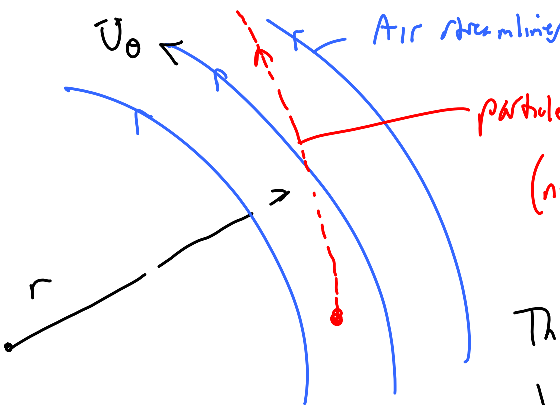
**Today, we will**:

- Discuss **cyclone collectors** in **Section 9.1**
- Do an example problem – parallel cyclone collectors
- Discuss **other inertial separation collectors and sampling issues** (cascade impactors and isokinetic sampling) in **Section 9.2**
- If time, begin to discuss **impaction between moving particles** (spray chambers, scrubbers, etc.) in **Section 9.3**

# CHAPTER 9 – PARTICLE CAPTURING DEVICES

* Goal – separate particles out of the air flow

How? Most of the devices use the principle of inertial separation

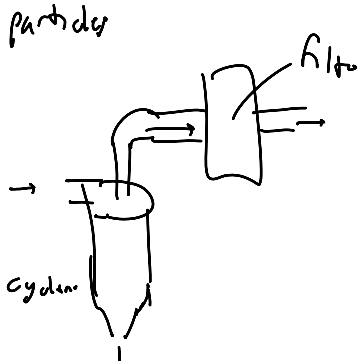



The degree of inertial separation depends on $\frac{U_\theta^2}{r}$

## Section 9.1 – Cyclone Collectors

* Very popular (ubiquitous)
- All sizes
- Very good at removing large particles
- Not so good at " small particles

Often used in series with a filter.




Two types – straight-through & reverse-flow

## Straight-through cyclone:

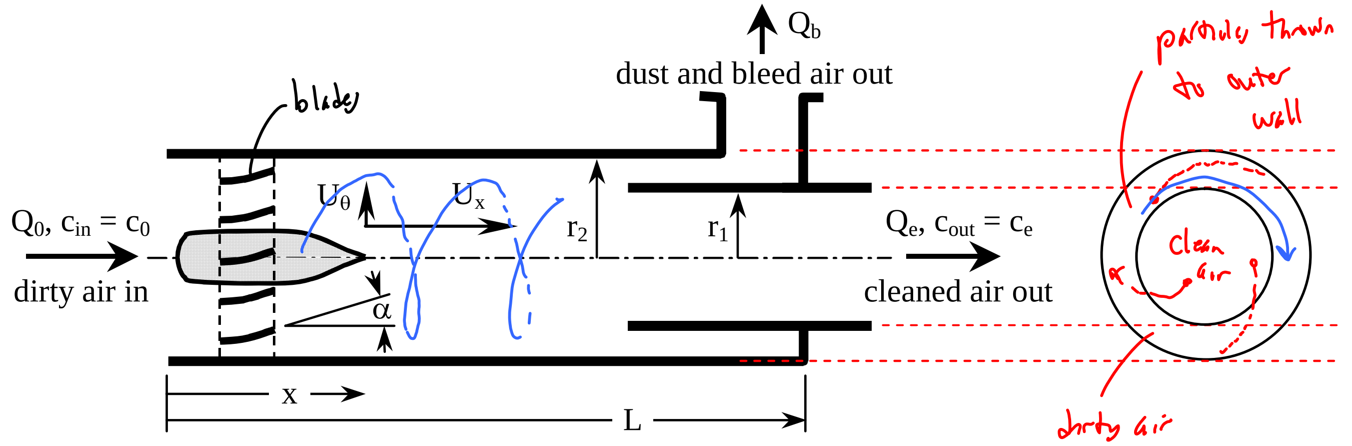
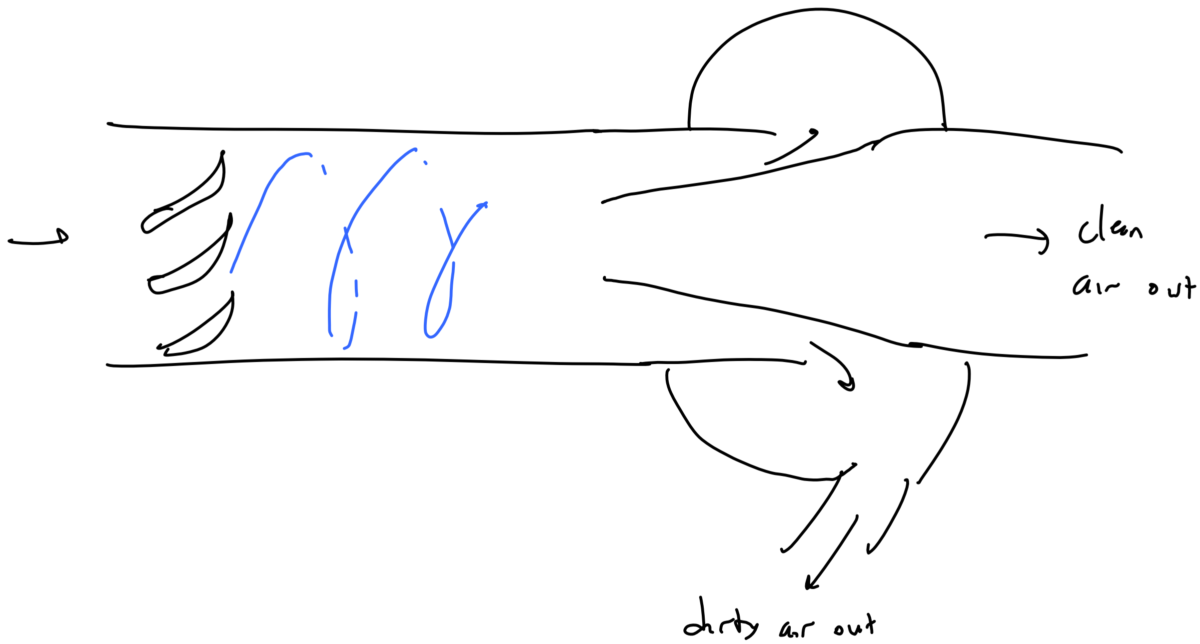



**Figure 9.1** Straight-through cyclone collector with helical turning blades; bleed air is required to remove particles.



## Reverse-flow cyclone:

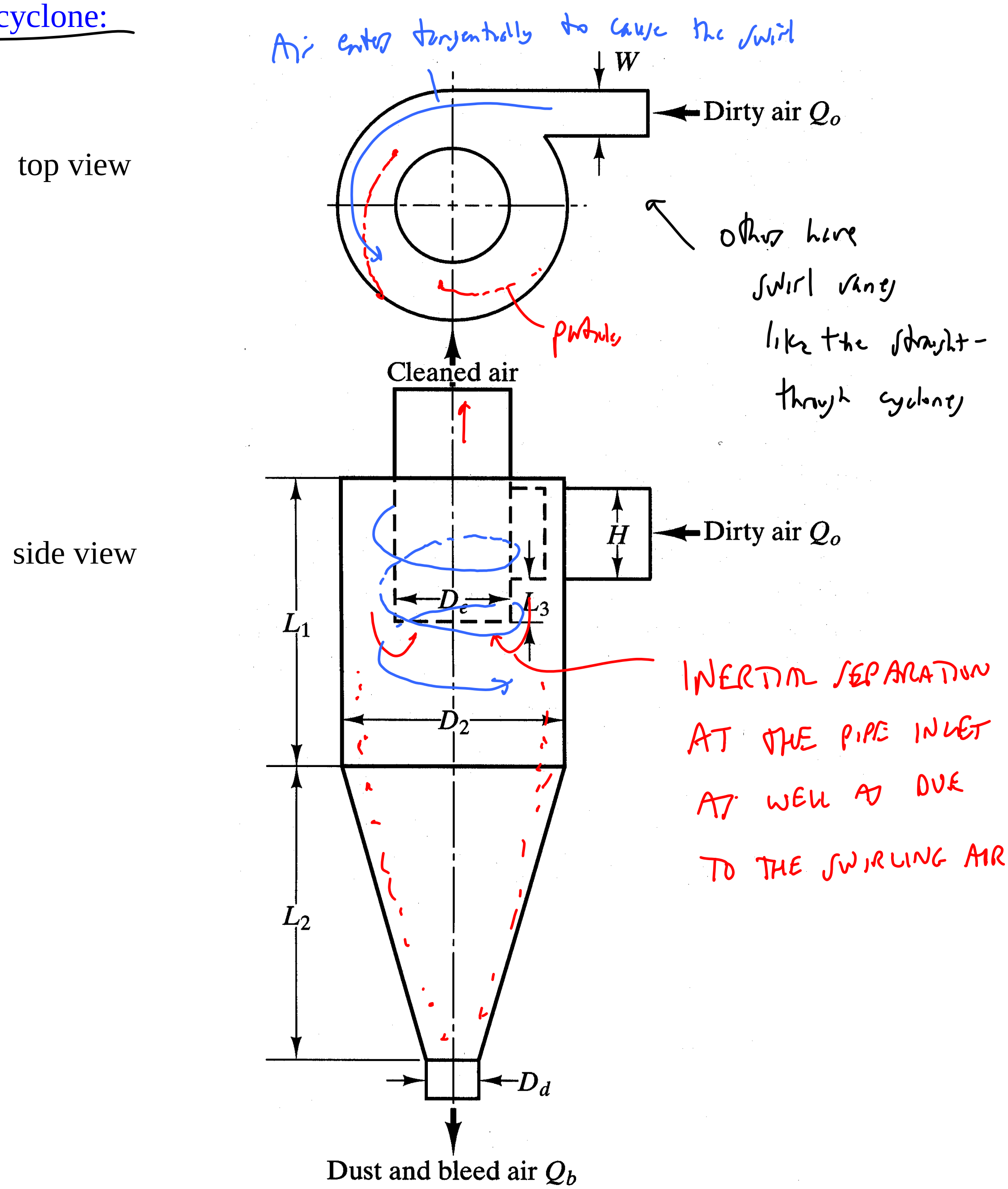


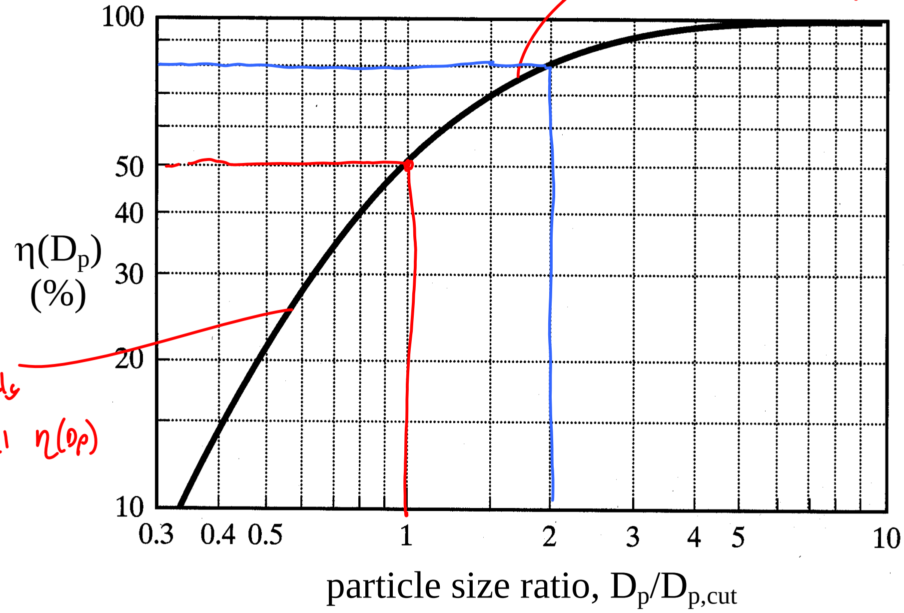

**Figure 9.2** Lapple standard reverse-flow cyclone collector with tangential entry, and with characteristic dimensions given by Eqs. (9-5) and (9-6).

See text for derivation → use principles of Ch. 8

We can generate a grade efficiency curve for any Lapple cyclone → i.e. plot it nondimensionally

## Lapple standard reverse-flow cyclone:

big particles have high $\eta(D_p)$




small particles have small $\eta(D_p)$

**Figure 9.3** Normalized grade efficiency of a Lapple standard reverse-flow cyclone.

$$\eta(D_p) = \frac{1}{1+\left(\frac{D_p}{D_{p,cut}}\right)^{-2}} \qquad (9\text{-}7)$$

curve fit for Fig. 9.3

$$D_{p,cut} = \sqrt{\frac{9\mu H W^2}{2\pi N_e Q(\rho_p - \rho)}} \approx \sqrt{\frac{9\mu H W^2}{2\pi N_e Q \rho_p}} \qquad (9\text{-}8)$$

$D_{p,cut}$ = $D_p$ at which the grade efficiency = 50%

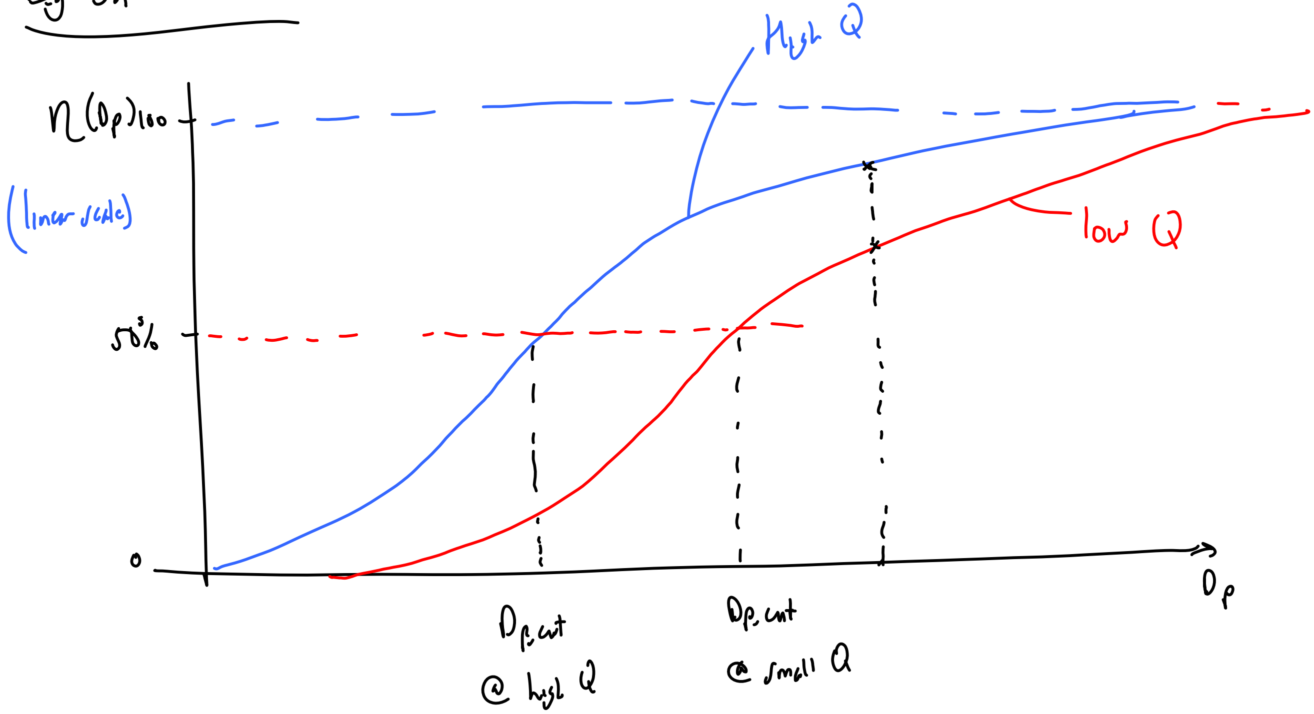
(removes half of the particles of dia $D_{p,cut}$)

$D_{p,cut}$ = fnc ( cyclone dimensions, $\rho_p$, $\mu$, $Q$ )

See Eq 9-8.

Comments: • Higher vol. flow rate gives higher collection efficiency

Eg 9.1 in text




But → Higher flow rate increases the pressure drop significantly

$\Delta P \propto Q^2$ required fan power $\dot{W} \propto Q^3$

- Smaller cyclones have better efficiency

Best solution → Put lots of small cyclones in parallel

overall → high $\eta(D_p)$

→ but small $\Delta P$

**Example**

**Given**: Several identical standard reverse flow Lapple cyclones are used in parallel to clean up a dusty air flow. The main body diameter of the cyclones is $D_2$ = 3.0 cm.

- particle density $\rho_p$ = 1500 kg/m$^3$
- total bulk volume flow rate of air $Q$ = 20.0 SCFM

**To do**: If the requirement is that $\eta(D_p)$ must be at least 80% for 15-μm particles, calclate how many parallel cyclones are required.

**Solution**:

@ $D_2 = 0.030 \rightarrow H = D_e = D_2/2 = 0.015$ m

$W = L_3 = D_d = D_2/4 = 0.0075$ m

$\mu$ of air @ STP = $1.81 \times 10^{-5}$ kg/m·s

$L_1 = L_2 = 2D_2 = 0.060$ m

# of turns of the air: $N_e = \frac{1}{H}\left[L_1 + \frac{L_2}{2}\right] = 6$ ← for any Lapple cyclone

Eq 9-8 →

$$D_{p,cut} = \sqrt{\frac{9 \mu H W^2}{2\pi N_e Q \rho_p}}$$

Solve for Q for one cyclone →

$$Q_1 = \frac{9 \mu H W^2}{2\pi N_e \rho_p D_{p,cut}^2} \quad (1)$$

Use Eq 9-7 (or the figure) for grade efficiency

$$D_{p,cut} = \frac{D_p(80\%)}{2.0} = \frac{15\ \mu m}{2.0} = 7.5\ \mu m = D_{p,cut} \quad (2)$$

· Plug (2) into (1) → solve for $Q_1$

$$m = \frac{Q}{Q_1} = \text{\# parallel cyclones required}$$

$Q$ – total flow rate

$Q_1$ – flow rate through 1 cyclone

$$M = \frac{Q}{Q_1} = \frac{2\pi N_e \rho_p D_{p_{cut}}^2 Q}{9 \mu H W^2}$$

#'s → $M = 218.4$

$M \approx 218$

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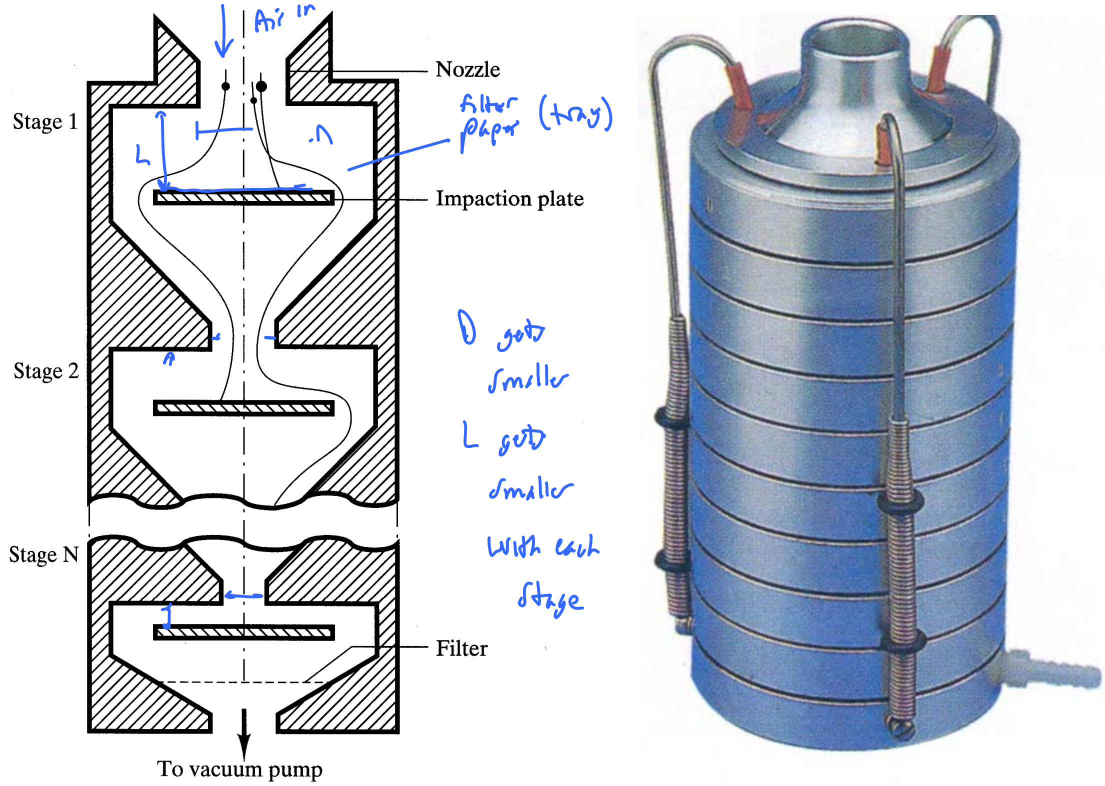
Other Inertial separation devices — See 9.2

e.g. Cascade Impactors → used to collect particles for analysis purposes (not for cleaning)

## Section 9.2.2 – Cascade Impactors




(a) (b)

**Figure 9.7** Cascade impactor: (a) schematic diagram, showing trajectories of particles of three different diameters (adapted from Willeke and Baron, 1993); (b) Andersen eight-stage, non-viable, 1 ACFM ambient air sampler (from Andersen Instruments Inc.).

Particles of certain sizes impact on certain trays

[separates particles by diameter onto the various stages] grade efficiency:

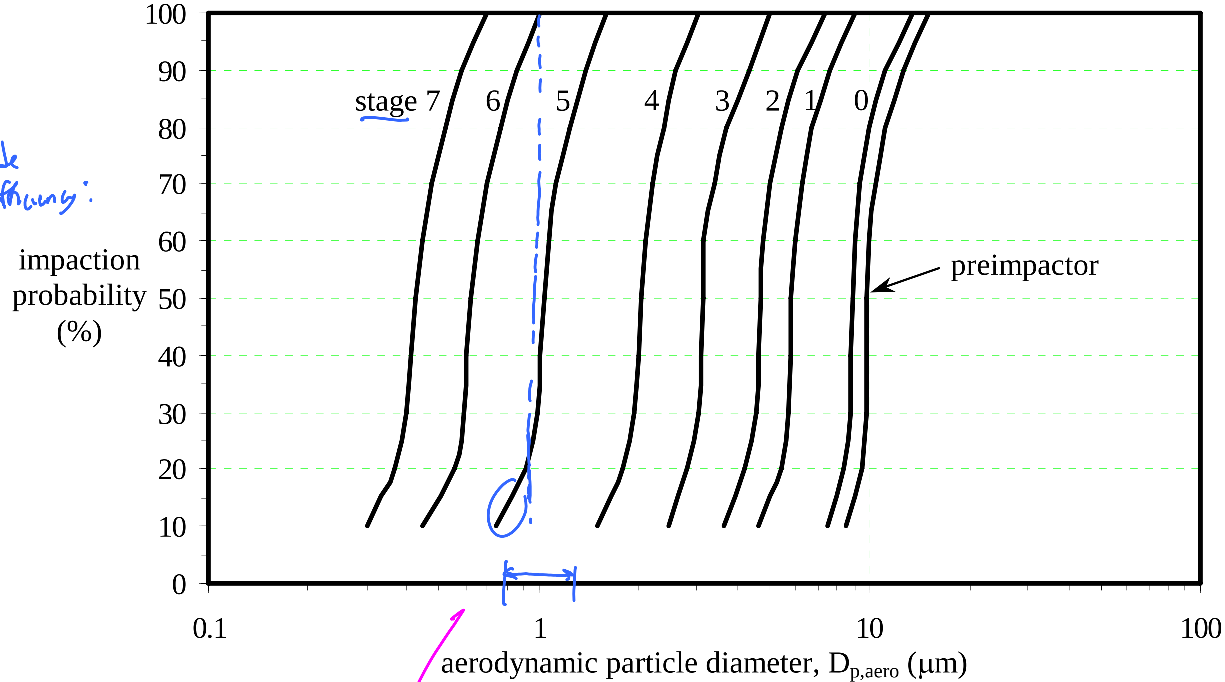



**Figure 9.8** Particle collection efficiency for each stage of an Andersen eight-stage, 1 ACFM ambient air sampler with preimpactor (redrawn from Andersen Instruments, Inc.).

As you can see, there is very little overlap between the grade efficiency curves for each stage

So → the cascade impactor separates particles by size

At the end, you weigh each plate to determine how many particles are in each stage

See CFD calculations of Ch. 10

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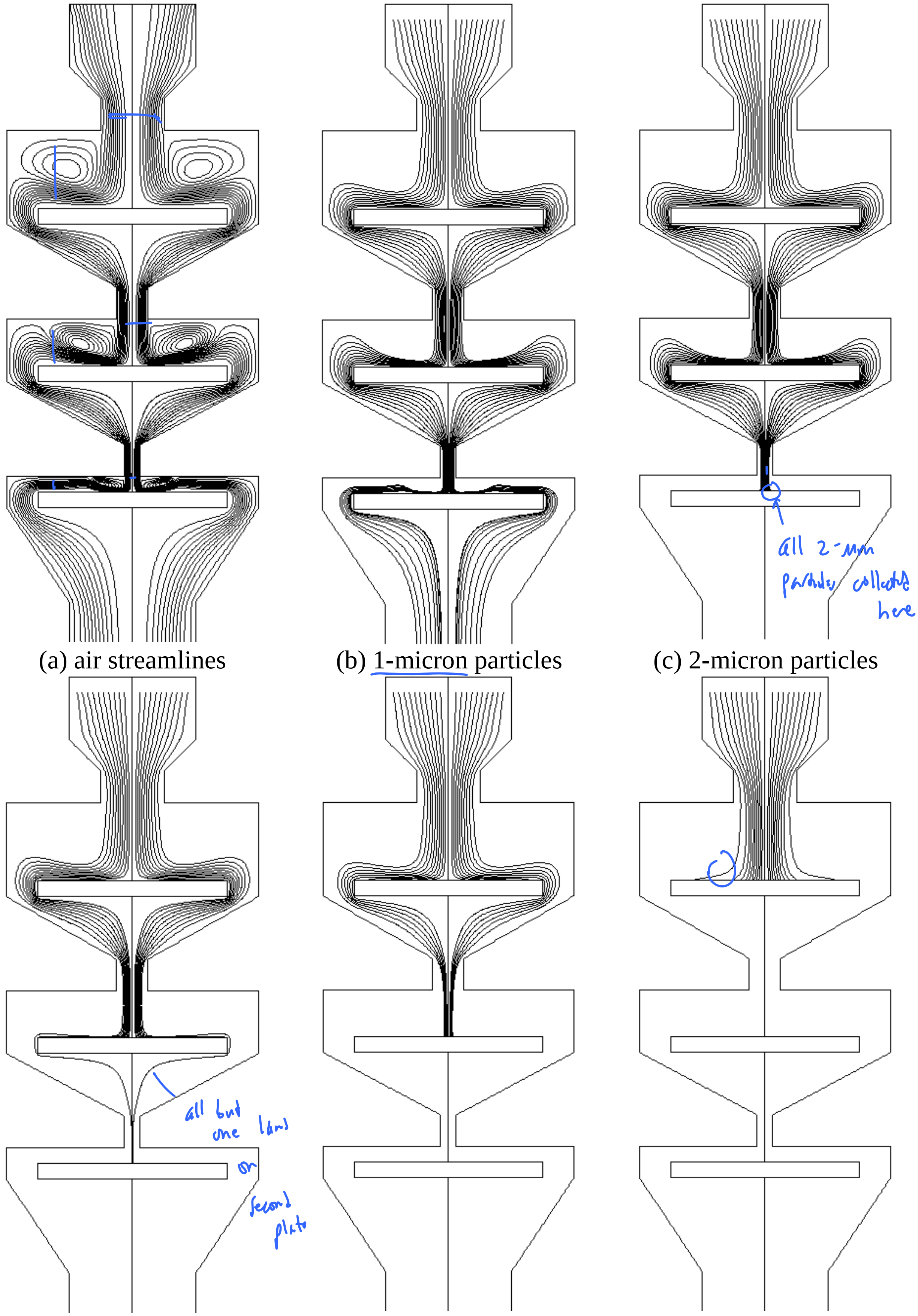


(a) air streamlines (b) 1-micron particles (c) 2-micron particles

(d) 5-micron particles (e) 10-micron particles (f) 15-micron particles

**Figure 10.17** CFD simulation of flow in a 3-stage cascade impactor; (a) streamlines, (b)-(f): trajectories of unit density particles of diameter $D_p$ = (b) 1, (c) 2, (d) 5, (e) 10, and (f) 15 μm.