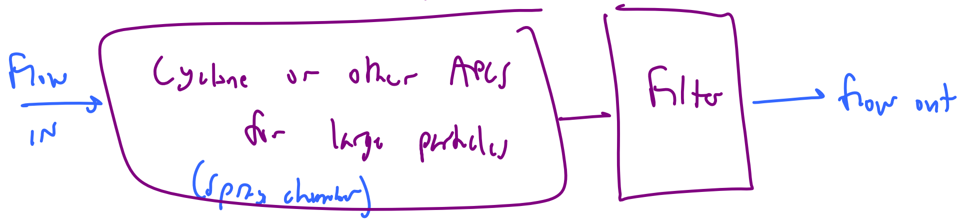
Today, we will:

- Discuss **air filters**, and how to classify them and analyze their efficiency
- Discuss **dust cakes** and their effect on air filters

AIR FILTERS

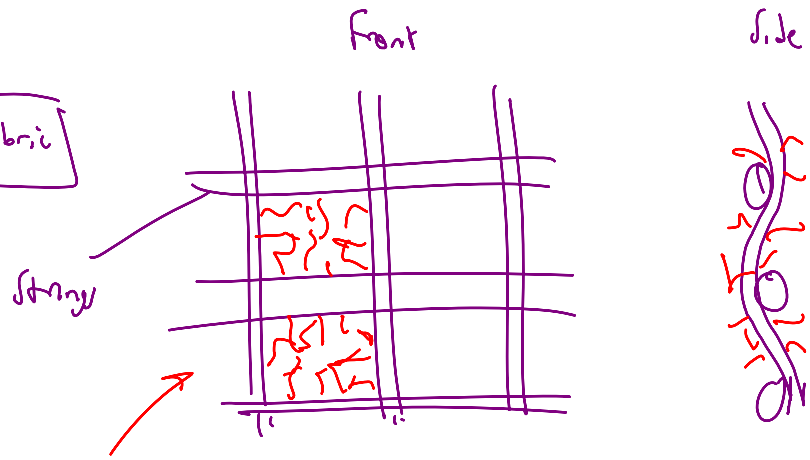
- Mostly used for collecting very smallest particles



Two main types

Woven Fabric

e.g. vacuum cleaner bags, filter cloth



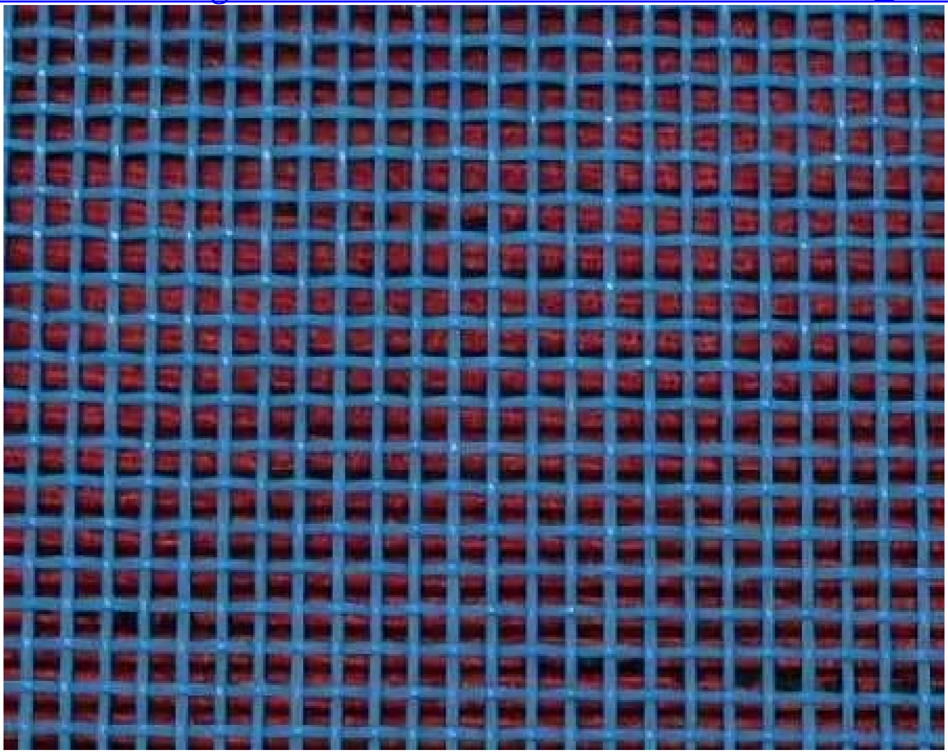
1) Strings are for structural support only. (coarse weave)
   The hairy fibers do most of the cleaning

2) Woven fabric is the filter itself (no hairy fibers) (close weave) — like cloth

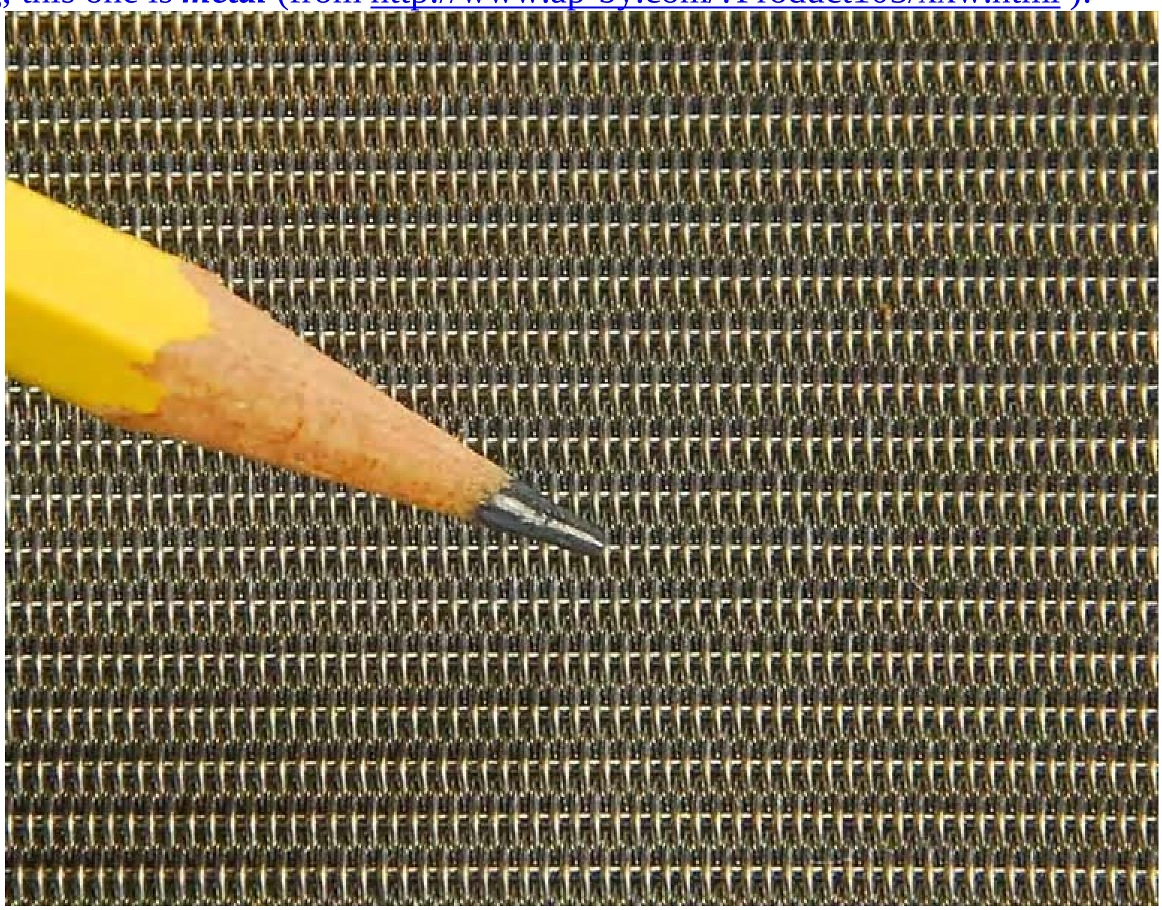
Felt → not woven string — a collection of small fibers that are randomly oriented & sometimes glued together

e.g. cigarette filter, common household furnace filter

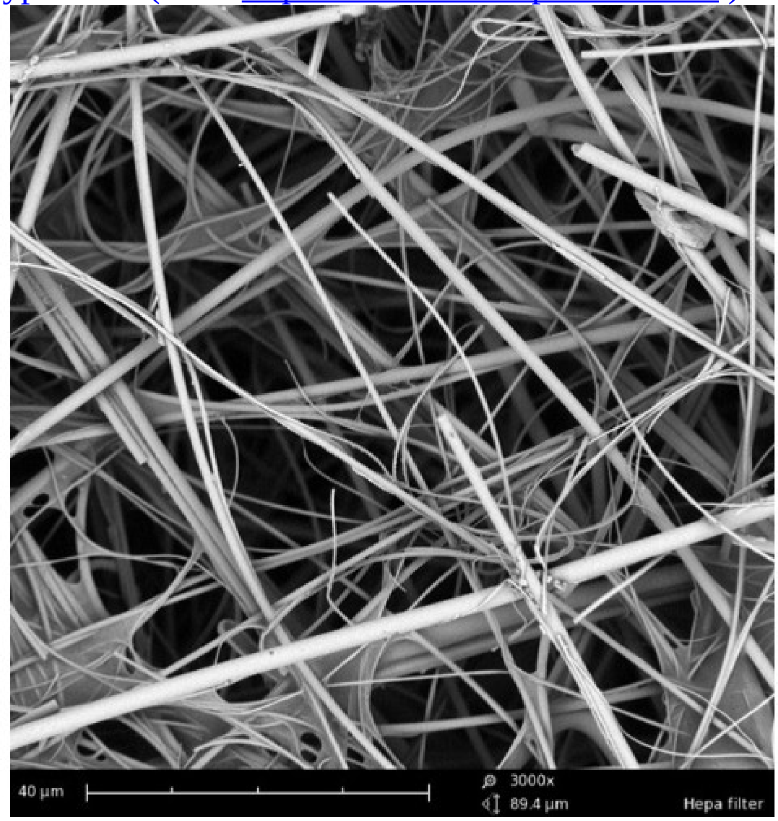
Example of a woven filter, where the woven threads are mostly just for support (from http://img.diytrade.com/cdimg/1716948/24752681/0/1329961910/Woven_filter_Belt.jpg):



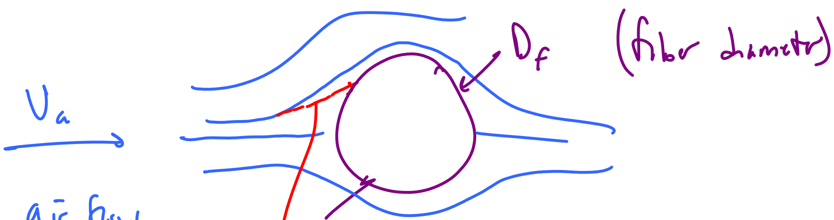
Example of a woven filter, where the woven "threads" are very tight and do the actual filtering; this one is ***metal*** (from http://www.ap-by.com/?Product105/xxw.html):



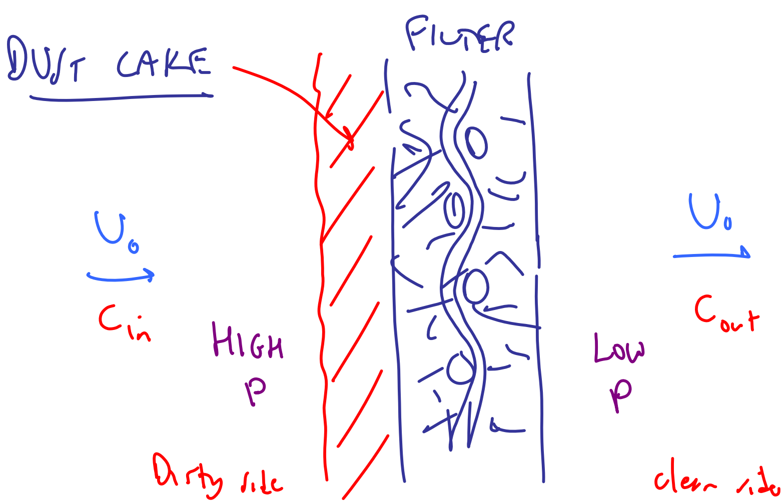
Example of a "felt" type filter (from http://www.lambdaphoto.co.uk/):



Principle of Operation — Similar to rain drops



particles hit the fiber & stick, due to inertial separation



As dust cake builds up,

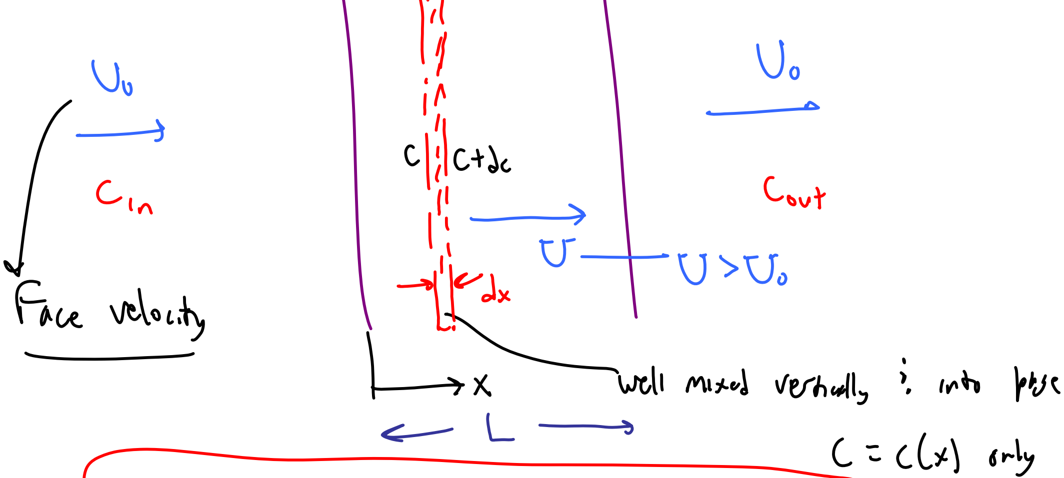
$\Delta P \uparrow$ ∴ cost ↑

(actually improves the removal efficiency)

↓

dust cake itself acts like a filter

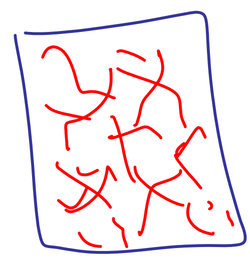
Analysis



Let ε = Porosity of the filter = open fraction

f_f = Blockage " " " $= 1 - \varepsilon$

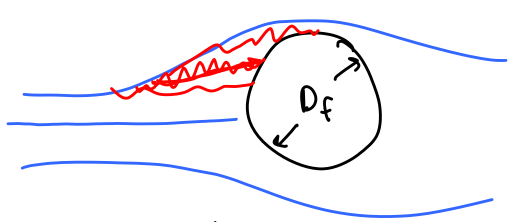
Strings & fibers block some of cross-sectional area



e.g. if $\varepsilon = 0.9$ (90%) → $f_f = 0.1$ (10%)

Strings & fibers block 10% of the cross-sectional area

Actual air velocity = $U = \dfrac{U_0}{\varepsilon}$ (air must flow faster through the filter to compensate for ε)



- Inertial separation
- Brownian diffusion
- Sometimes electrostatic attraction (static electricity)

Analyze very similar to raindrops

Define **Single-Fiber Collection Grade Efficiency**

$$E_f(D_p) = \left(\frac{Stk}{Stk + 0.425} \right)^2$$

Calvert & England Model

Stk = Stokes # → same defn as for rain drops
except use U instead of U_0 $\left[U = \frac{U_0}{\varepsilon} \right]$

– use D_f instead of D_c for the collector dia.

– Don't worry about gravimetric settling

$$Stk = \frac{(\rho_p - \rho) D_p^2 \left(\frac{U_0}{\varepsilon} \right)}{18 \mu D_f}$$

Result:

$$E(D_p) = 1 - \exp\left(-\frac{L}{L_c} \right) \quad (1)$$

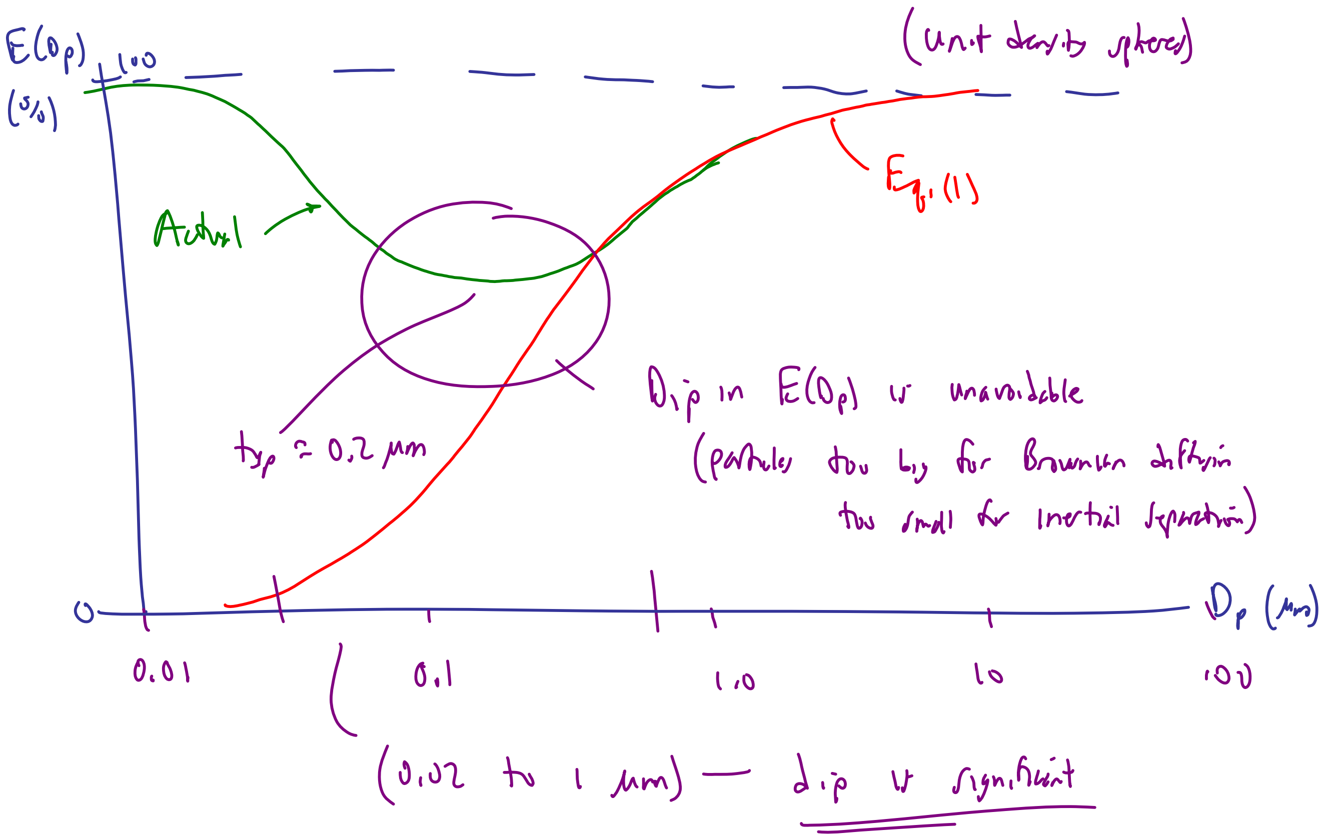
same eq. as previously

Calvert & England model →

$$L_c = \frac{\pi}{4} \frac{\varepsilon}{1-\varepsilon} \frac{D_f}{E_f(D_f)} \quad (2)$$

The C & E model does not account for Brownian diffusion

So – it is conservative estimate



Example: Performance of an Air Filter

Given: An air filter is used to clean air. Here are some properties:

- D_f = 20 microns = 20E-06 m (diameter of the hairy fibers inside the filter)
- U_0 = 0.200 m/s (air speed upstream and downstream of the filter)
- ε = 0.76 (porosity of the air filter, i.e., fraction of open area)
- D_p = 1 micron = 1.0E-06 m (diameter of the air pollution particles we are targeting)
- ρ_p = 1000 kg/m^3 (air pollution particles are treated as unit density spheres)
- L = 5.0 mm = 0.0050 m (total length (thickness) of the filter)
- Air at STP: ρ = 1.184 kg/m^3, $\mu = 1.849 \times 10^{-5}$ kg/(m s)

To do: Calculate the collection grade efficiency of the filter for these particles. You're your answer as a percentage to three significant digits. (Does not include Brownian diffusion)

Solution: Some equations: $Stk = \frac{(\rho_p - \rho) D_p^{\ 2} (U_0/\varepsilon)}{18 \mu D_f}$, $E_f(D_p) = \left(\frac{Stk}{Stk + 0.425} \right)^2$,

$L_c = \frac{\pi}{4} \frac{\varepsilon}{1-\varepsilon} \frac{D_f}{E_f(D_p)}$, $E(D_p) = 1 - \exp\left(-\frac{L}{L_c} \right)$

$Stk = 0.039488$

$E_f(D_p) = 0.0072273$ ← Small!

$L_c = 0.0068825$ m

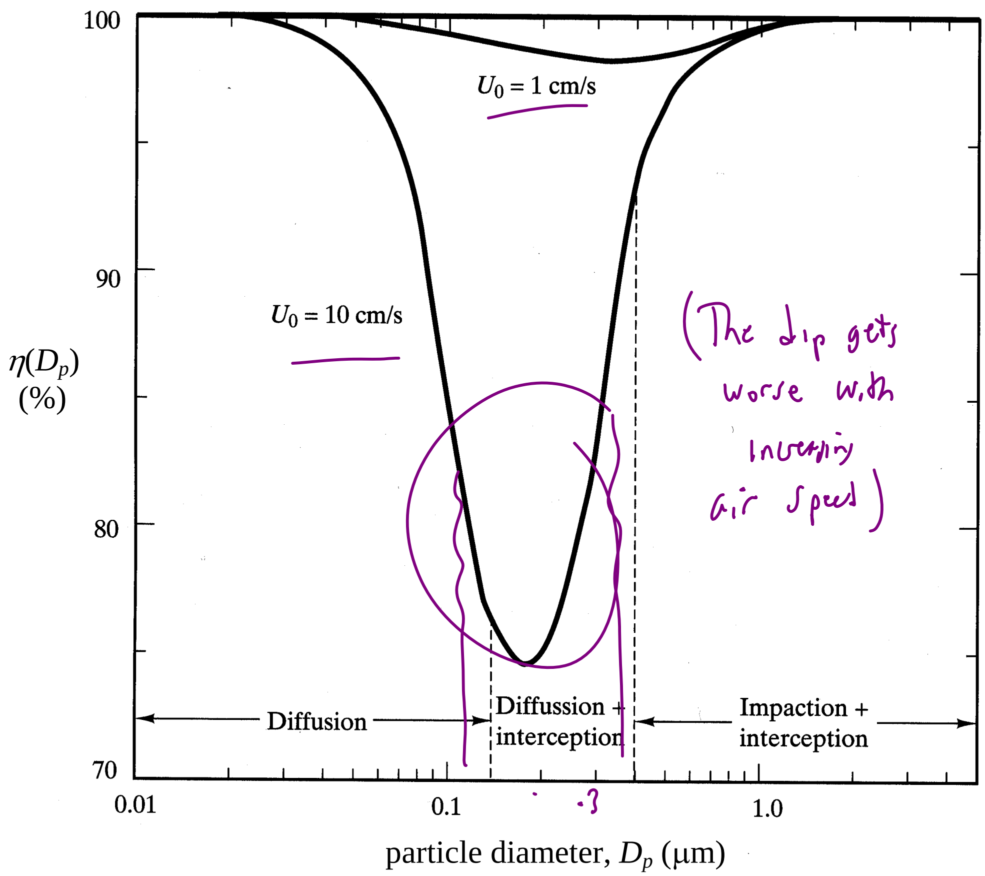
$E(D_p) = 1 - \exp\left(-\frac{L}{L_c}\right) \rightarrow 0.51639$ **51.6%**

The bigger the L (thicker filter), the better the removal efficiency. BUT ΔP increases significantly with increasing L – so it costs more to remove more particles

(there is no free lunch)

Example from a real air filter, showing the “dip” around 0.1 to 0.5 microns:

We use $E(D_p)$ instead of $\eta(D_p)$ →



Filter grade efficiency for two face velocities; filter thickness H = 1.0 mm, solids fraction f_f = 0.05 (porosity ε = 0.95), single fiber diameter D_f = 2 μm (adapted from Hinds, 1982).

☆ 0.1 to 0.3 μm particles are very hard to filter

Filter Classification:

☆ HEPA filter = High Efficiency Particulate Air filter

$E(D_p) > 99.97\%$ for $D_p = 0.3\ \mu m$

☆ ULPA filter Ultra Low Penetration Air filter

$E(D_p) > 99.999\%$ for $D_p = 0.12\ \mu m$