inertial effects result in the so-called MPPS. The MPPS is a characteristic of depth filters, where minimum capture efficiency is observed, typically in the size range of 0.05 to 0 0.6 µm. The MPPS arises because particles smaller than 0.05 micron are captured efficiently via a diffusion mechanism, whereas particles larger than 0.6 micron are captured more efficiently by a combination of interception and inertial impaction[4].

Absolute filters are rated at MPPS, since the filter efficiency scores its lowest value. The diffusion mechanism is dominant in the sub-MPPS and the interception and inertial impaction mechanisms are dominant in larger than MPPS, as shown in Figure 2. MPPS is only significant when dealing with absolute filters, such as HEPA and ULPA filters. The MPPS is a function of air velocity and filter media characteristics. Therefore, the air velocity is of critical importance to the filtration process, as it highly influences filter performance.

THE AIR VELOCITY IS OF CRITICAL IMPORTANCE TO THE FILTRATION PROCESS, AS IT HIGHLY INFLUENCES THE FILTER PERFORMANCE.

ABSOLUTE FILTERS DESIGNS

It needs to be noted at this juncture that increasing the velocity reduces the single fibre efficiency due to diffusion. Conversely, the collection efficiency of Absolute filters increases when the velocity of the air stream flowing through the filtration medium is reduced. This can be done by virtue of increasing the filter surface area by means of pleating. The oldest HEPA filter design introduced higher surface area by pleating the filtration media and inserting corrugated aluminum foil spacers between the pleats to minimise contact between the pleated filter medium. However, this sort of design limits the increase of the surface area, since the spacers occupy a volume of their own. Further, there is a considerable risk that the spacers might damage the pleats, either during transport, installation and/or during operation. Needless to say, if excessive flow rate is used, the pleats might deform, distort or dislocate from their original position, leading to fluctuation in permeability and, eventually, possible ruptures in pleated panels.

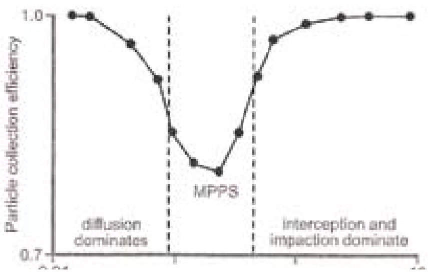

Figure 2: The typical relationship between capture mechanism and particle size[4]

Another technique used to extend the surface area is the minipleat technology, using hot melt to separate the pleats, as shown in Figure 3. A higher surface area can be introduced via this technique. It can be observed that the filter exhibits lower pressure drop when compared to the aluminum spacer technique for the same efficiency.

Extending filter surface area by pleating the flat media, if done appropriately and professionally, can reduce the air velocity and extend the particle residence time inside the filter media and, thus, enhance the overall filter efficiency.

Absolute filters are manufactured in different designs to accommodate various applications. There are pleated panel filters, as shown in Figure 4 and the cartridge type, as shown in Figure 5.

It is evident that an appropriate selection of a filter involves careful consideration of the particle concentration and flow rate. Using lower surface area filters with relatively high flow rates leads to pleat distortion, pleated panel deformation and possible disintegration of the filter elements. Figure 6 highlights distortion of the pleats due to high flow rates used, which will lead to permeability reduction and flucation in the local velocities.

Figure 3: A close-up of a few minpleats separated by hot melt

According to Darcy's Law, permeability is inversely proportional to pressure, which in turn means, any reduction in filter's permeability will be translated into increase in pressure drop. If permeability continues to decrease, the pressure drop will start to rise in a non-linear manner, causing more distortion of the media, eventutally casuing filter material to rupture, as shown in Figure 7, and pleated panels to deform, as shown in Figure 8.

Making appropriate filter selection requires a comprehensive understanding of the parameters that influence filter performance. In this article, we have addressed the use of the required surface area for the operational flow rate. It was also demonstrated how using a filter with lower surface area would sacrifice

Figure 4: HEPA filters in pleated panel design

Figure 5: HEPA filters in V-bank design

the entire performance of the filter. Here, it is important to highlight the fact that flow rate is not the only parameter that should be addressed with care, as dust type, density and concentration are also other factors that are critically important to the filter performance. An in-depth analysis of filter performance using different filtration materials and dust types tested under various operating conditions would, therefore, facilitate a platform to make appropriate filter selection.

UNANSWERED QUESTIONS AND UNSOLVED MYSTERIES

From a filter design standpoint, the filtration of particles is dependent on particle size, filter media characteristics and flow velocity, as discussed earlier. However, the filter media itself is full of mysteries that only future research might reveal. Hopefully, it will disclose its secrets and unfold its untold stories some day.

Figure 9 shows a scanning electron microscopic image of filter media of a given area, where only one fibre of nearly 45 µm diameter occupies this area. On the other hand, Figure 10 depicts for the same given area several fibres of different diameters shown in another filter media. This leaves us with the question: What is the effect of different packing densities on the filter efficiency and the pressure drop? The auxiliary questions that follow are: Is fibre diameter distribution a measureable quantity? Is it readily available to be looked up in manufacturers' catalogues? Do the number of fibres in the filter material and their diameter distribution significantly influence the filter performance to an extent that it cannot be overlooked?! The body of data required to answer these questions succinctly and satisfactorily, demand not only attention, but also acquisition – acquisition of knowledge.

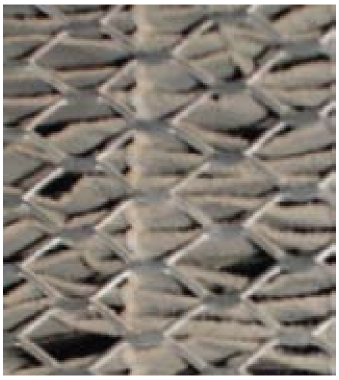

Figure 6: Pleat distortion after being subjected to high flow rates

Figure 7: Rupture in the pleats in a panel pleated filter

Figure 8: Deformation of the entire filter pleated panel

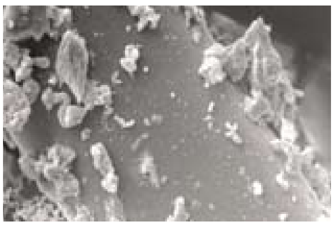

Figure 9: Comparison between two different filter media of the same sampling area.

USING LOWER SURFACE AREA FILTERS WITH RELATIVELY HIGH FLOW RATES LEADS TO PLEAT DISTORTION, PLEATED PANEL DEFORMATION AND POSSIBLE DISINTEGRATION OF THE FILTER ELEMENTS.

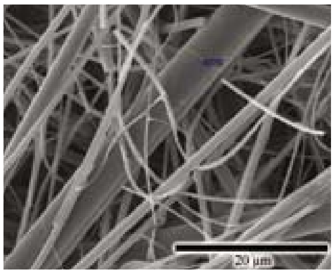

Figure 10

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