The mechanisms for the separation of particles and gaseous contaminants from the air are fundamentally different. Particles are separated by mechanical or electromechanical effects, whereas gases are generally separated by adsorption or absorption.

**PARTICLE CAPTURE FUNDAMENTALS**

**Particle capture theory**

Theories of filtration are generally based on particulate trajectories around an isolated cylinder (a fibre) and particulate deposits due to inertia, interception and diffusion onto fibrous strands.

Particle capture by a particulate air filter fibre involves two different mechanisms:

- The probability that one of the dust particles will collide with one of the media fibres, (deposition).
- The probability that the particle, once contacting the filter fibre, will continue to adhere to it (adherence).

Fibrous filters consist of a maze of fine fibres, with a large bed depth in comparison to the dimensions of the particles to be filtered. The diameters of the fibres must be small relative to the inter-fibre distances or the filter will clog with a consequent rapid rise in air resistance. Filter construction depends on the duty for which it is designed.

The media of a filter designed for sub-micron particles is usually composed of fine fibres, many of which will be less than one micron in diameter. Air velocity is restricted to a few centimetres per second allowing diffusion to take place. Initial resistances for these types of air filters are usually high. Pleating of the filter media is used to increase the surface area and hence lower the resistance. Initial resistances of 1800Pa or higher are experienced when such air filters are operating in their normal air velocity range.

For removal of relatively low concentrations of particles, larger than a few microns in diameter, filters composed of coarser fibres are used in the form of a loose mat with larger inter-fibre distances. Air velocities are high to make use of inertial effects and initial resistances are usually lower than 150Pa.

Initial resistance, for both sub-micron and larger than 1 micron filters, at normal air velocity range, varies from 10pa to 300pa and more, due to a wide range of factors.

Industrial filters are typically made from woven fabrics and, when new, operate inefficiently by this impact.

The particle is larger than the gap between the fibres. It cannot pass through and is captured. Straining effects are typically only applicable to relatively large particles or very fine media.

Despite obvious limitations to theories, some consideration has been given to assessing single fibre capture ability and calculation of mean fibre diameter from pressure drop measurements. From this information an assessment of efficiency is possible.

**Particle capture methods**

There are five ways in which particles can be deposited on, or be captured by, the fibres of an air filter media. As shown in Figure 1, these are:

- **Straining (sieved by fibres)**
- **Inertia (impingement)**
- **Interception (being caught)**
- **Diffusion (dispersal)**
- **Electrostatic attraction (attracted to fibre)**

These particle-capture processes all occur simultaneously within the filter media and each contributes, to some extent, to the overall filter efficiency.

**Straining**

The particle is larger than the gap between the fibres. It cannot pass through and is captured. Straining effects are typically only applicable to relatively large particles or very fine media.

**Inertia**

Larger particles do not move around the fibres (with the airstream); they are carried straight into the fibre by their own inertia and are captured by this impact.

The effectiveness of particle collection by inertia forces increases with increasing particle mass (i.e., increasing particle size) and increasing particle (air) velocity. For the typical air velocity used in HVAC systems the impingement effect becomes dominant for particles with diameters greater than 10μm.
Interception

Midsize particles do move along the airstream lines and these also contact fibres and are captured by the fibre. The probability of a particle hitting a fibre due to interception increases with increasing particle size and fibre size. Interception dominates arrestance for particles with diameters between 0.5 and 1.0μm.

Diffusion

The smaller particles move randomly across the airstream lines and contact fibres by Brownian motion. This random movement, outside of airstream lines, causes the particle to contact the fibre and be captured.

The effectiveness of particle collection by diffusion increases with decreasing particle size and decreasing air velocity. Where there is no predominant electrostatic interaction, particles with a diameter of less than 100nm are deposited almost exclusively by diffusion.

Electrostatic interaction

Under the electrostatic interaction mechanism the particles are pulled toward the fibre due to an electrostatic charge that is imposed on the fibre.

The effectiveness of particle collection by electrostatic interaction increases with decreasing air velocity and particle size and increases with charge on fibre or particle.

Electrostatically charged fibres may lose their charge over time resulting in rapid and permanent reduction in arrestance.

Capture efficiency and air velocity

The relationship between air velocity and the efficiency of the interception impingement and diffusion processes are shown in Figure 2. Although this is a simplistic view, a relationship between efficiency and velocity has been demonstrated experimentally.

The diffusion effect decreases with increased air velocity while the impingement effect increases with increased air velocity (up to a point) and the interception effect is relatively constant, i.e., it is independent of air velocity.

Capture efficiency and particle size

The relationship between particle size and the efficiency of the interception and diffusion processes are shown in Figure 3.

Penetration of sub-micron particles

The particle size that most greatly penetrates a filter is a function of filter media construction, particulate challenge density, and air velocity. This size is called the most penetrating particle size (MPPS) for that filter. Figure 5 shows a typical particle size-penetration distribution curve for a hypothetical filter media, indicating the MPPS.

MPPS for this filter lies between 0.2 and 0.3 micron and this performance characteristic can be modified by changing the media filter fibre diameter and packing density and by adding electrostatic charges onto fibres. MPPS can be any particle size in the range (not necessarily 0.3 micron), dependent on flow, velocity and fibre packing/diameter.
Filters are tested in the MPPS range (e.g. HEPA filters tested at 0.3 micron) in the knowledge that if an efficiency rating is established at this particle size range then the efficiency at all other size ranges would be better.

Adhesion

The second mechanism needed for particle filtration theory is the adhesion of the particle to the fibre.

For the filter to be effective, particles must adhere (stick) to the fibre surfaces they come into contact with. See Figure 6. In general, it is assumed that particles adhere to surfaces when they come into contact. Particles can: fail to adhere when there is high relative velocities between the particle and filter fibre surface, resulting in re-entrainment of dust in the airstream. All air filtration devices depend on adhesive forces. Factors contributing to adhesion include:

- Surface tension due to films of moisture on particles or nearby surfaces. Relative humidity is significant in the retention of particles larger than one micron and in the cohesion of aggregates. Capture efficiency usually decreases as relative humidity of the air decreases. This, however, is not true for high-efficiency filters removing sub-micron particles.
- Surface contaminants such as soluble materials or very small particles that affect the closeness of contact between the filter surface and particle.
- Size of particles, shape and filter surface roughness, which influence areas of contact.
- Duration of contact. The forces of adhesion between a filter surface and particles larger than 10 microns increase with time.
- Temperature. By altering surface tension forces, temperature can influence adhesion.

FIBRE COATING ENHANCEMENT EFFECTS

Impingement filters can be treated with adhesives or gel coatings that coat the fibres and create a bond between them and any dust particles that may impinge upon the fibre, increasing the adhesion. This coating helps prevent the particle from being dislodged, due to air velocity or fibre vibration by increasing the adhesion between the particles and the filter fibres.