Aerosol Technology Basics

What's Particle?

TAIPEI TECH

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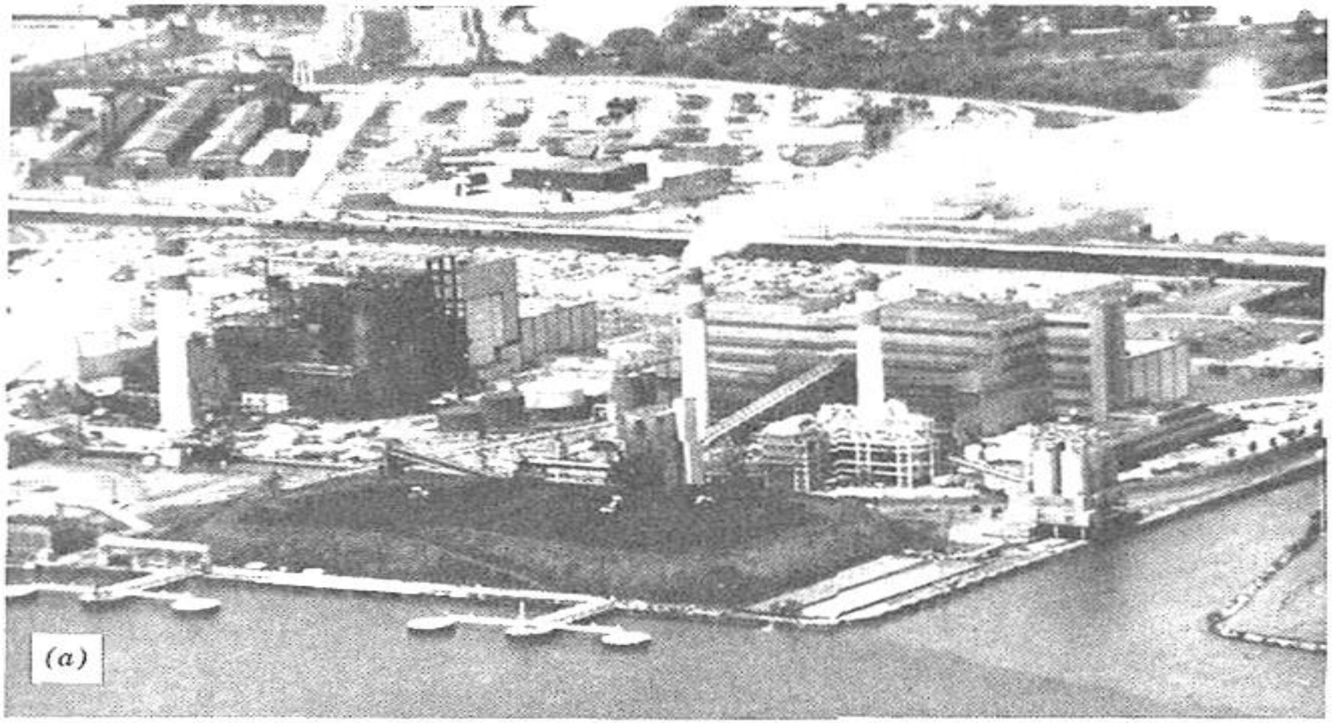
Introduction

- The word aerosol was coined about 1920 as an analog to the term hydrosol, a stable liquid suspension of solid particles. Aerosols are also referred to as suspended particulate matter, aerocolloidal system, and disperse systems.

TABLE 1.1 Types of Particulate Suspensions

Suspending Medium	Type of Suspended Particles: Gas	Liquid	Solid
Gas	—	Fog, mist, spray	Fume, dust
Liquid	Foam	Emulsion	Colloid, suspension, slurry
Solid	Sponge	Gel	Alloy



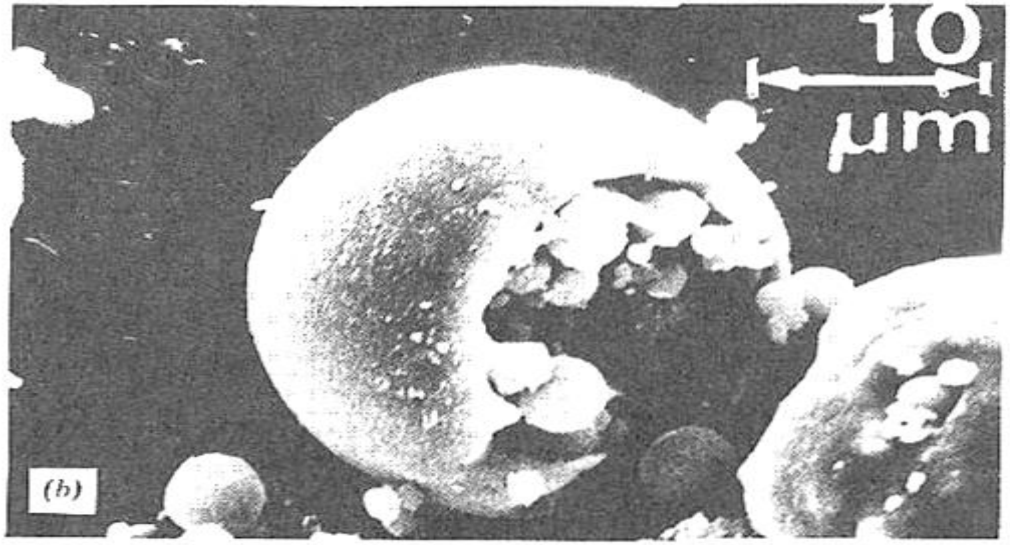


FIGURE 1.1 (*a*) Coal-burning power plant. (*b*) Scanning electron microscope (SEM) photograph of coal fly ash particles.

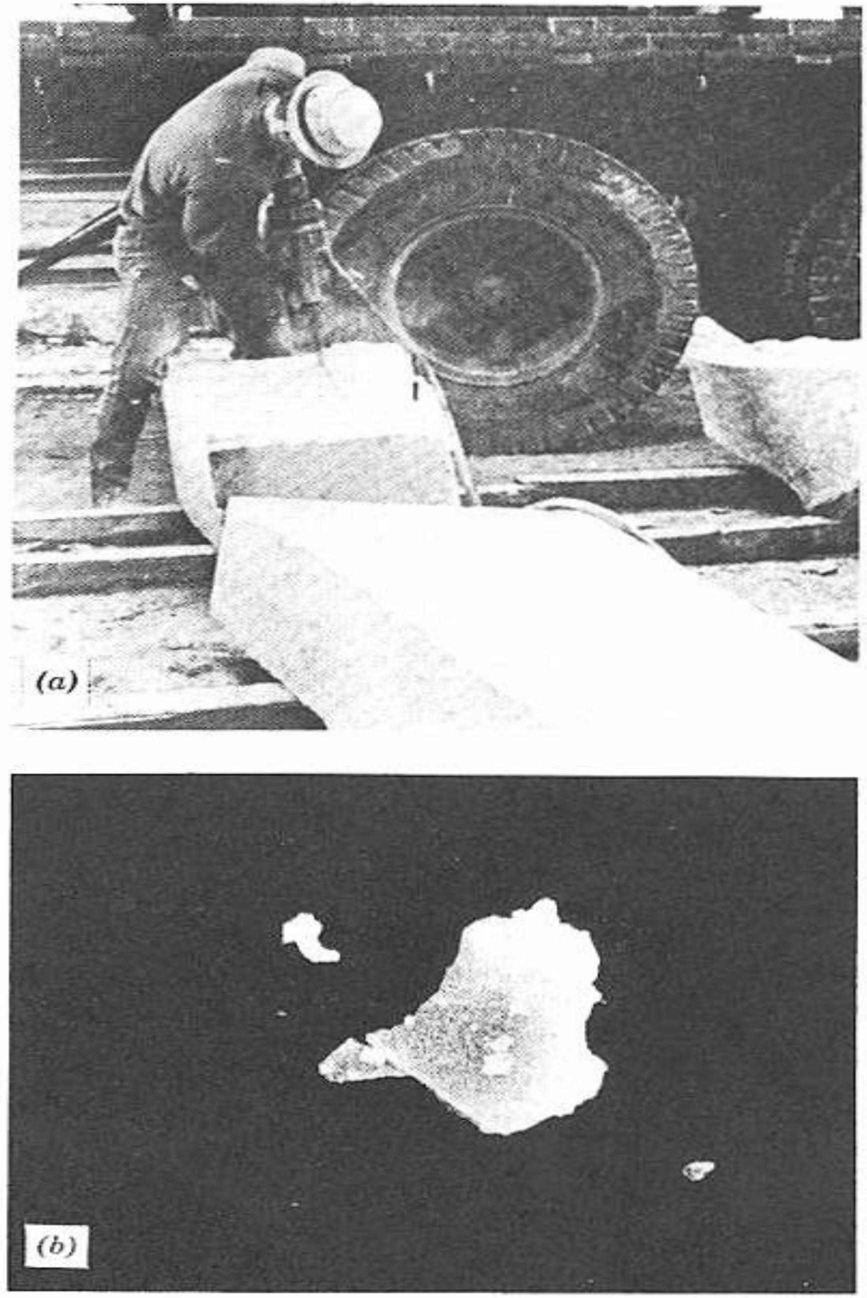


FIGURE 1.2 (*a*) Granite cutting. (*b*) SEM photograph of quartz particles. Magnification 2650×.

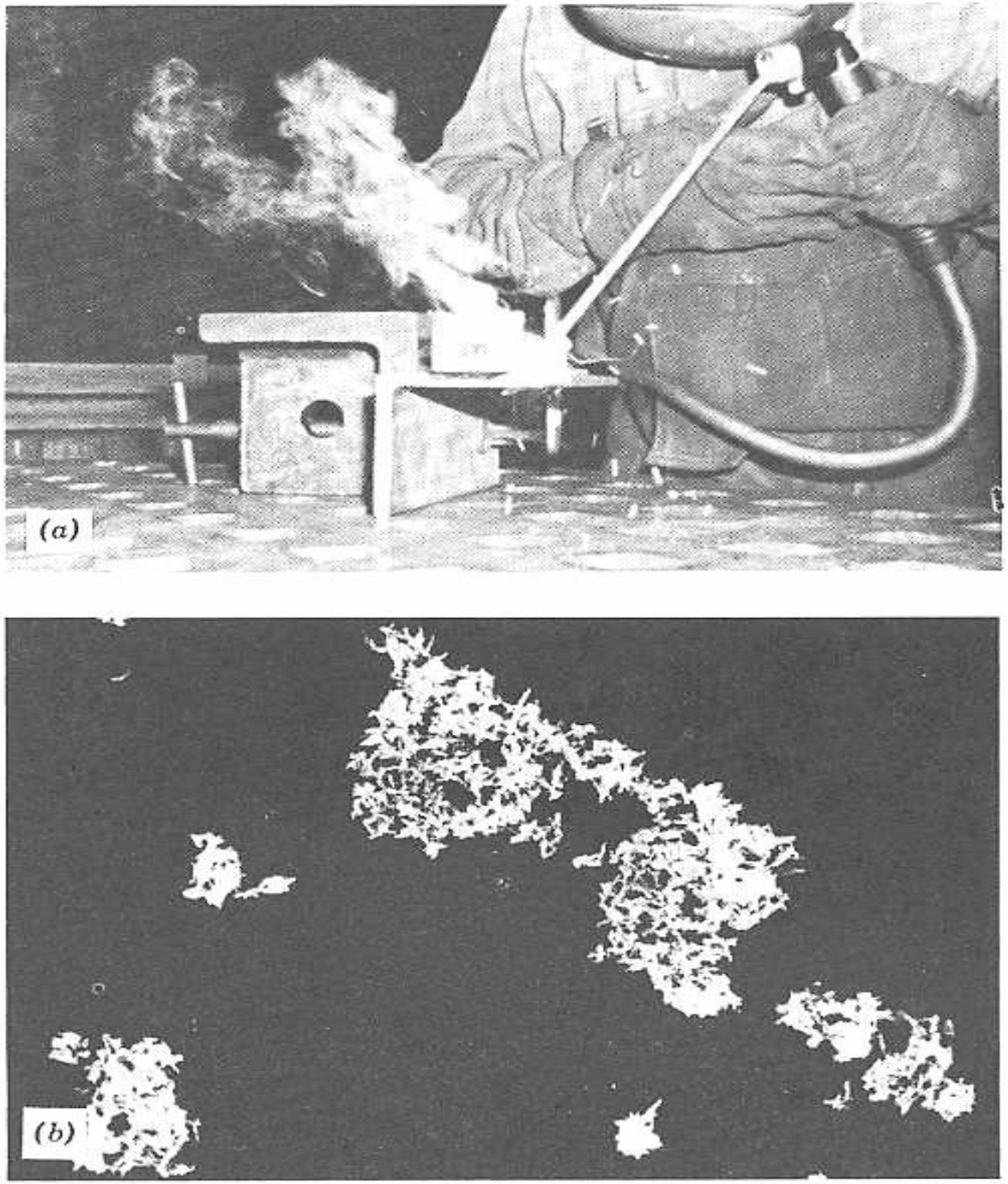


FIGURE 1.3 (*a*) Arc welding. (*b*) SEM photograph of iron-oxide particles. Magnification 2300×.

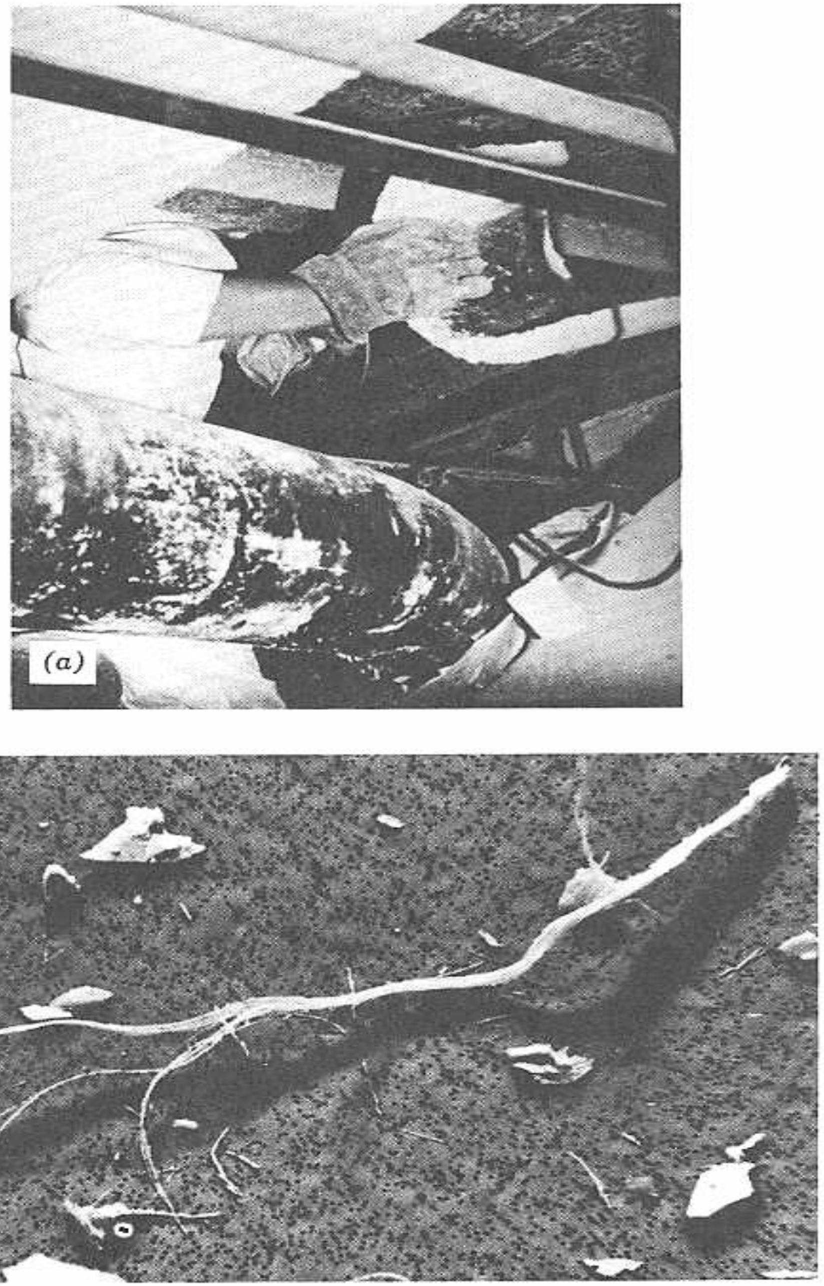
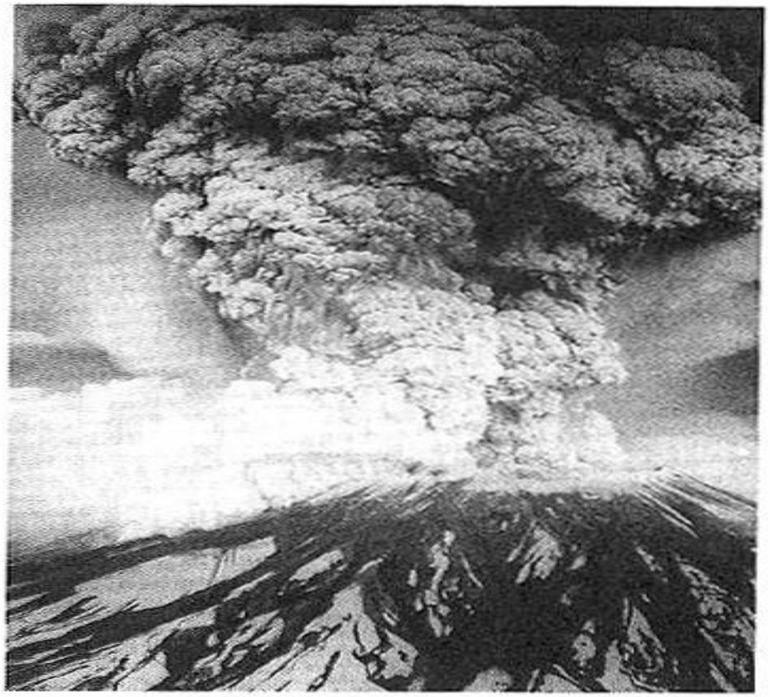


FIGURE 1.4 (*a*) Removal of asbestos pipe covering. (*b*) SEM photograph of asbestos fibers. Magnification 1250×.



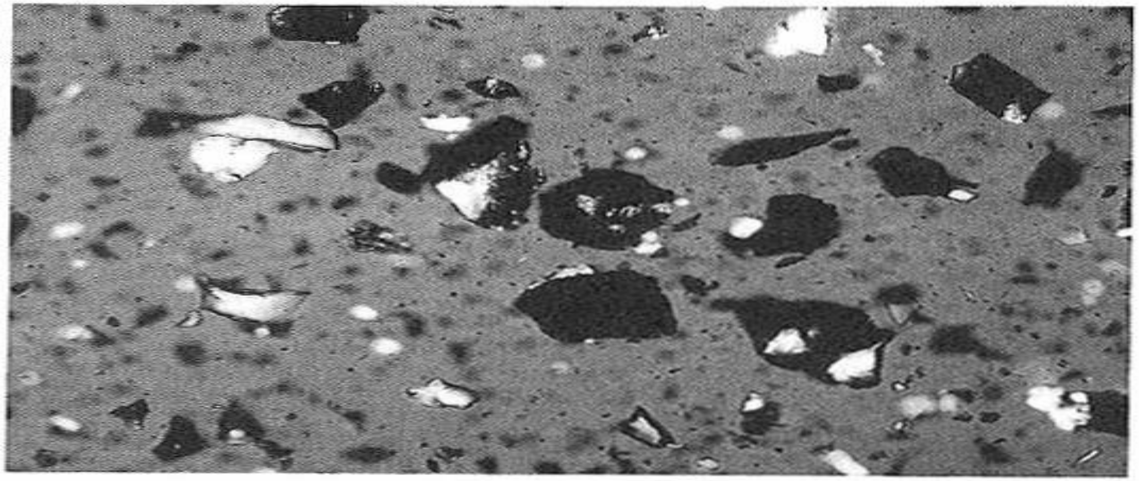


FIGURE 1.5 (a) Volcanic eruption of Mount St. Helens, May 1980. (b) Optical microscope photograph of volcanic ash. Magnification 125×. USGS photograph by Austin Post. Reprinted from *Mount St. Helens: Five Years Later*. Courtesy of Eastern Washington University Press and W. C. McCrone and J. G. Delly, *The Particle Atlas*. Reprinted by permission from McCrone Research Institute.

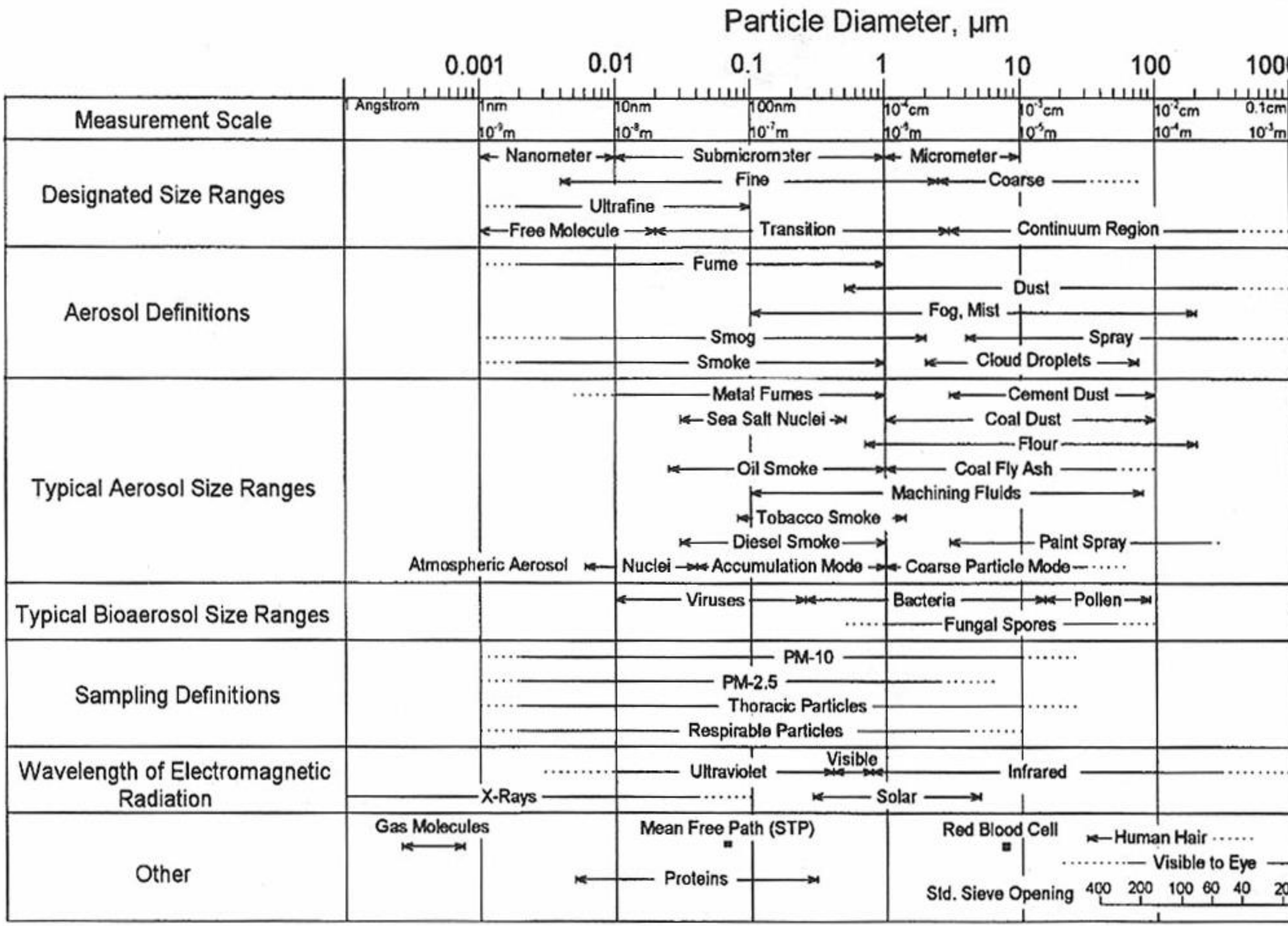


FIGURE 1.6 Particle size ranges and definitions for aerosols.

TABLE 1.2 Examples of Mass Concentration Expressed in Parts per Million[a]

	Mass Concentration, Mass/Volume (mg/m^3)	Parts per Million, Volume/Volume (ppm)	Parts per Million, Mass/Mass (ppm)
U.S. PM-10, annual average	0.05	5×10^{-5}	0.04
Threshold limit value for nuisance dusts (Particulates not otherwise classified)	10	0.01	8
Uncontrolled stack effluent (typical)	10,000	10	8,000

[a]Standard-density spheres.

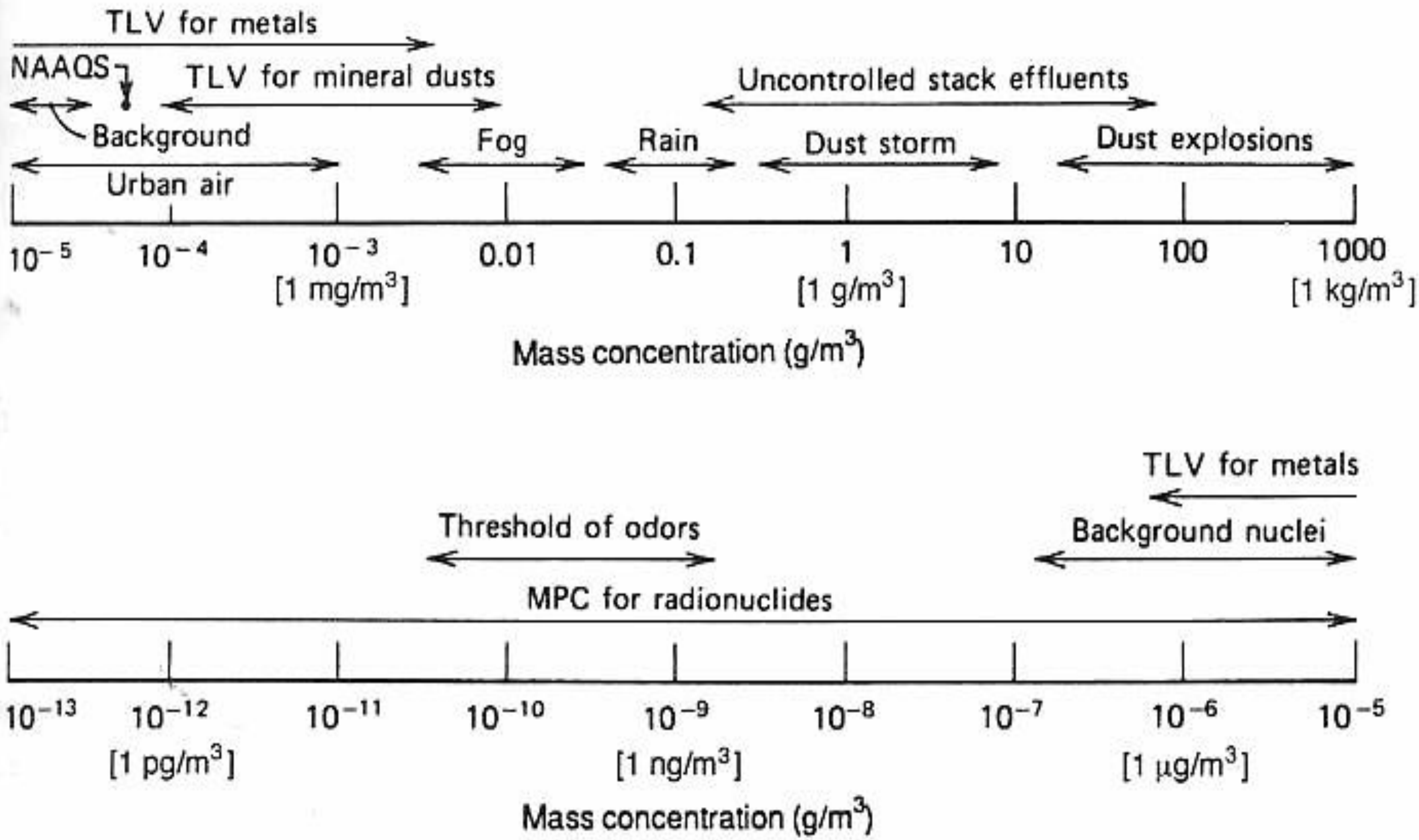
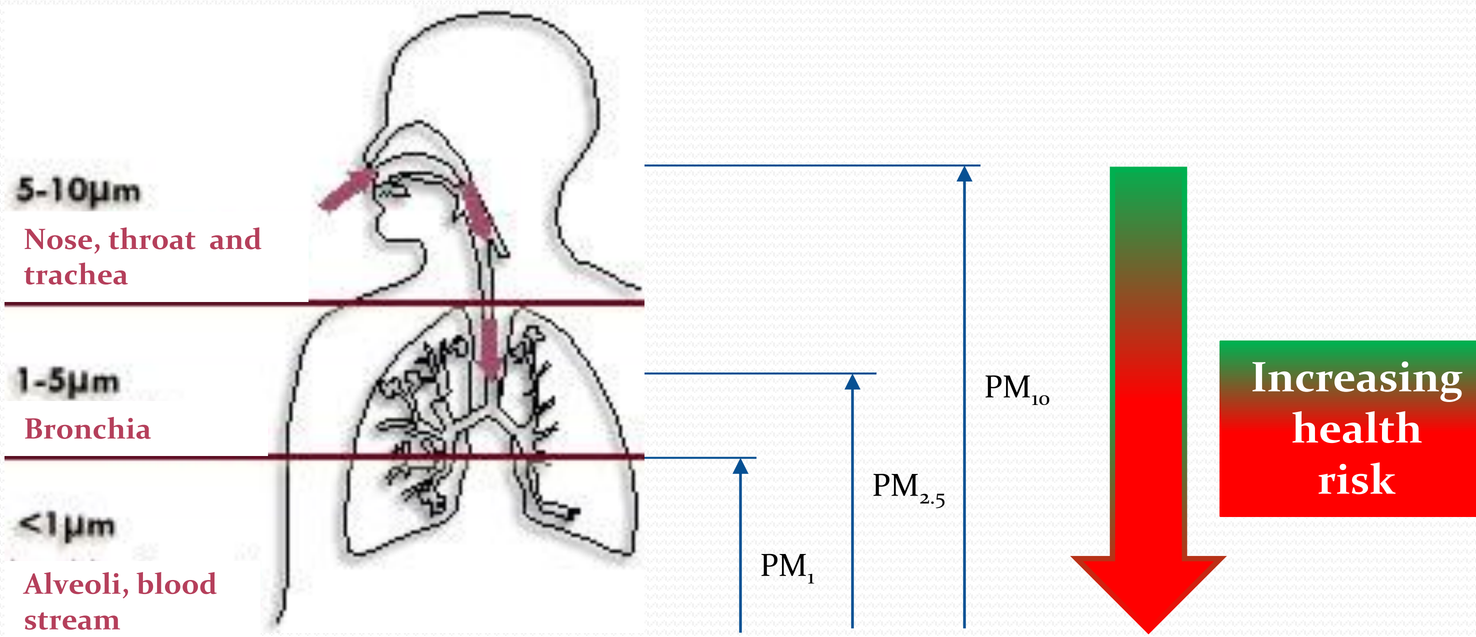


FIGURE 1.7 Range of aerosol concentration.

PM X
(X = 10, 2.5, 1)

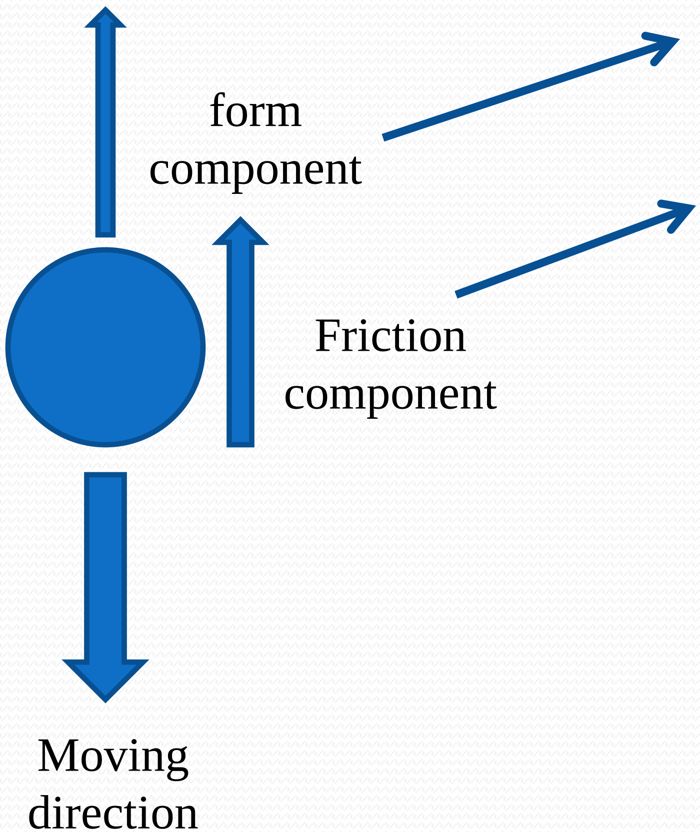
- PM_X are all particles with an *Aerodynamic Equivalent Diameter (AED)of less than X μm.*
- AED is the diameter of a "unit density sphere 1 kg/m^3" that would have the identical settling velocity as the particle …
- Within ISO16890 particle measurement is done using an optical particle counter (OPC)
  - This device is limited in measurable particle size
  - AED is not used
  - The particle size range used is from 0.1μm ~ 10μm

The human respiratory system and respirable aerosols



- Particles below 10μm are inhalable
- The smaller the particle the deeper it will end up in our respiratory system
- Special concern for particles below 2.5 μm

Particle in the Air



$$F_n = \pi\eta Vd \text{..............}(3.6)$$

$$F_\tau = 2\pi\eta Vd \text{..............}(3.7)$$

$$F_D = 3\pi\eta Vd \text{..............}(3.8)$$

Forces

$$F_D = 3\pi\eta Vd = C_D \frac{\pi}{8}\rho_g V^2 d^2 \quad \text{for Re<1}..............(3.9)$$

$$C_D = \frac{24\eta}{\rho_g Vd} = \frac{24}{\text{Re}}...............(3.10)$$

- η Air viscosity (1.81*10^-5 N · s/m^2)
- V Particle Speed(m/s)
- d Particle Diameter(m)
- ρ_g Air density (~1.20 kg/m^3)

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Terminal Settling Velocity(V_{TS})

- Gravitational force = F_G
- Air Drag Force F_D
- Equal Force on particle: F_G=F_D

$$F_D = F_G = mg ....(3.11)$$

$$3\pi\eta V d = \frac{(\rho_P - \rho_g)\pi d^3 g}{6} ....(3.12)$$

$$V_{TS} = \frac{\rho_P d^2 g}{18\eta}, \quad \text{for d >1 } \mu\text{m and Re <1.0................(3.13)}$$

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Particle Slips

- When particle is smaller than 1 μm, F_D will reduce

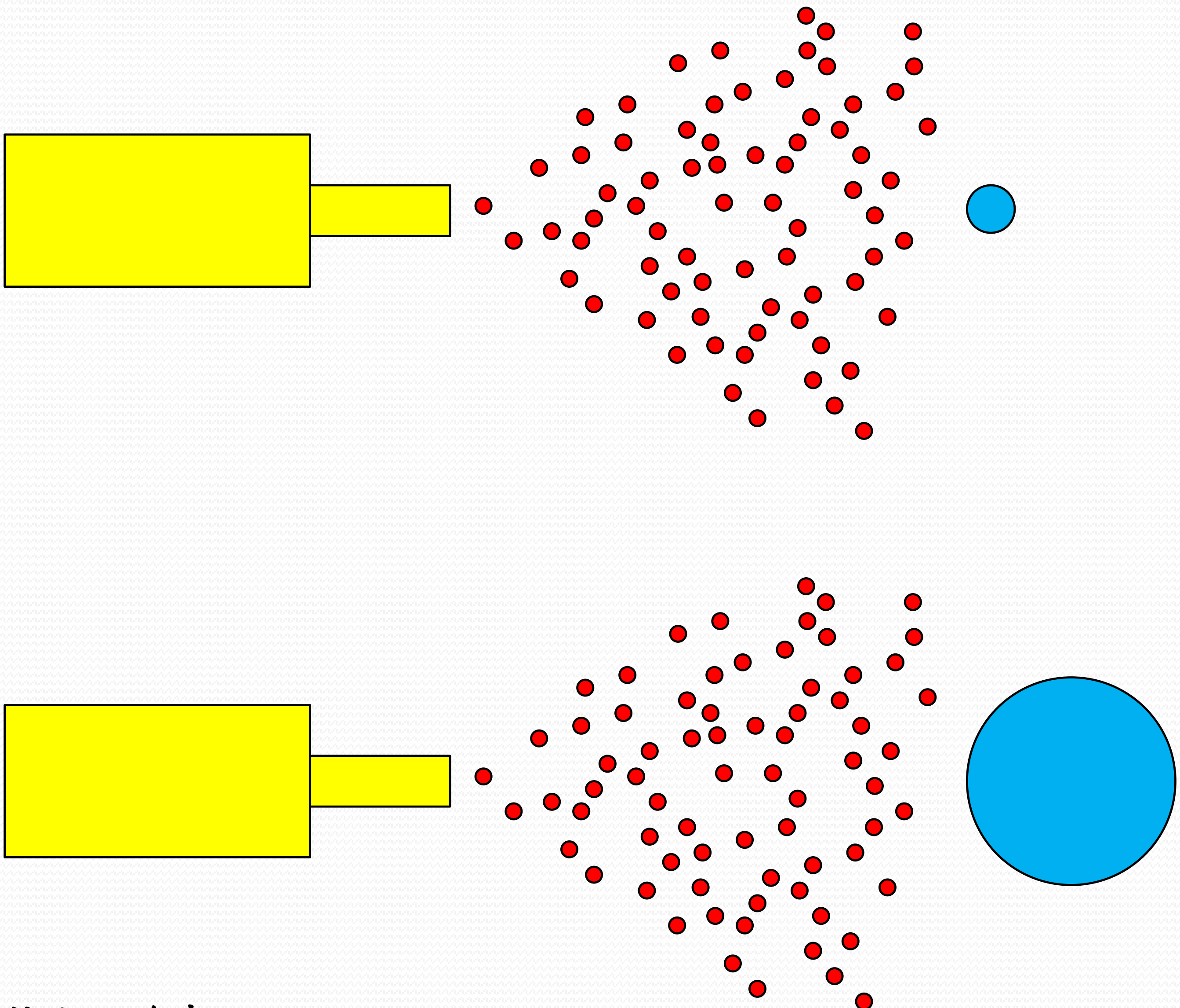
$$F_D = \frac{3\pi\eta V d}{C_C} \text{................}(3.18)$$

$$C_C = 1 + \frac{2.52\lambda}{d} \text{................}(3.19)$$

$$V_{TS} = \frac{\rho_P d^2 g C_C}{18\eta} \text{ for Re} < 1.0\text{..........}(3.21)$$

- λ　　Mean Free Path(air: 0.066μm)

- <u>**For 0.1μm < d ≤ 1μm**</u>

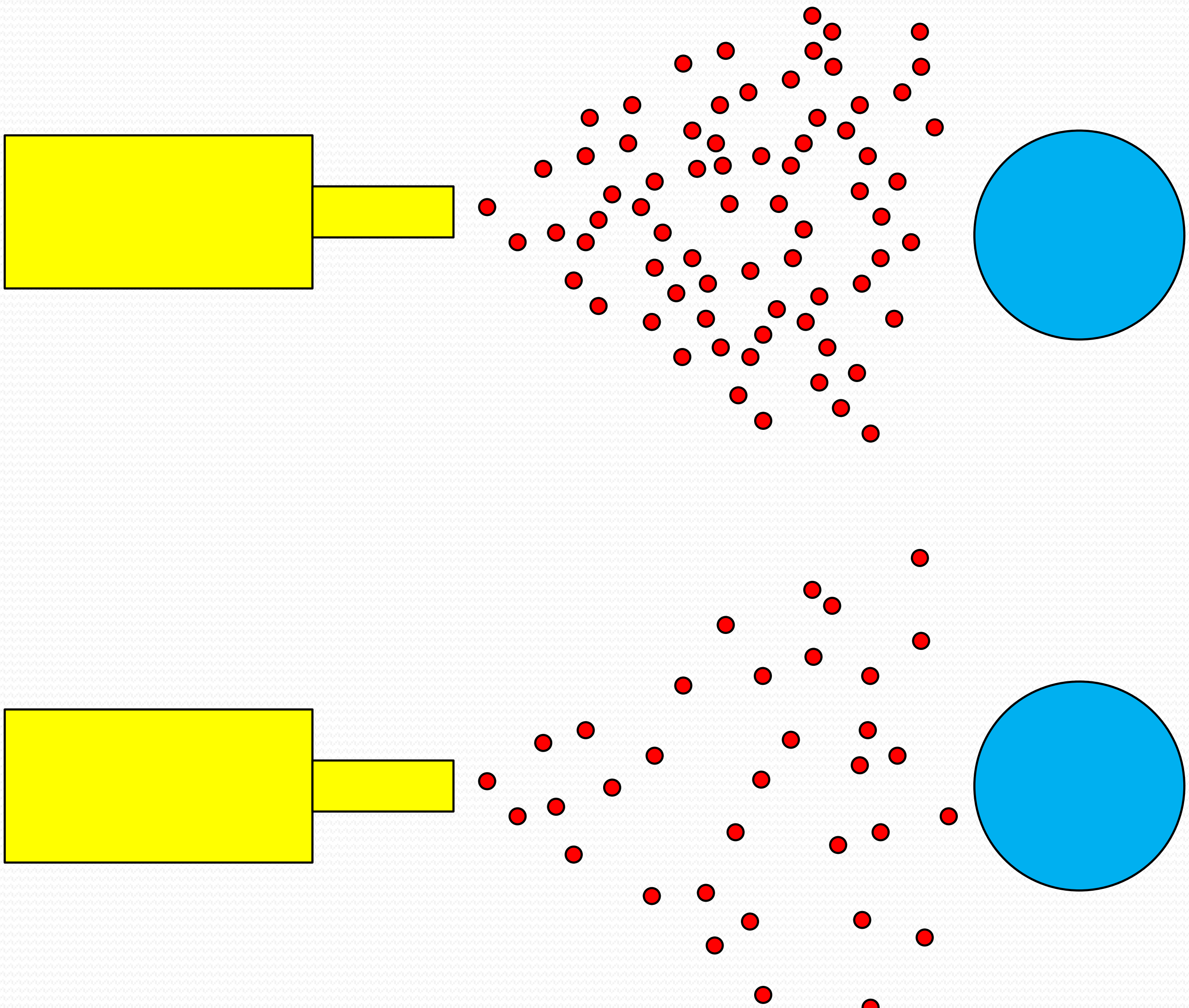


Pressure reduces

- Air Pressure reduce =>F_D also reduce 。

$$C_C = 1 + \frac{1}{Pd}[15.60 + 7.00\exp(-0.059Pd)]\ldots\ldots\ldots\ldots\ldots(3.22)$$

- P Absolute Pressure(kPa)
- d Particle diameter(μm)



Particle Filter

Fiber

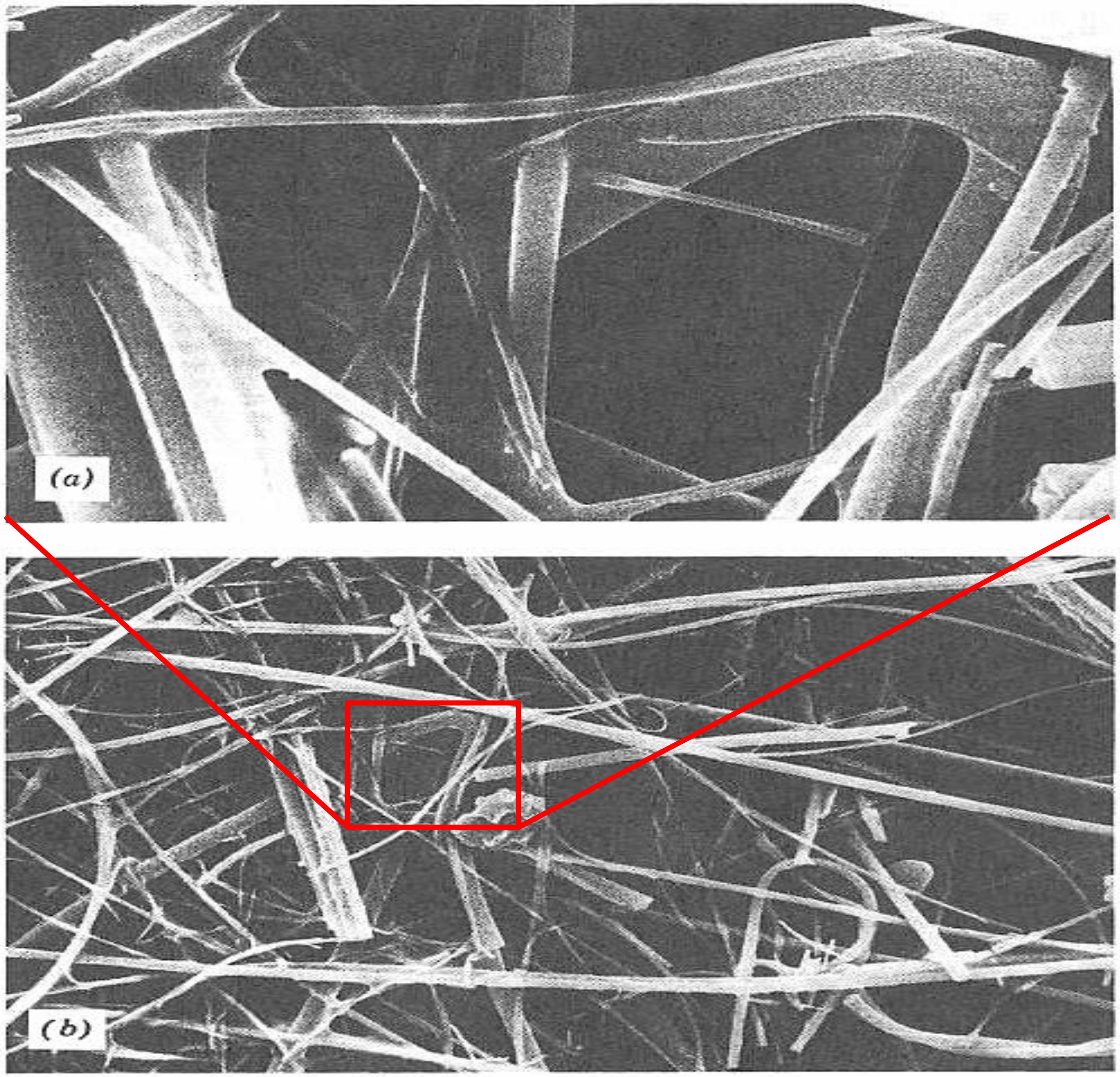


FIGURE 9.1 Scanning electron microscope photograph of a high-efficiency glass fiber filter. Magnification of (a) 4150× and (b) 800×.

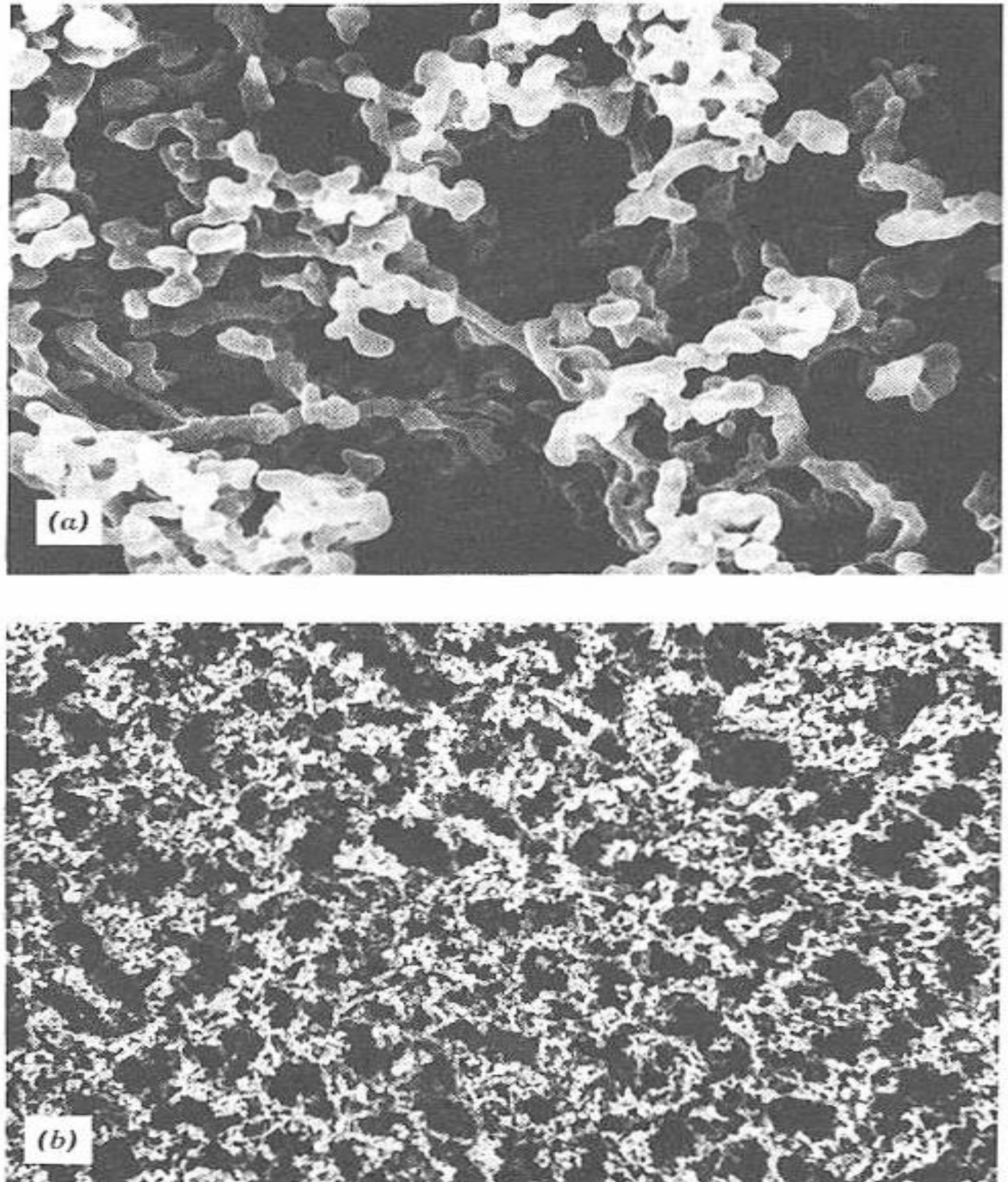


FIGURE 9.2 Scanning electron microscope photograph of a cellulose ester porous membrane filter with a pore size of 0.8 μm. Magnification of (*a*) 4150× and (*b*) 800×.

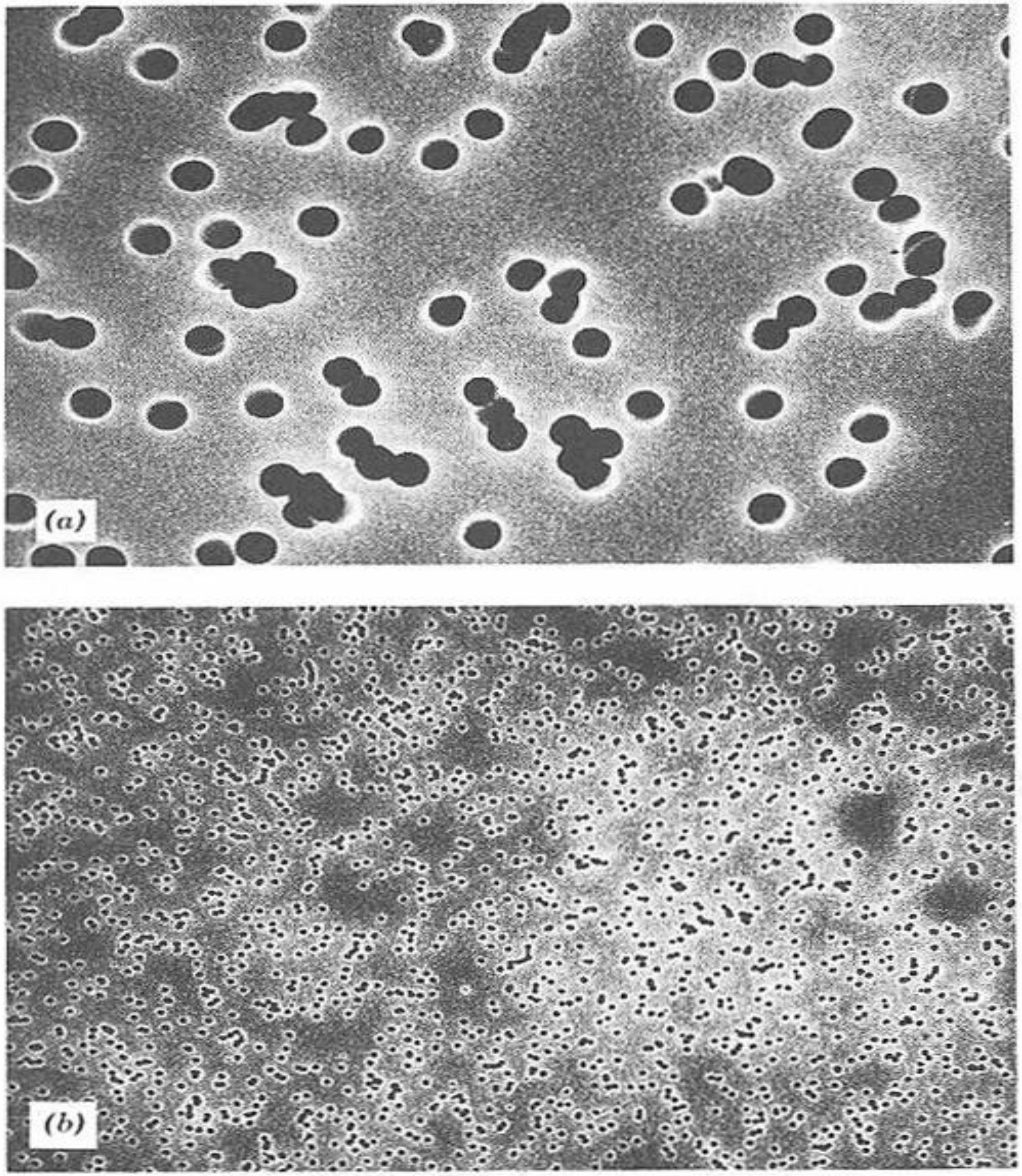
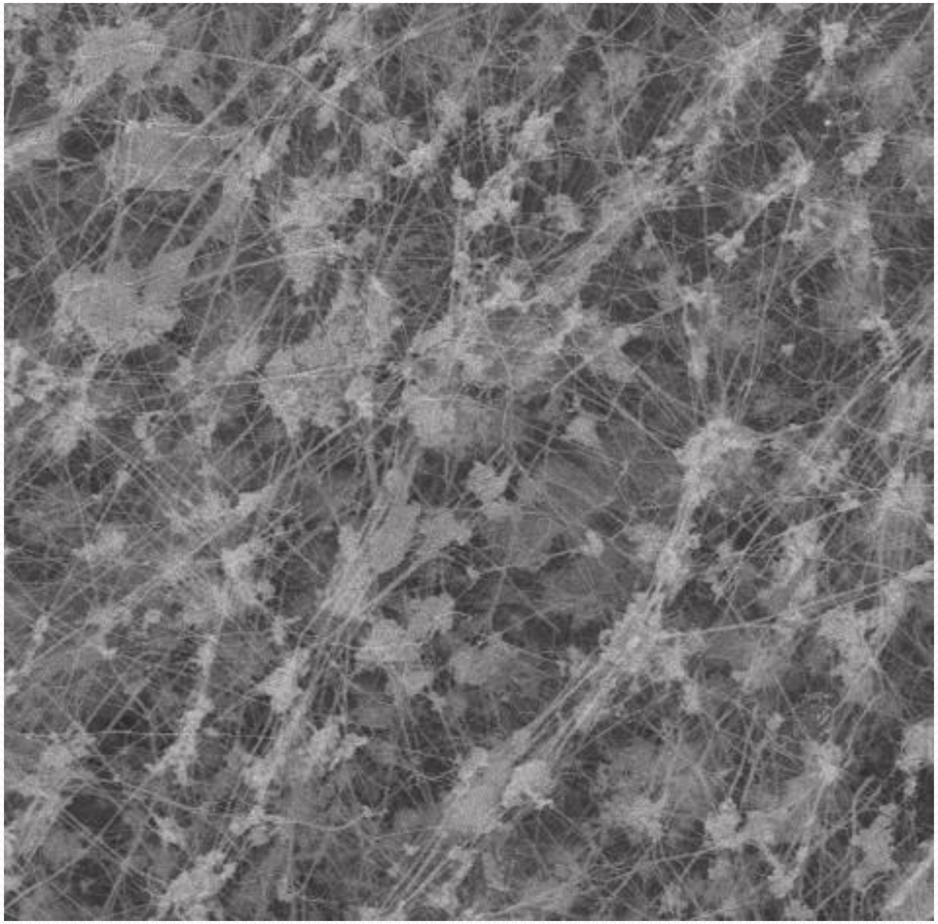


FIGURE 9.3 Scanning electron microscope photograph of a capillary pore membrane filter with a pore size of 0.8 μm. Magnification of (*a*) 4150× and (*b*) 800×.

e-PTFE filter



Efficiency & Penetration

$$E = \frac{N_{in} - N_{out}}{N_{in}} \ldots\ldots\ldots\ldots\ldots(9.1) \qquad P = \frac{N_{out}}{N_{in}} = 1 - E \ldots\ldots\ldots\ldots\ldots(9.4)$$

In= 10000, out=100, P=100/10000

P=1% => Efficiency =99%

$$E_m = \frac{C_{in} - C_{out}}{C_{in}} \ldots\ldots\ldots\ldots\ldots(9.2) \qquad P_m = \frac{C_{out}}{C_{in}} = 1 - E_m \ldots\ldots\ldots\ldots\ldots(9.3)$$

In= 10000#/m^3, out=100#/m^3, P=100/10000

P=1% => Efficiency =99%

There are five basic mechanisms by which an particle can be deposited onto a fiber in a filter.

1 Interception

2 Inertial impaction

3 Diffusion

4 Gravitational settling

5 Electrostatic attraction

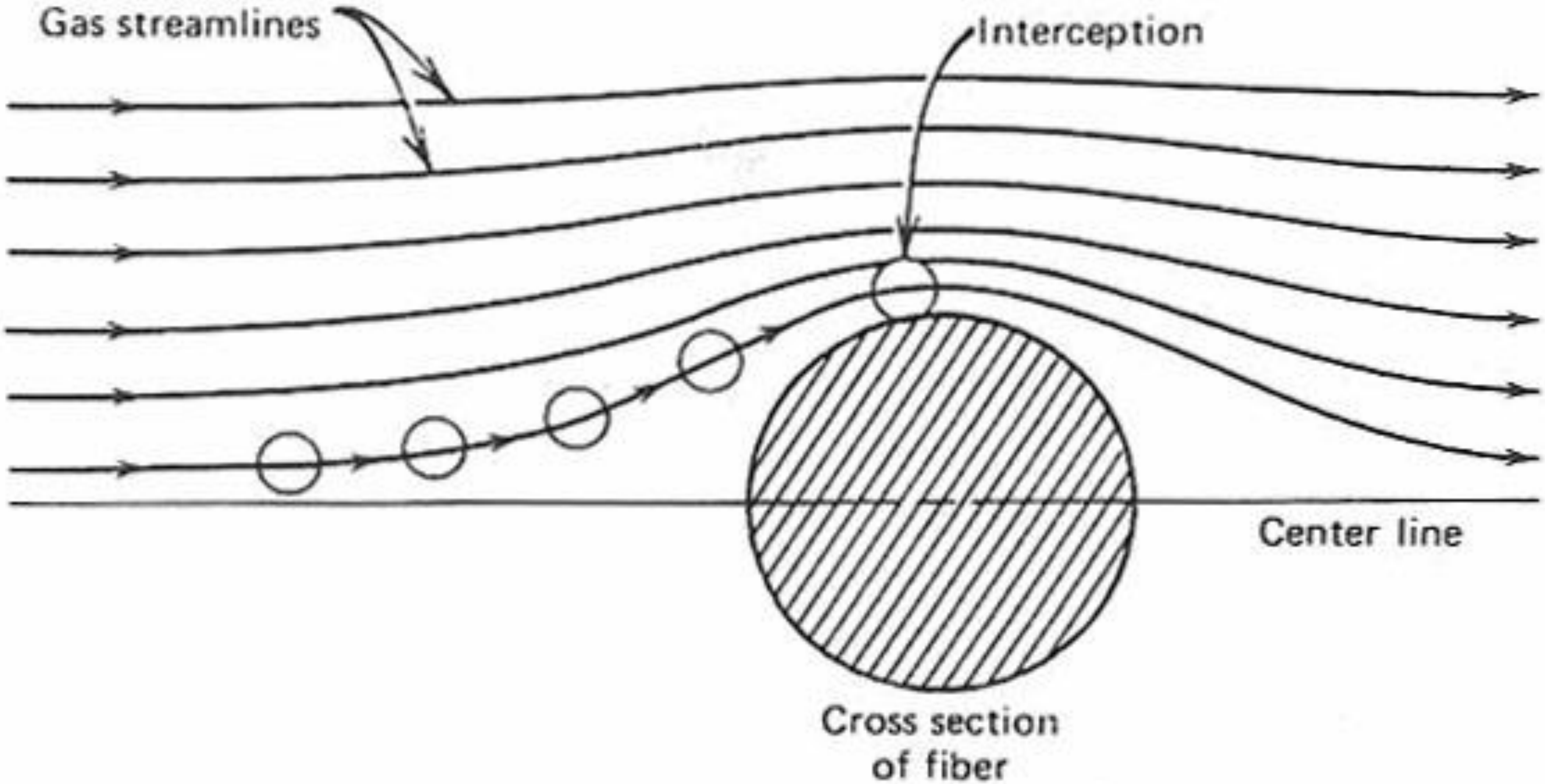


FIGURE 9.5 Single-fiber collection by interception.

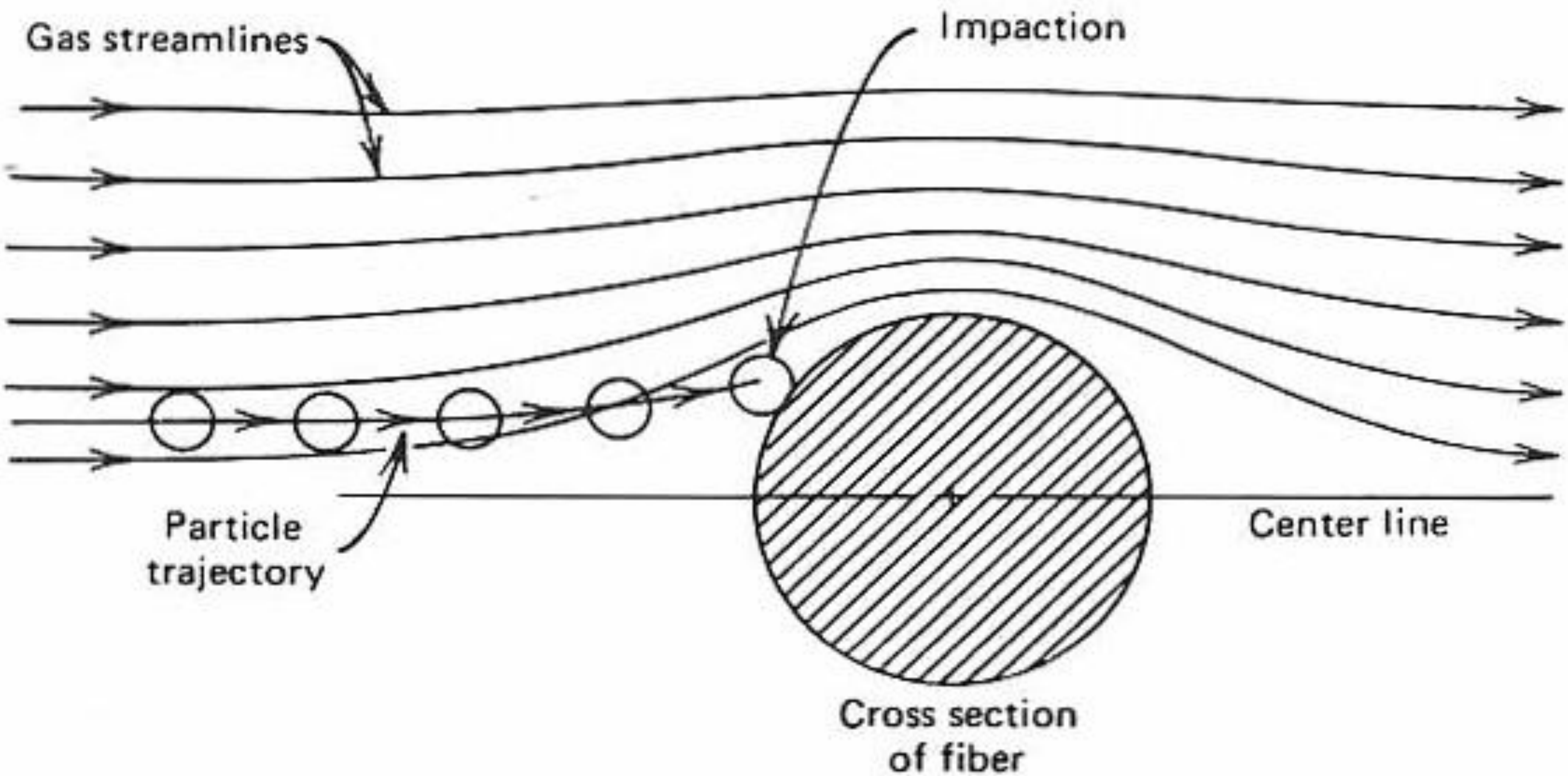


FIGURE 9.6 Single-fiber collection by impaction.

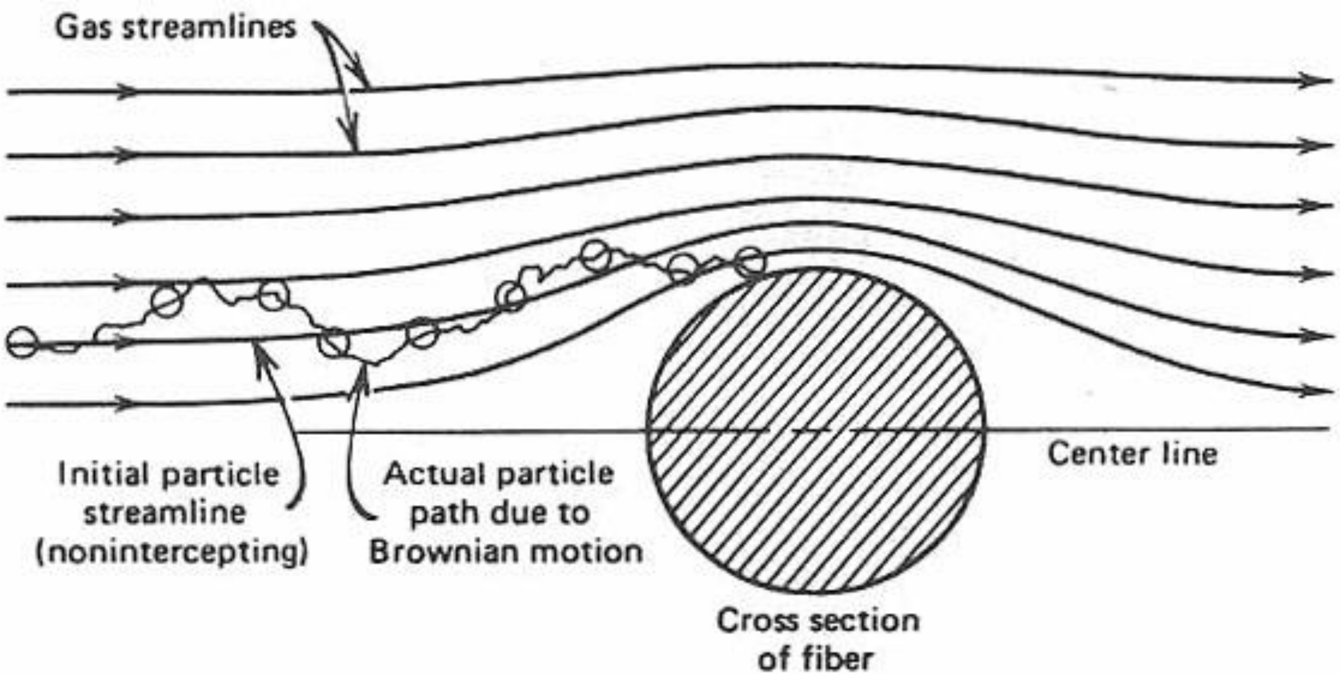


FIGURE 9.7 Single-fiber collection by diffusion.

TABLE 9.2 Single-Fiber and Total Efficiency for a Filter Having t = 1 mm, α = 0.05, d_f = 2 μm, and U_0 = 0.1 m/s [10 cm/s]

Particle Diameter (μm)	Single-Fiber Efficiency[a] E_R	E_I	E_D	E_{DR}	E_G	E_Σ	Overall Filter Efficiency[b] (%)
0.01	0.000	0.000	0.840	0.020	0.000	0.861	100.0
0.02	0.000	0.000	0.339	0.016	0.000	0.356	100.0
0.05	0.001	0.000	0.106	0.013	0.000	0.119	97.7
0.1	0.003	0.000	0.046	0.011	0.000	0.059	84.9
0.2	0.010	0.002	0.021	0.010	0.000	0.043	74.3
0.5	0.055	0.034	0.009	0.009	0.000	0.108	96.8
1.0	0.183	0.238	0.005	0.010	0.001	0.437	100.0
2.0	0.550	0.887	0.003	0.011	0.003	1.454	100.0
5.0	1.965	3.500	0.002	0.012	0.027	3.500	100.0
10.0	4.585	6.000	0.001	0.014	0.183	6.000	100.0

[a]Calculated by Eq. 9.33b, assuming spheres of standard density at standard conditions.
[b]Calculated by Eq. 9.19.

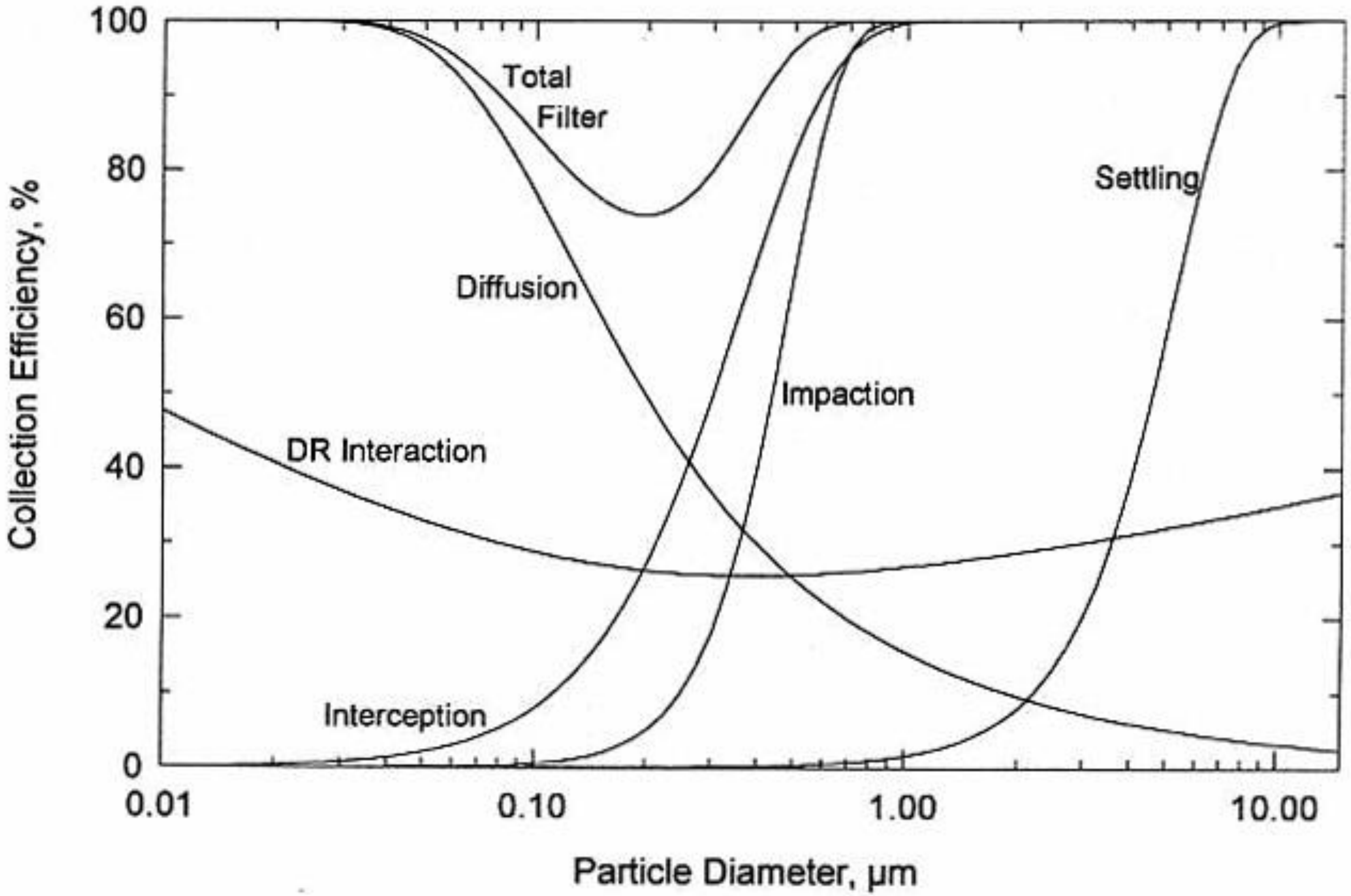


FIGURE 9.8 Filter efficiency for individual single-fiber mechanisms and total efficiency; $t = 1$ mm, $\alpha = 0.05$, $d_f = 2$ μm, and $U_0 = 0.10$ m/s. [10 cm/s].

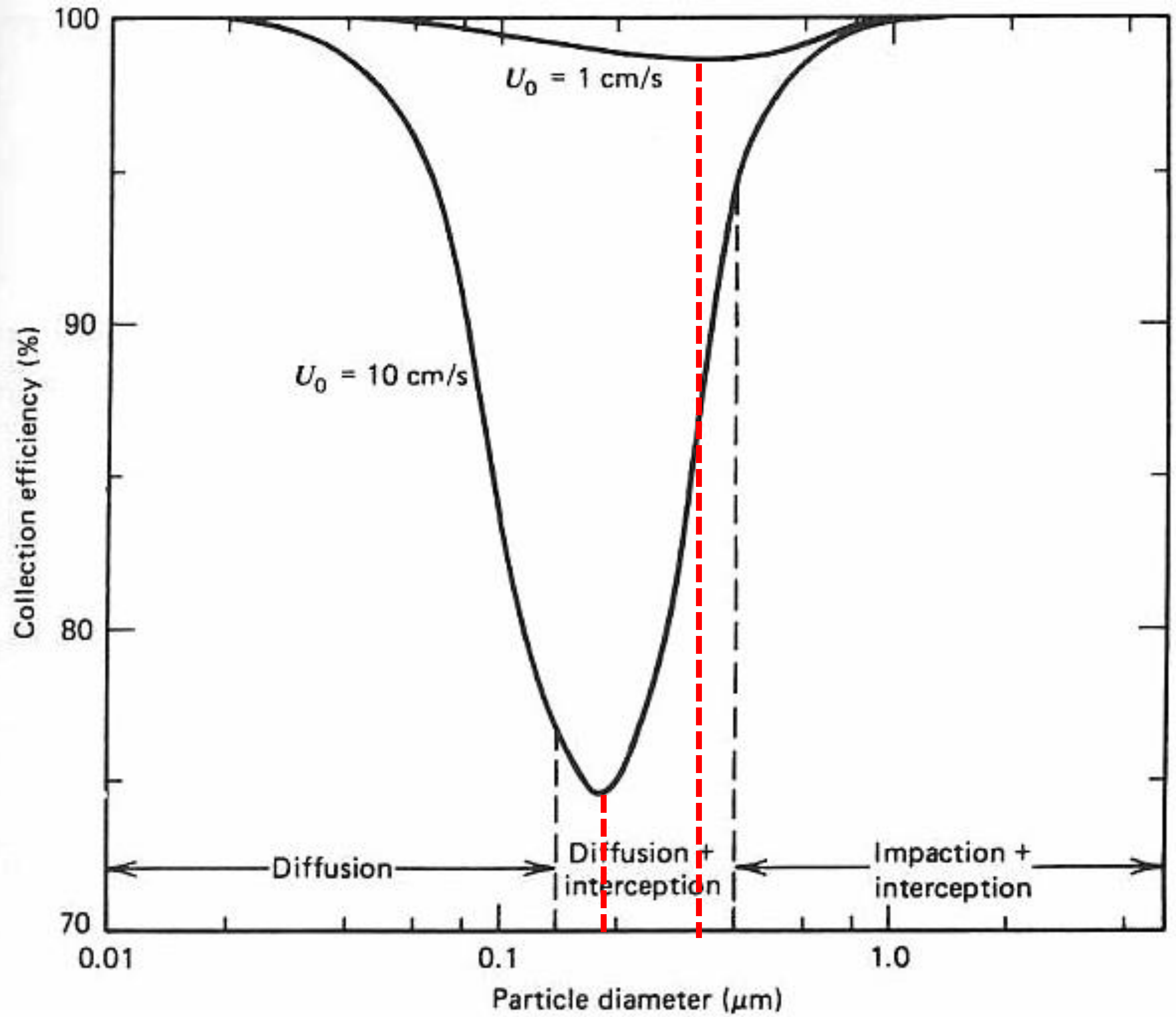


FIGURE 9.9 Filter efficiency versus particle size for face velocities of 0.01 and 0.1 m/s [1 and 10 cm/s]; $t = 1$ mm, $\alpha = 0.05$, and $d_f = 2$ μm.

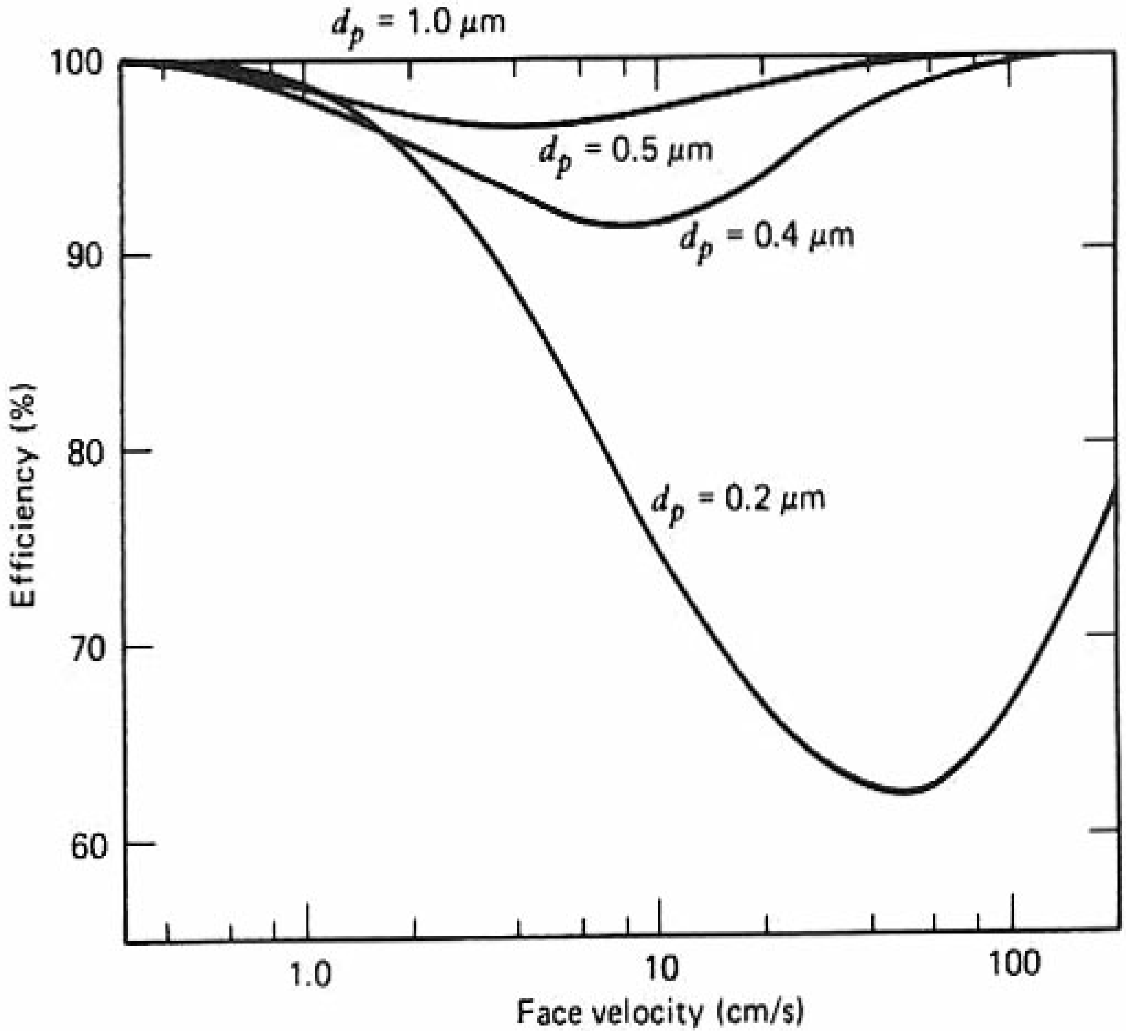


FIGURE 9.10 Filter efficiency versus face velocity for particle diameters of 0.2, 0.4, 0.5, and 1 μm; t = 1 mm, α = 0.05, and d_f = 2 μm.

Filter types

Gas & Particle

Filter category

- Particle size
  - Coarse, medium, Fine
  - Pre-filter, Mid-filter, High eff. filters(HEPA, ULPA)
- Molecular / Particle
  - Chemical filter, Fiber filters

Particle Filter

Classifications

- ISO-16890, ISO-29463
- EN-779, EN-1822
- ASHRAE 52.2

EN1822 to EN779 to ASHRAE

EN1822: 2009 Classes	EN1822: 2009 Efficiency	EN779:2012 Classes		EN779: 2002 Classes	ASHRAE Standard 52.2 MERV	Approx. ASHRAE Standard 52.1 Values	
		Filter Grade	Discharged Initial Efficiency			Avg. Dust Spot Efficiency	Arrestance
U17	>99.999995%	n/a	n/a	n/a	n/a	n/a	n/a
U16	>99.99995%	n/a	n/a	n/a	n/a	n/a	n/a
U15	>99.9995%	n/a	n/a	n/a	n/a	n/a	n/a
H14	>99.995%	n/a	n/a	n/a	20	n/a	n/a
H13	>99.95%	n/a	n/a	n/a	19	n/a	n/a
E12	>99.5%	n/a	n/a	n/a	18	n/a	n/a
E11	>95%	n/a	n/a	n/a	17	n/a	n/a
E10	>85%	n/a	n/a	n/a	16	n/a	n/a
n/a	n/a	F9	>70%	F9	15	>95%	n/a
n/a	n/a	F8	>55%	F8	14	90% - 95%	>98%
n/a	n/a	F7	>35%	F7	13	80% - 90%	>98%
n/a	n/a	M6	<35%	F6	12	70% - 75%	>95%
n/a	n/a	M6	<35%	F6	11	60% - 65%	>95%
n/a	n/a	M5	n/a	F5	10	50% - 55%	>95%
n/a	n/a	G4	n/a	G4	9	40% - 45%	>90%
n/a	n/a	G4	n/a	G4	8	30% - 35%	>90%
n/a	n/a	G4	n/a	G4	7	25% - 30%	>90%
n/a	n/a	G3	n/a	G3	6	<20%	85% - 90%
n/a	n/a	G3	n/a	G3	5	<20%	80% - 85%
n/a	n/a	G2	n/a	G2	4	<20%	75% - 80%
n/a	n/a	G2	n/a	G2	3	<20%	70% - 75%
n/a	n/a	G2	n/a	G2	2	<20%	65% - 70%
n/a	n/a	G1	n/a	G1	1	<20%	50% - 65%

Bag-Filter (G1~F9)

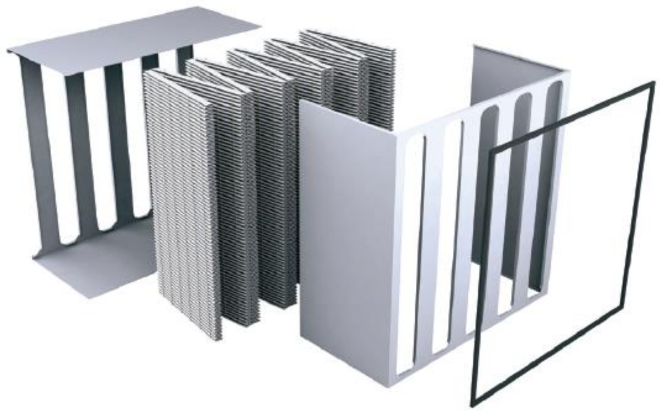
Pleated Type Filter E10~U17

Deep Pleat design

Mid Velocity

minipleat/closepleat design

Low Velocity



'V' bank design

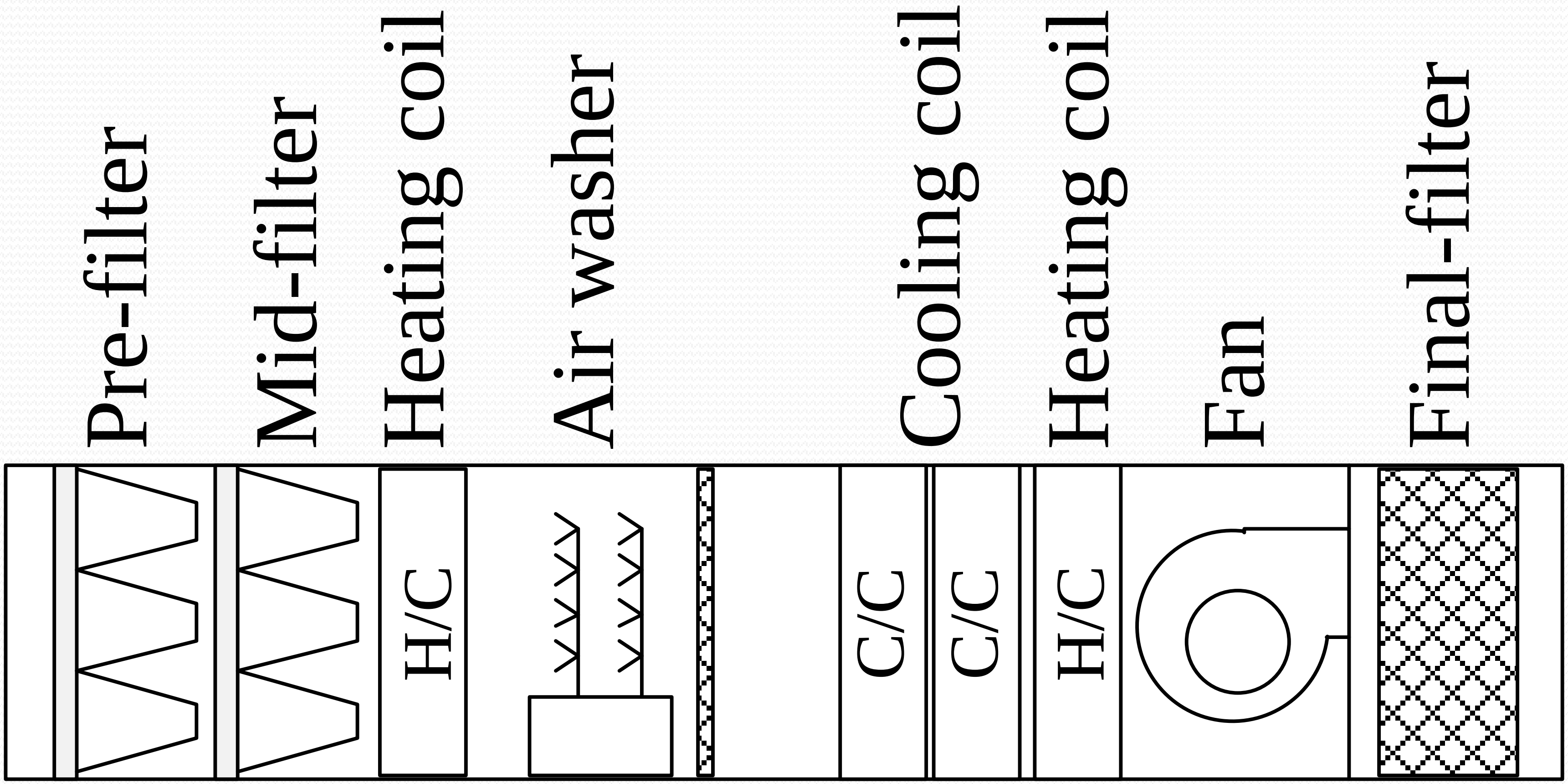
High Velocity

Fiber-Glass HEPA filter

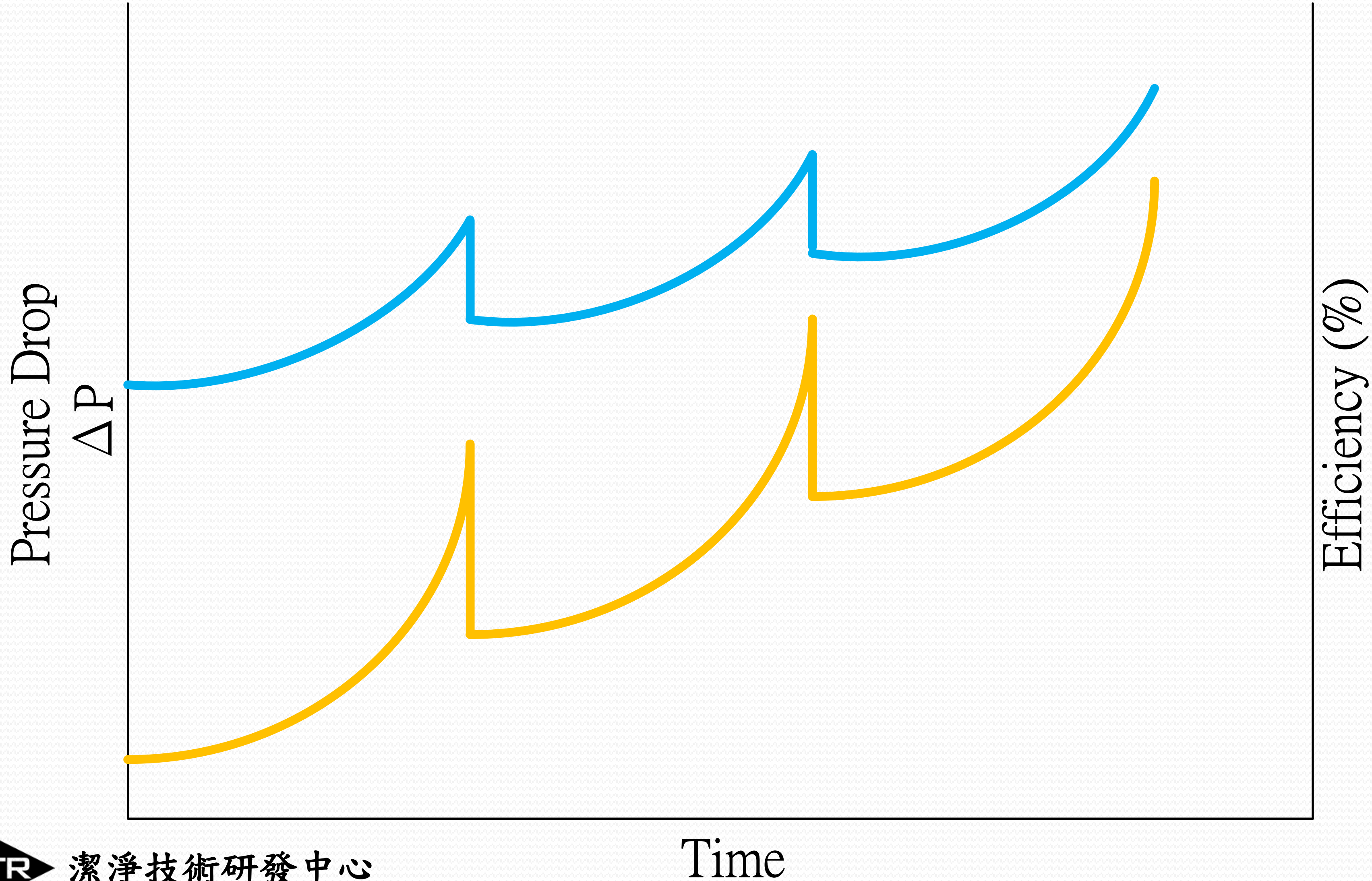
During:

- filter installation
- filter validation
- cleaning of ceiling
- cleanroom modifications
- working activities in the cleanroom

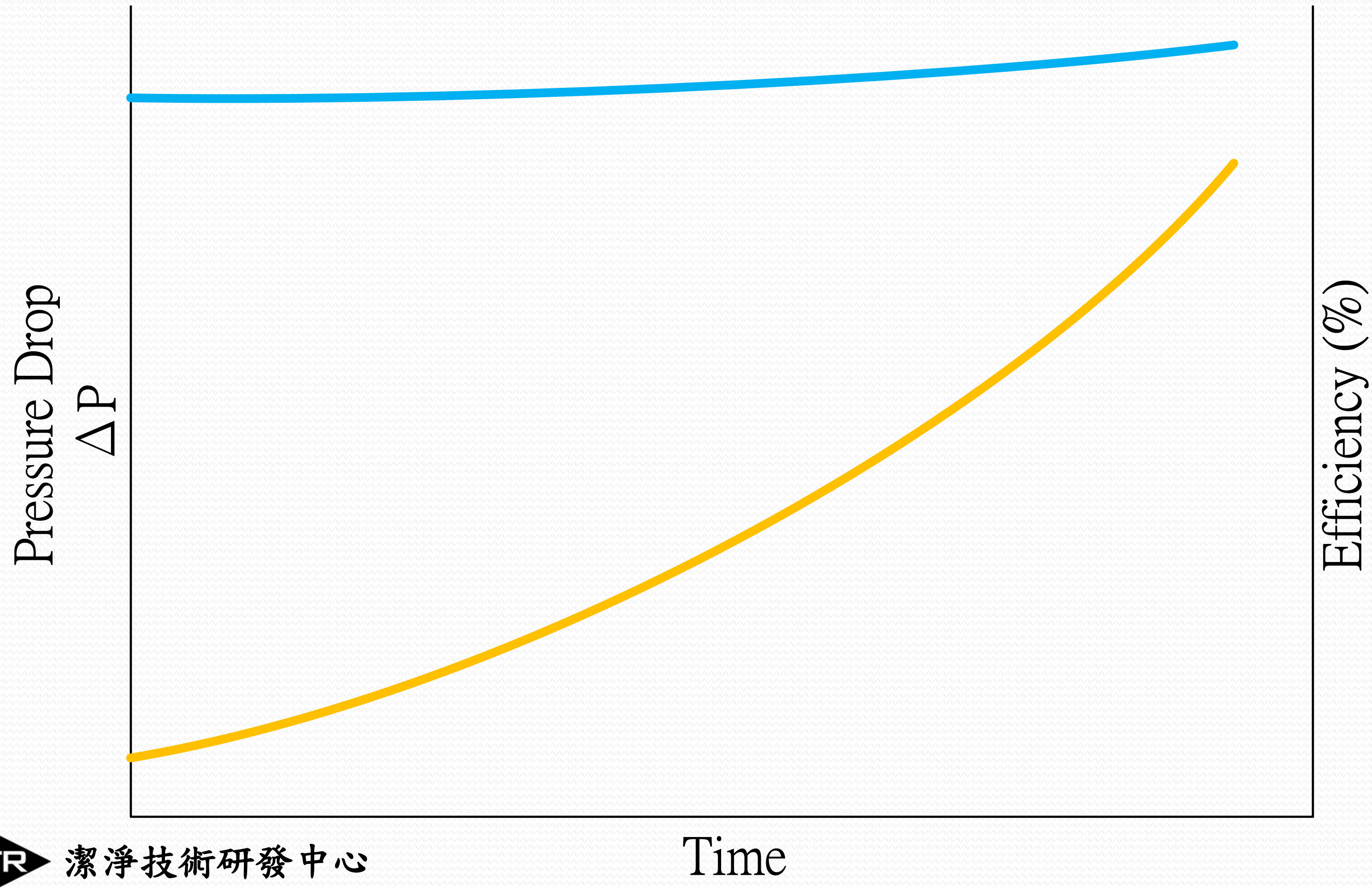
Filter installation Locations



Filter Pressure drop & Eff. (PF&MF)



Filter Pressure drop & Eff. (HEPA)



Chemical Filter

Classification of AMCs

Acids : water soluble

HF H_2SO_4
HCl HNO_3
H_3PO_4 HBr

Bases

AMINE
NH_3
NMP
HMDS

No Classes

H_2O_2 O_3
IPA Acetone

Condensable i.e VOCs

DOP DBP DEP
Siloxanes BHT

Dopants

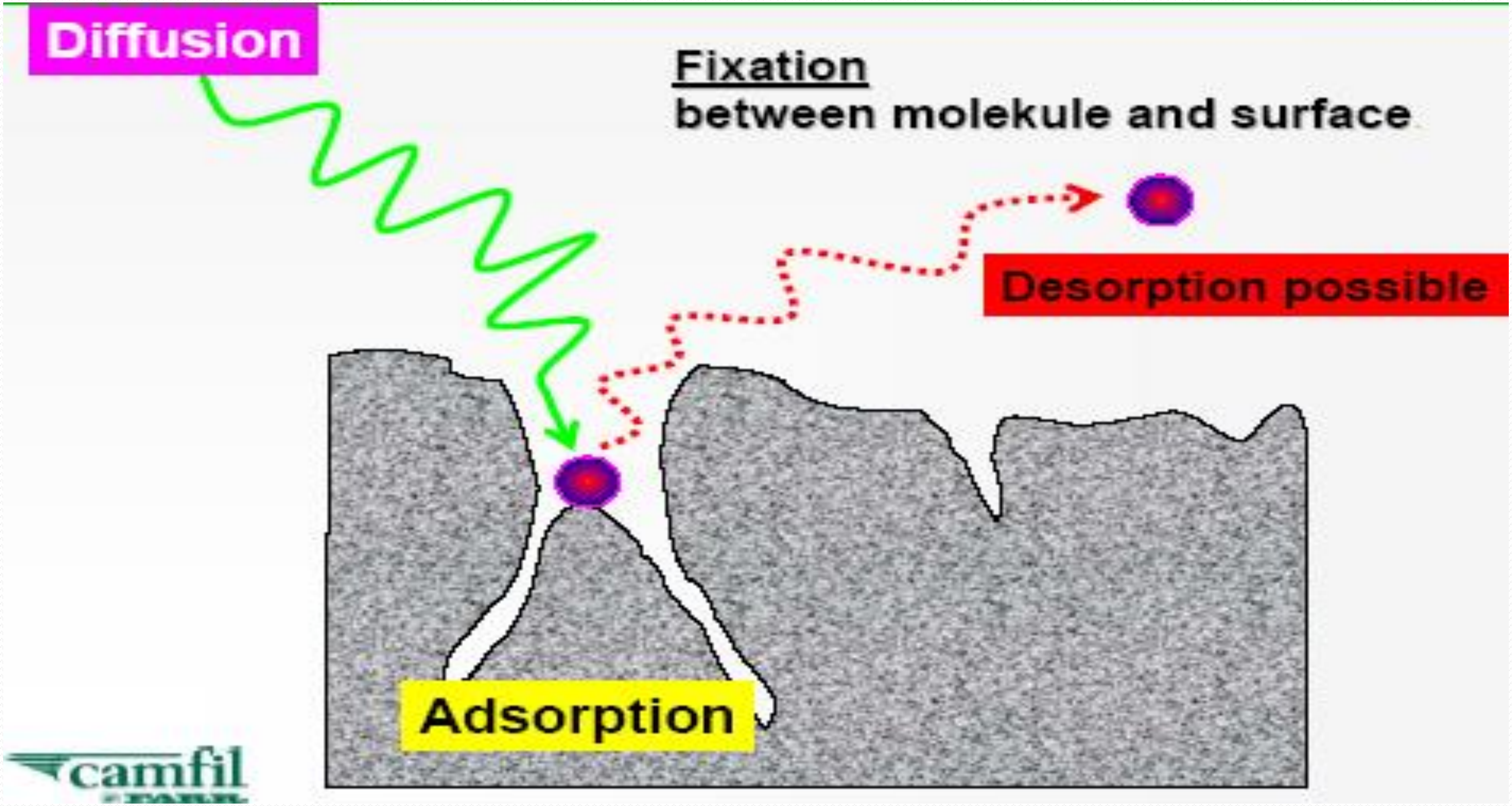
B_2H_6 BF_3 AsH_3
TCEP TEP TPP

REF: SEMI Standard F21-95, 1996

Gas-Phase Air Filtration Principles

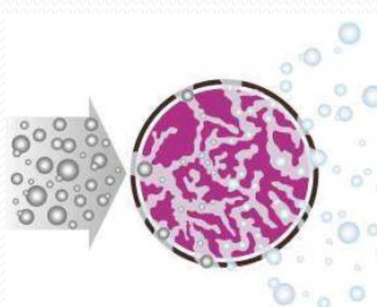
- Adsorption
  – Most commonly involves the use of granular activated carbon (GAC) media.
  – High surface area to volume ratio.
  – Very good against most hydrocarbons, many aldehydes and organic acids, and nitrogen dioxide.
  – Organical gases with more than 3 carbon atomes eg: Solvents, Benzinesteams, Kerosene, Odours

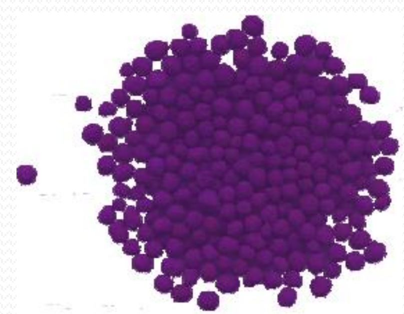
Gas-Phase Air Filtration Principles (cont.)



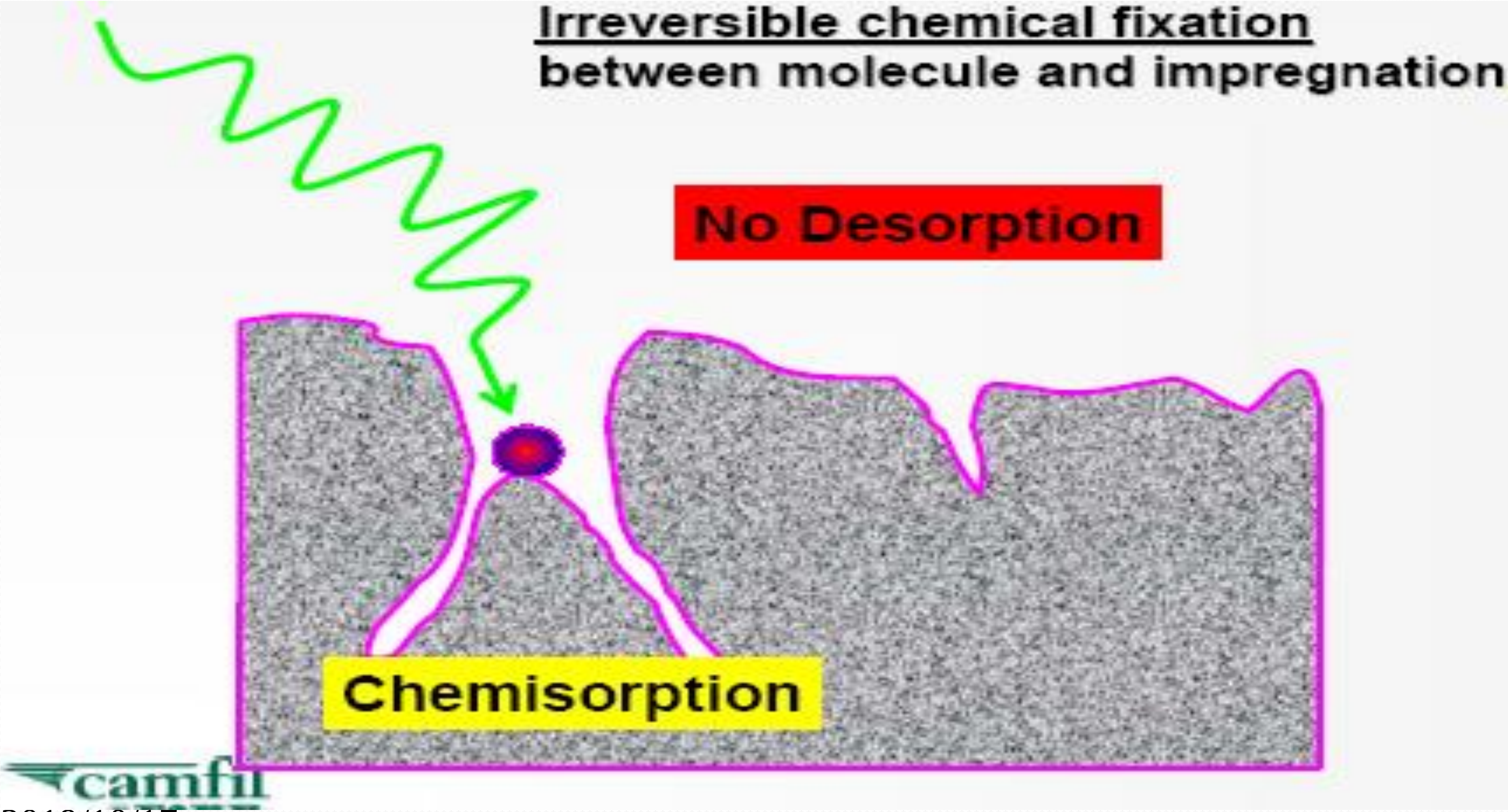
Gas-Phase Air Filtration Principles (cont.)

- **Chemisorption**
  - Most commonly involves permanganate impregnated alumina (PIA) media.
  - Chemically converts contaminants to carbon dioxide, water, and non-toxic salts.
  - Effective against oxides of sulfur, lower molecular weight aldehydes and organic acids, nitric oxide, and hydrogen sulfide.
  - Anorganicalgases eg:–Acids (SO_2, NO_x,H_2S), Ammonia (NH_3), Formaldehyde, Nuclear Filter (eg. Methyliodine), Mercury

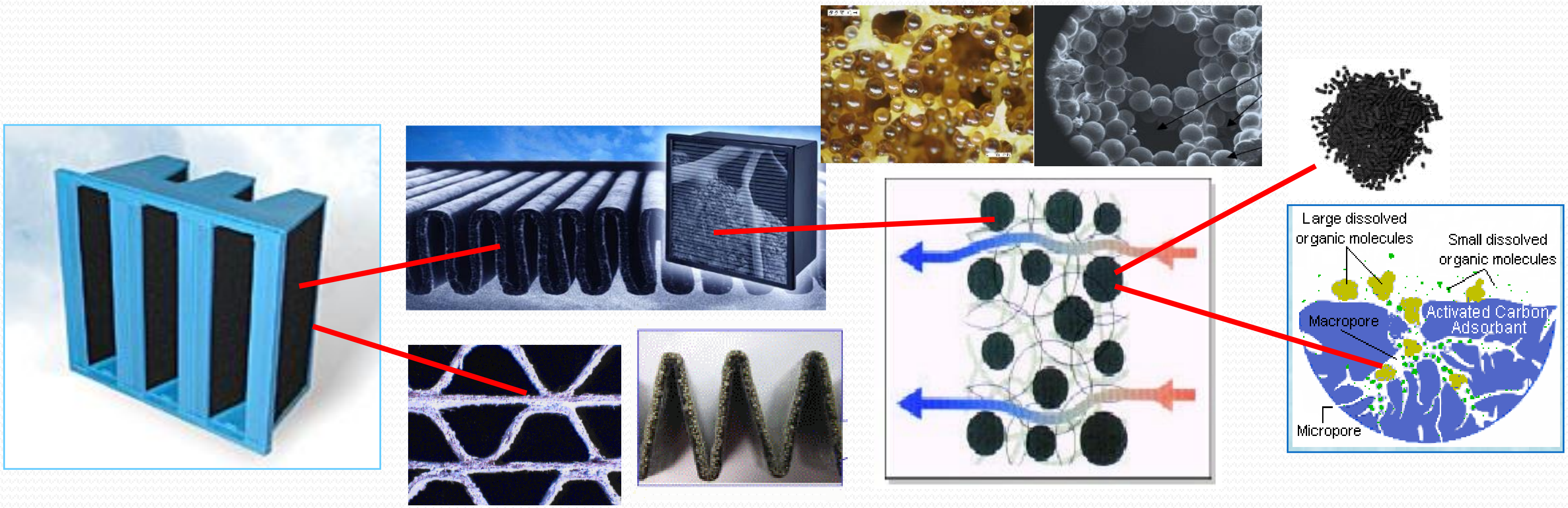




Gas-Phase Air Filtration Principles (cont.)

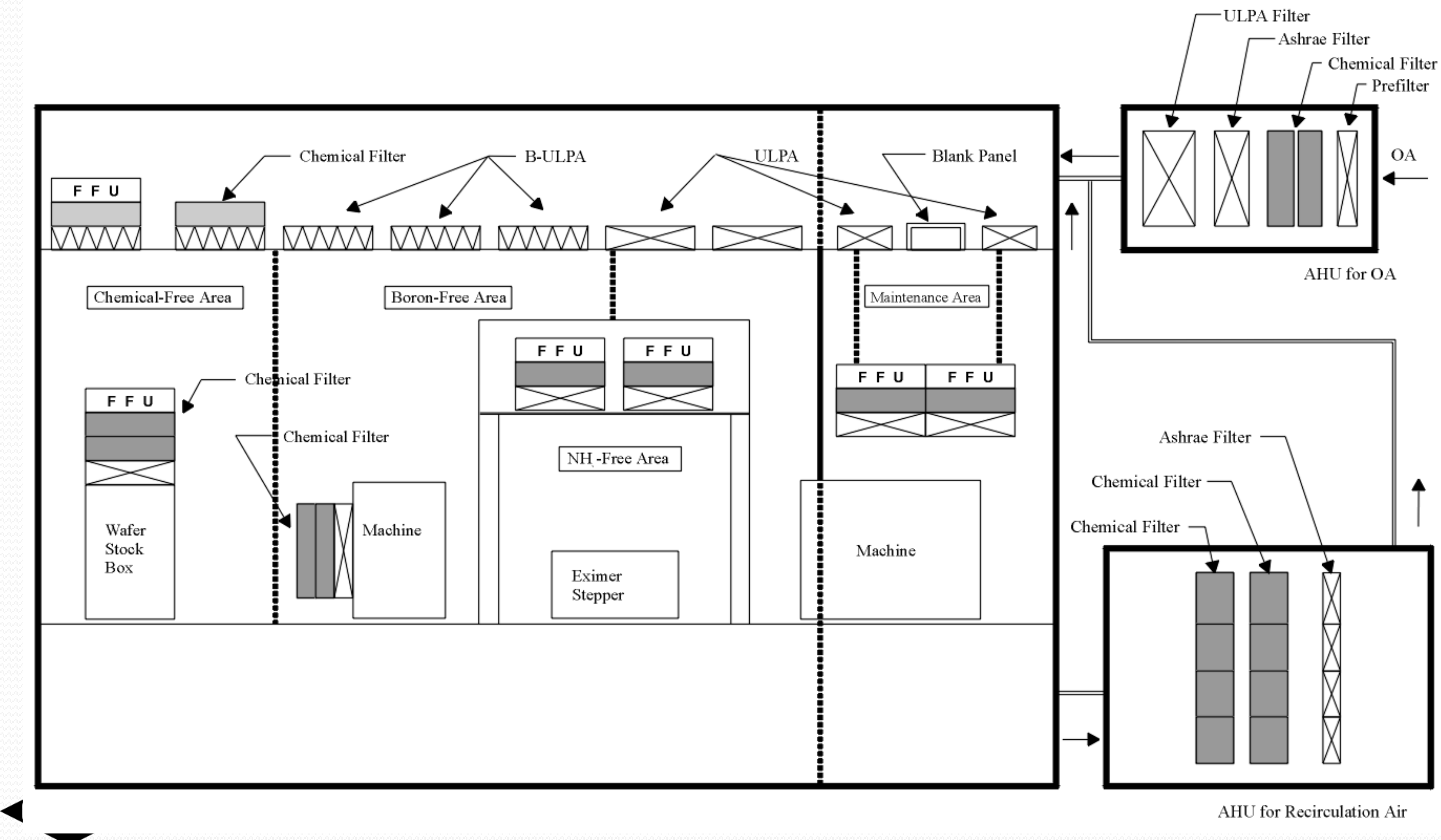


Chemical filters



Chemical filter	construction	loading	media

Filter installation Locations



Filter Pressure drop & Eff. (Molecular Filter)