Air Filtration for Pathogen Mitigation: Mechanism of Filter Action

Chris Hogan
Department of Mechanical Engineering
University of Minnesota
Editor-in-Chief
Journal of Aerosol Science

Outline

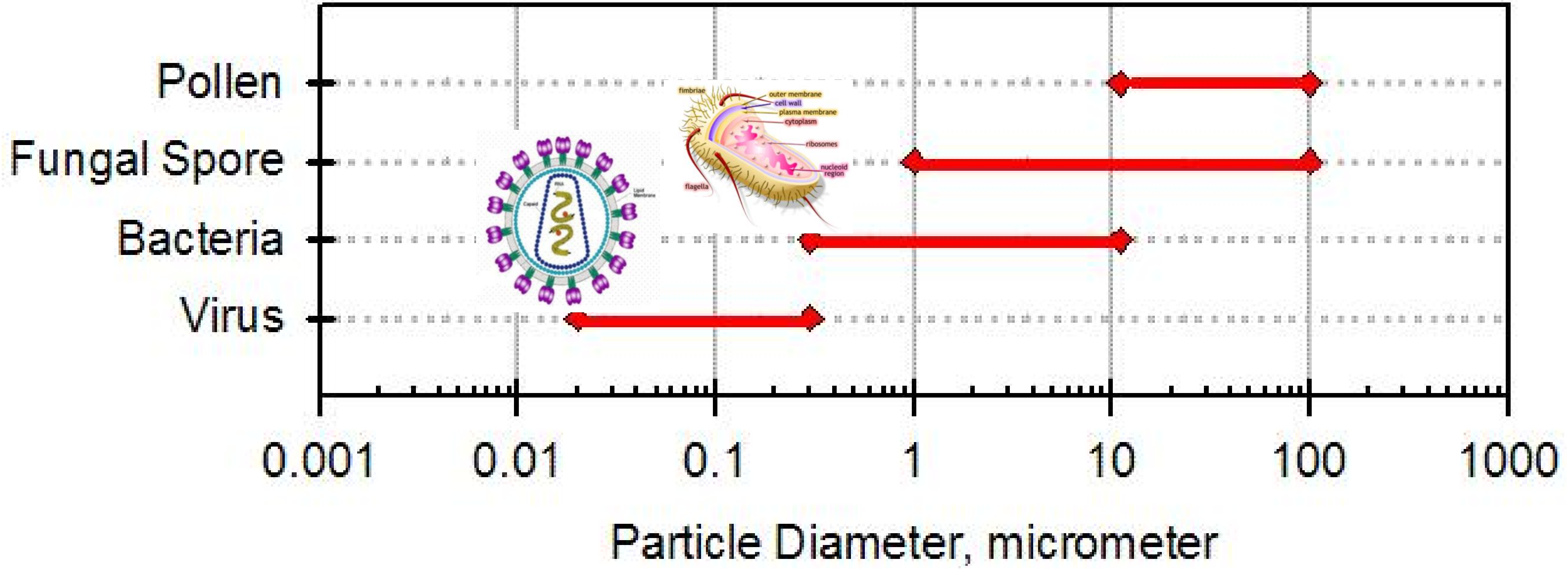
- Aerosols: Definition
- Settling Velocity and Lifetime
- Aerosol based disease transmission
- Filtration
  - Fibrous Filters
  - How they work
  - How they are tested and rated

Aerosols

- An aerosol is a suspension of particles or droplets in a gas
  - Aerosol = particles +gas
- However, even in published literature, the term “aerosols” is often used to refer to just the particles or droplets
- Aerosol science is a highly interdisciplinary field focused on applications ranging from atmospheric chemistry to materials science

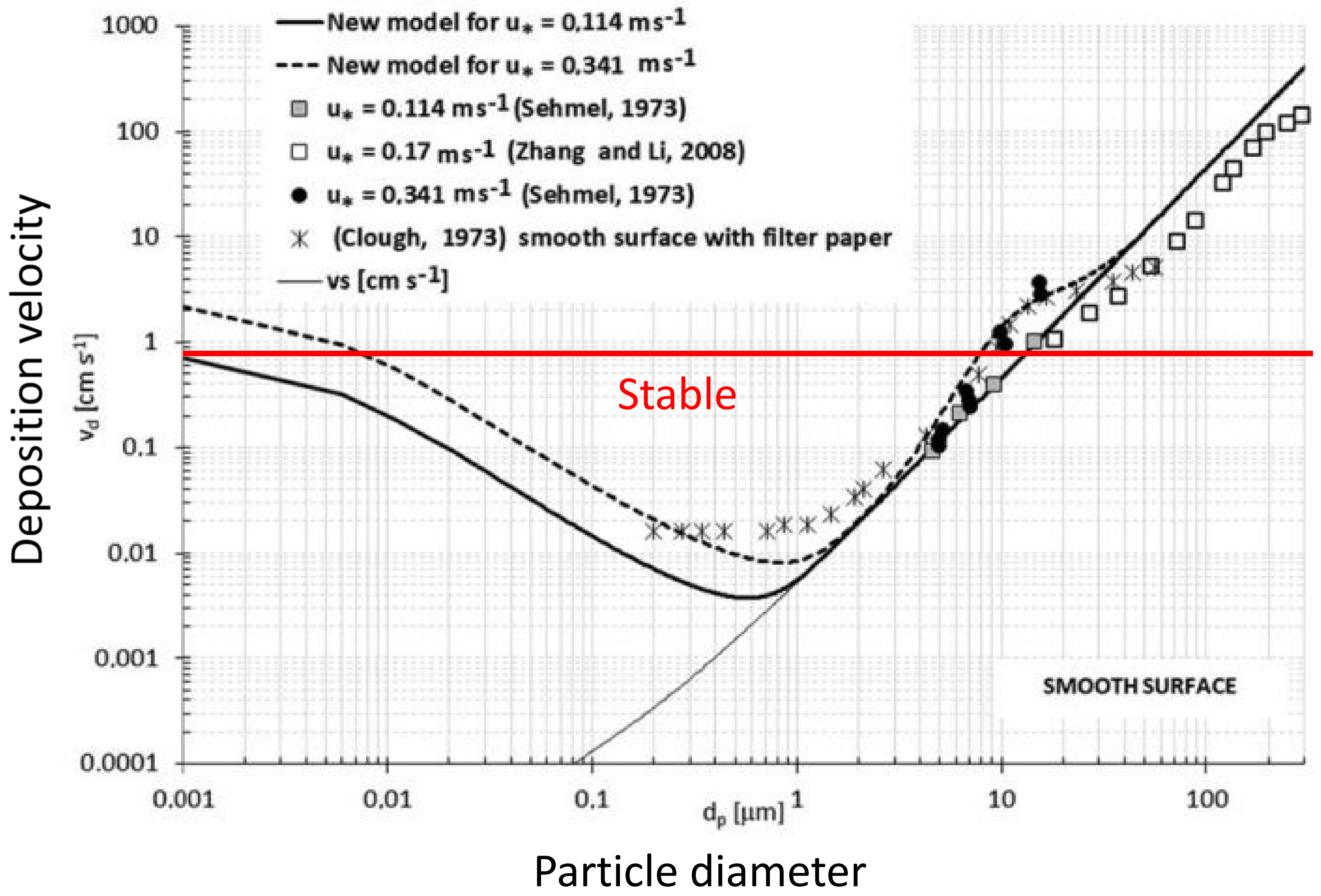
Bioaerosols

- Aerosols of biological origin, containing viable cells or viruses

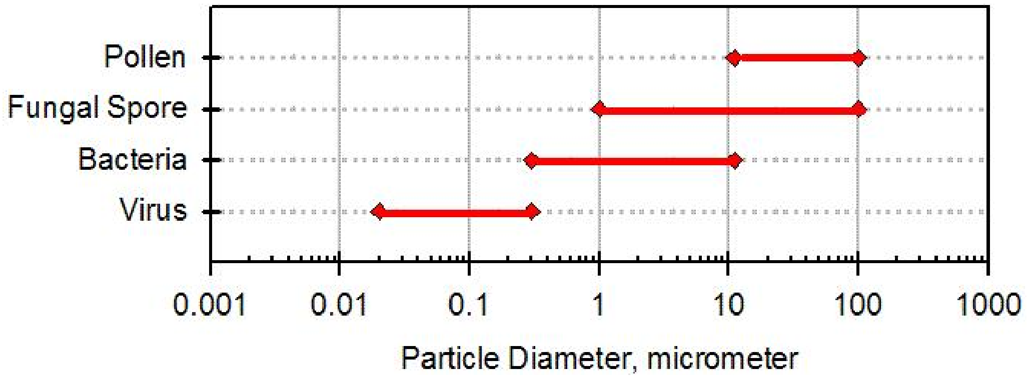


Source: CY Wu, University of Florida

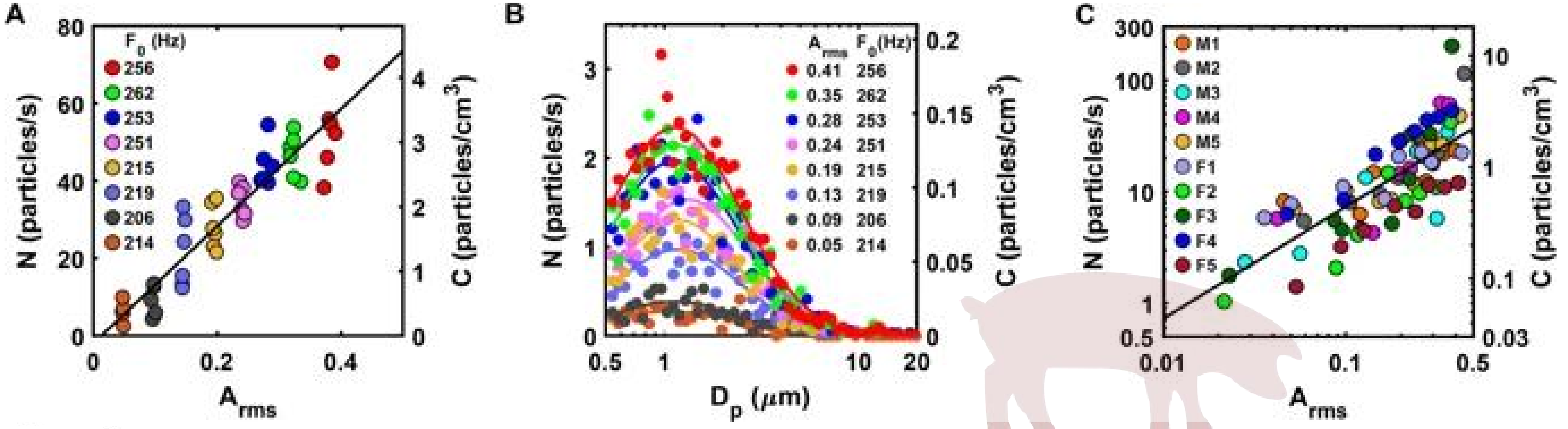
A note on aerosol size



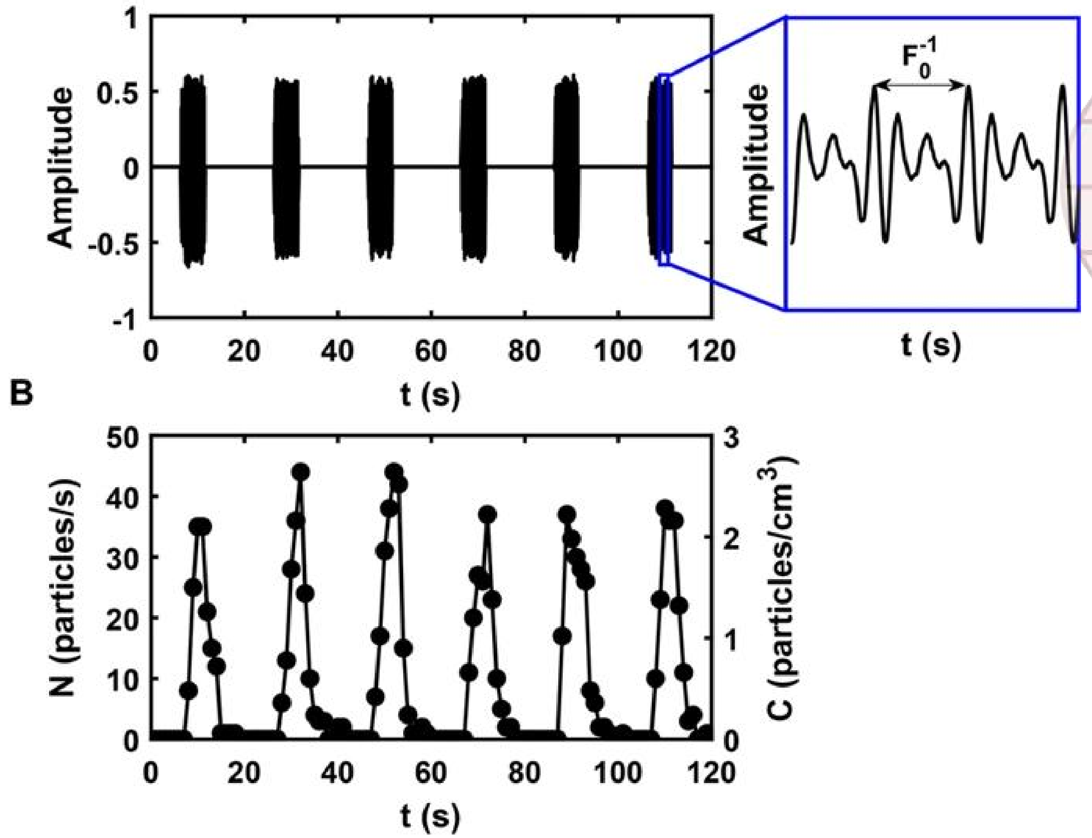
Giardina & Buffa, Atmospheric Environment 2008, 180, 11-22

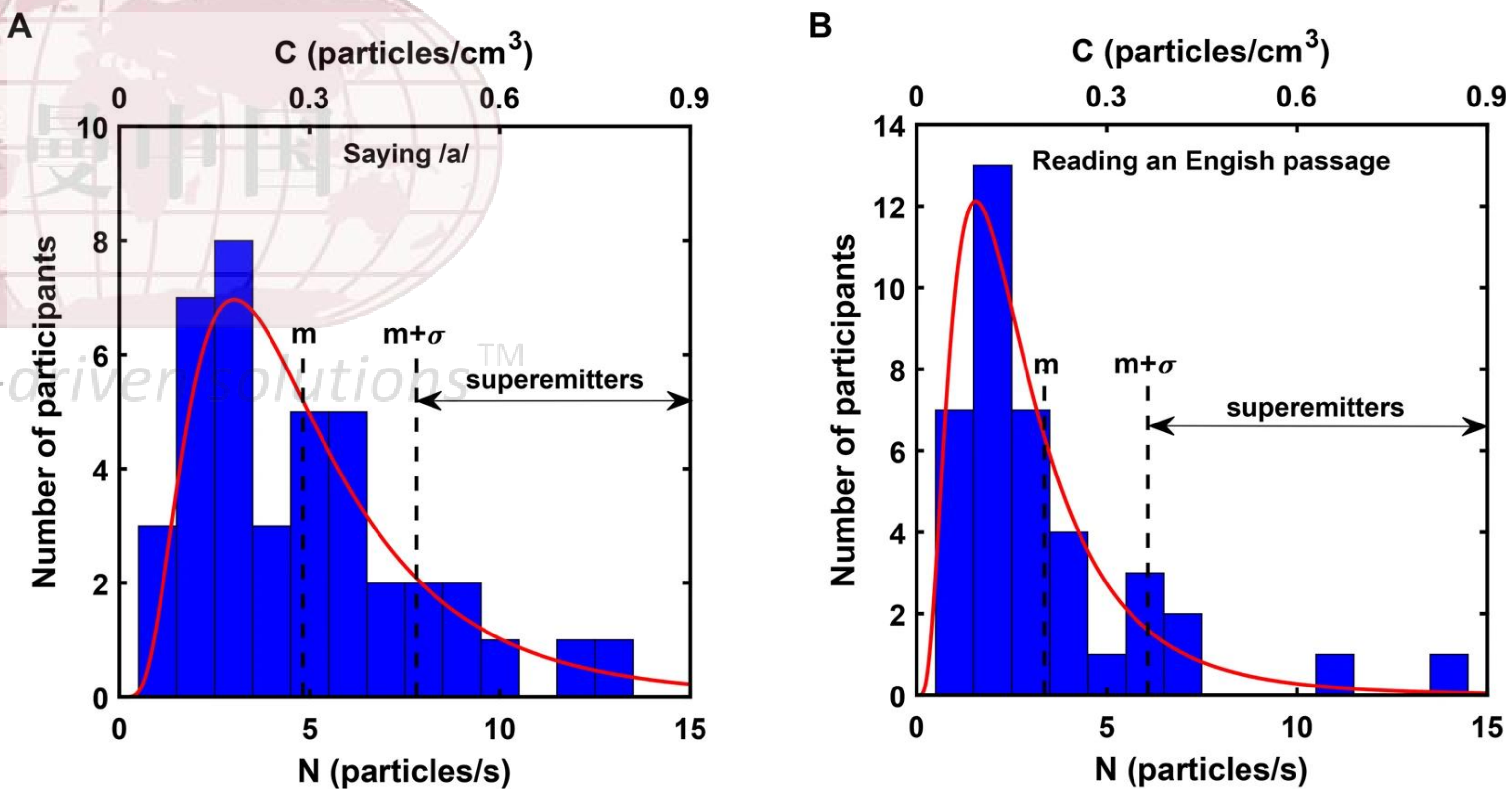


Exhaled Aerosol



Asadi et al, Scientific Reports 2019





Aerosol based respiratory disease transmission- early evidence

American Journal of Epidemiology
Vol 142, No. 1
Printed in U.S.A.

HISTORICAL PAPER

AERIAL DISSEMINATION OF PULMONARY TUBERCULOSIS

A TWO-YEAR STUDY OF CONTAGION IN A TUBERCULOSIS WARD [1]

BY

R. L. RILEY, C. C. MILLS, W. NYKA, N. WEINSTOCK, P. B. STOREY, L. U. SULTAN, M. C. RILEY AND W. F. WELLS [2]

(Received for publication March 26, 1959)

The first report of this series, entitled "Air hygiene in tuberculosis," dealt with the preparation of a pilot ward for the performance of quantitative studies of the infectiousness of the air (1). In the second, basic theoretical carefully controlled and calibrated closed circuit ventilating system, and a large animal exposure chamber located in the exhaust duct of this system (1, 2). Preliminary experiments demonstrated that the air passing through the

Aerosol based disease transmission- Swine Viruses

viruses

MDPI

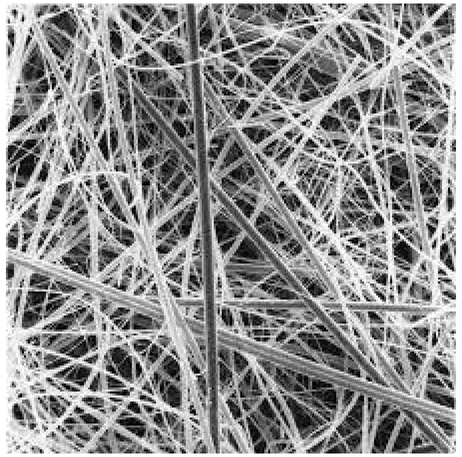
Review

Aerosol Detection and Transmission of Porcine Reproductive and Respiratory Syndrome Virus (PRRSV): What Is the Evidence, and What Are the Knowledge Gaps?

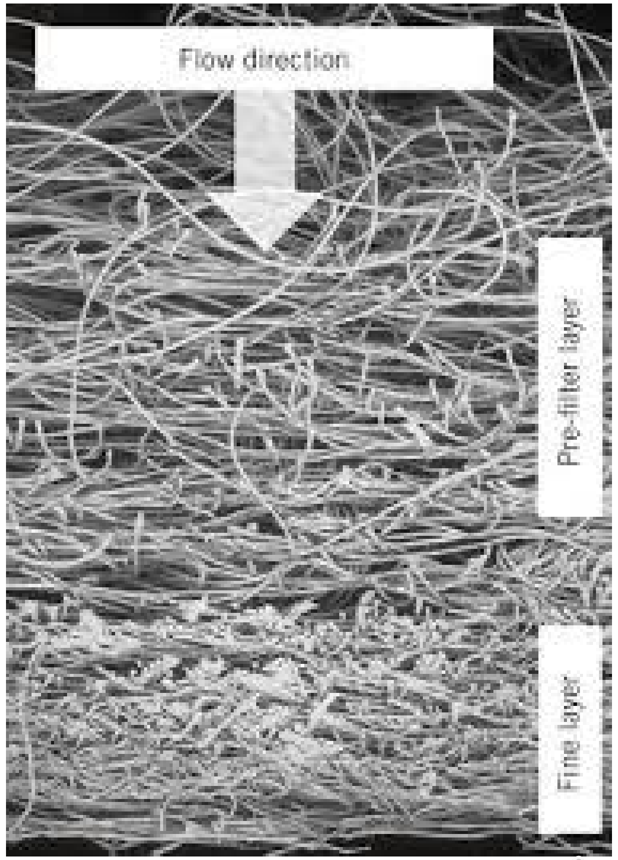
Andréia Gonçalves Arruda [1,*], Steve Tousignant [2], Juan Sanhueza [3], Carles Vilalta [3], Zvonimir Poljak [4], Montserrat Torremorell [3], Carmen Alonso [5] and Cesar A Corzo [3]

Filtration (Fibrous Filters)

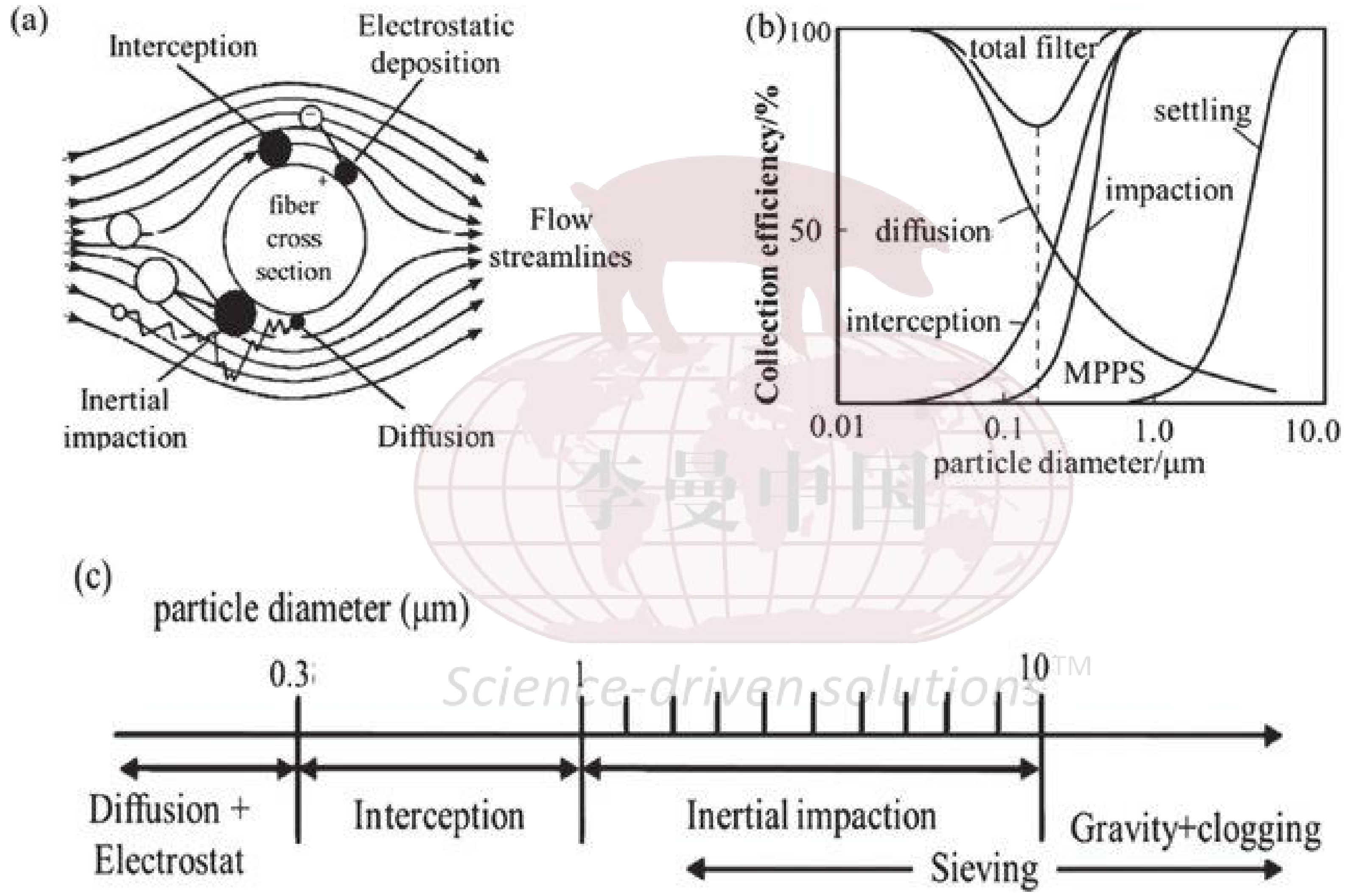
HEPA Filtration Units
(High Efficiency Particle Air Filter)



Multiple
Layer Filter



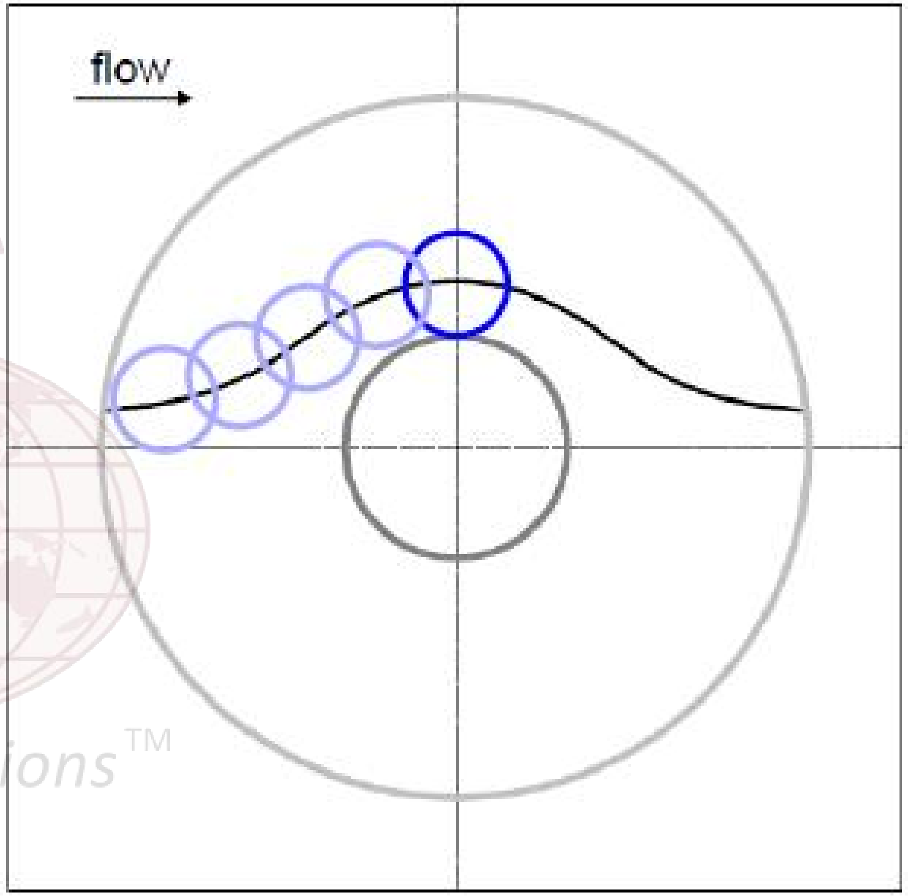
How filters work



Lv et al, 2018, Macromolecular Materials & Engineering, Green Electrospun Nanofibers and Their Application in Air Filtration

Interception

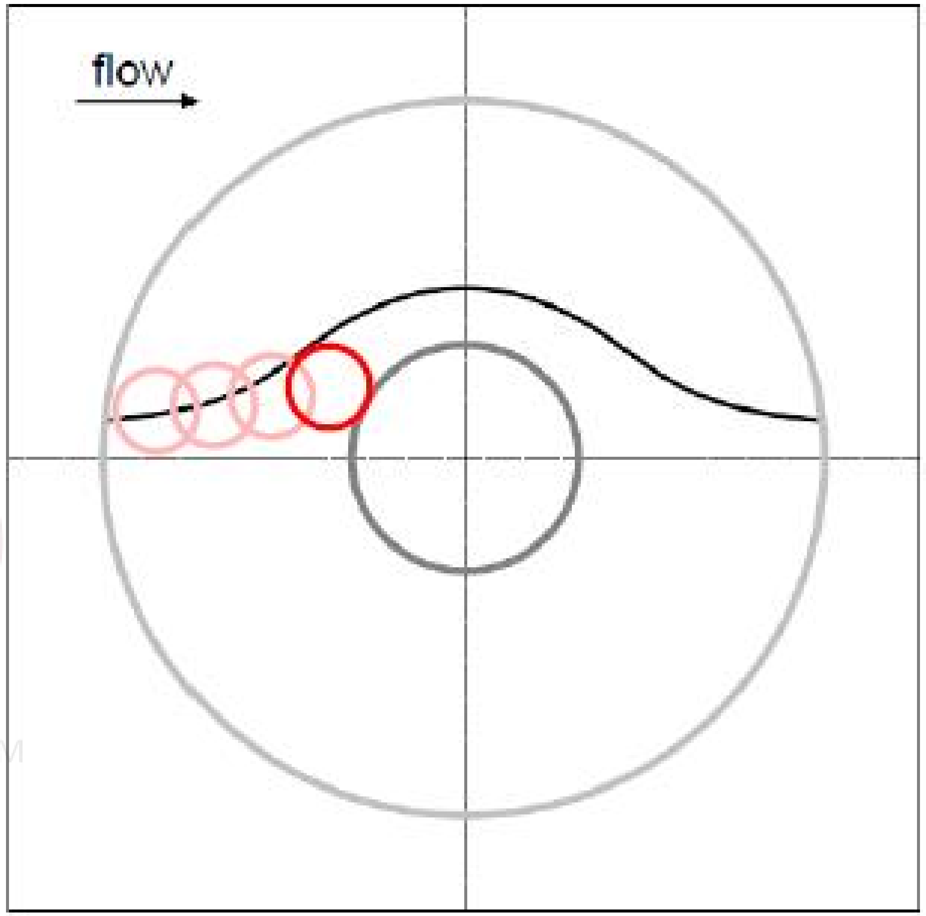
Particles follow fluid streamlines, but travel close enough to the filter fiber to be collected



Interception

Impaction

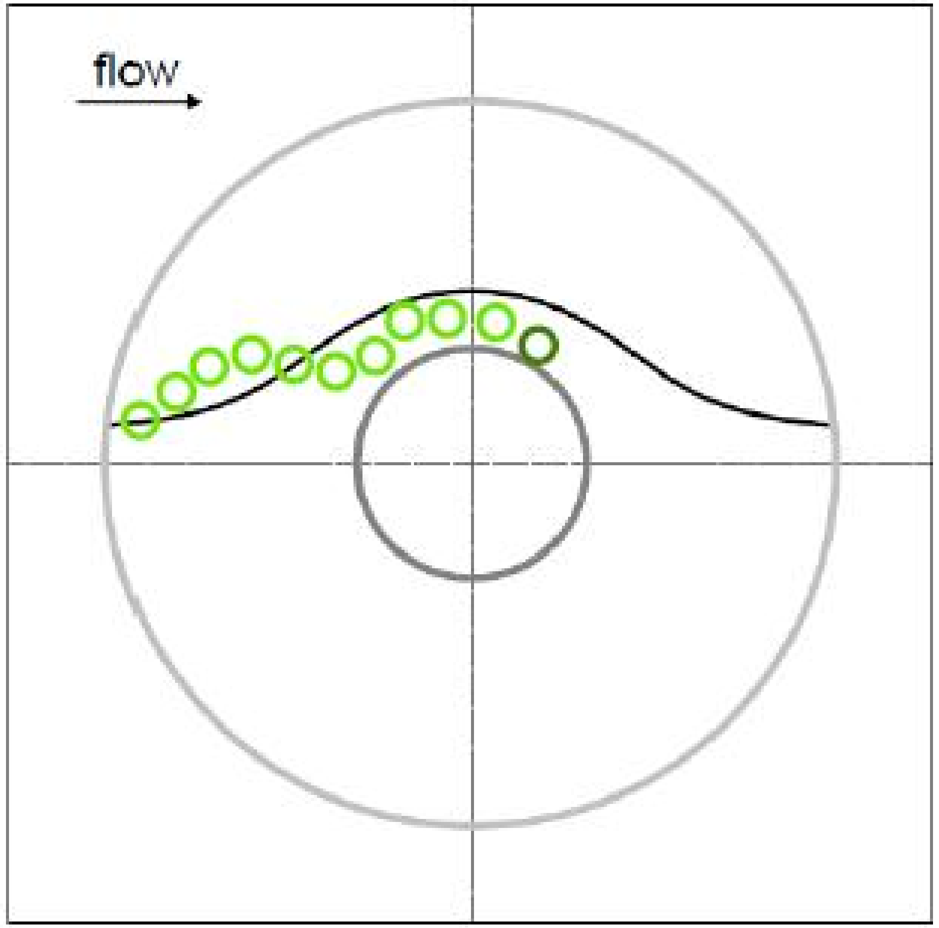
Particles cannot follow bending streamlines and impact onto the filter fiber



Impaction

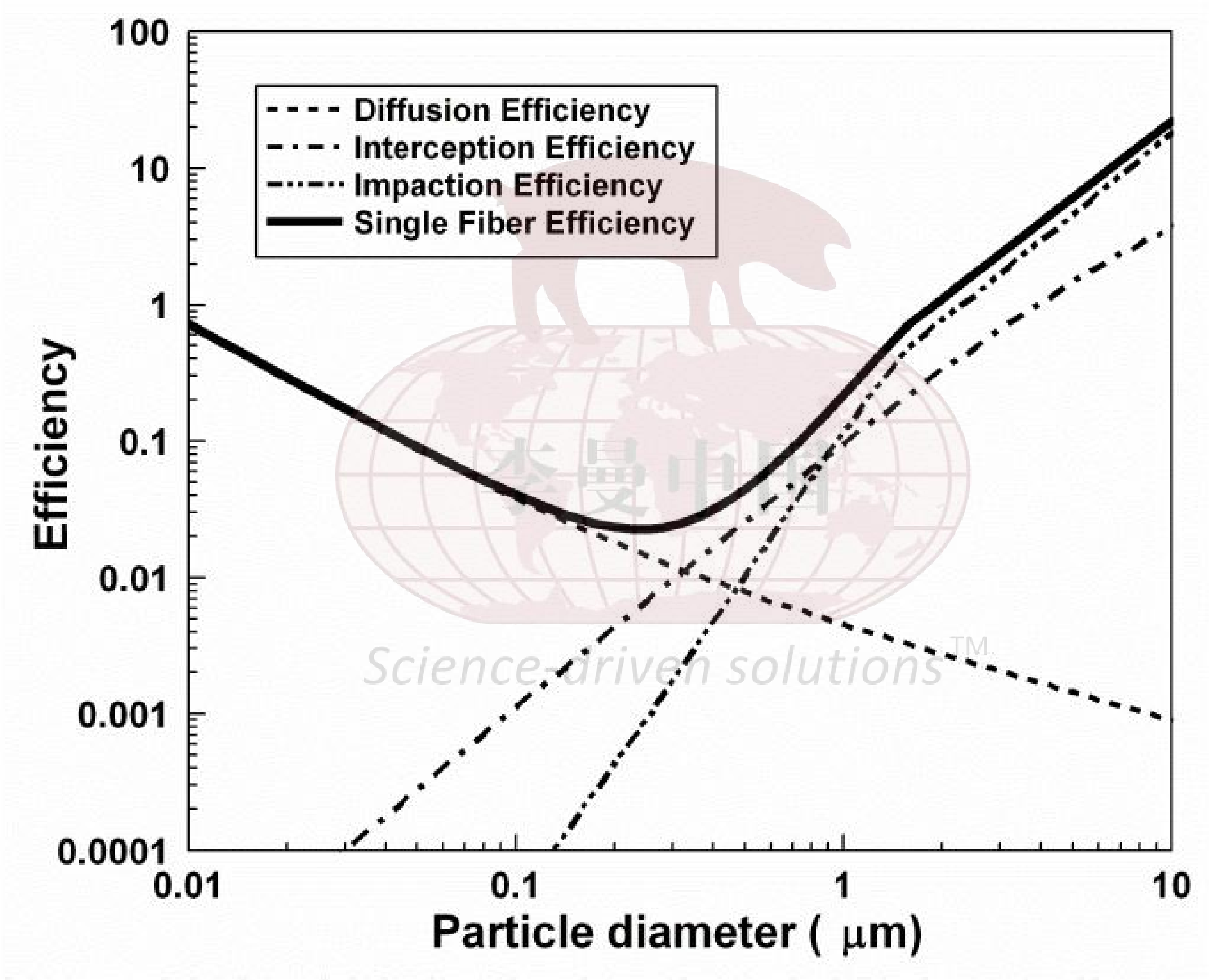
Diffusion

Smaller particles move diffusively, and collide with fibers

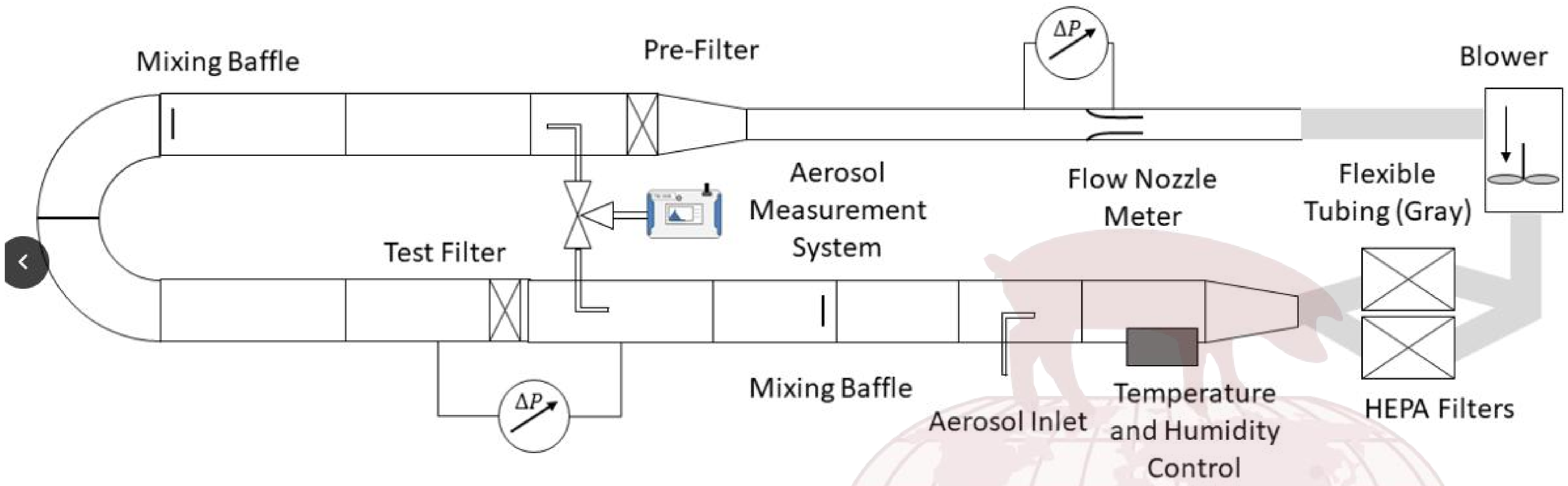


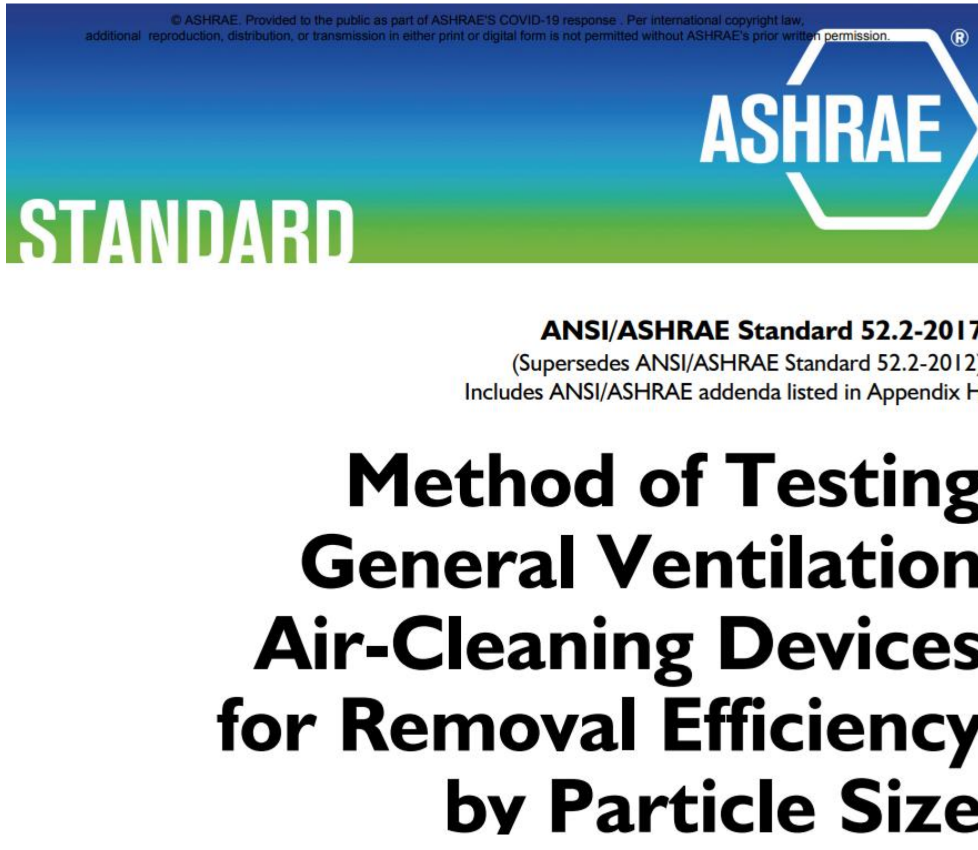
Diffusion

Single Fiber Collection Efficiency



Filter Testing




© ASHRAE. Provided to the public as part of ASHRAE'S COVID-19 response . Per international copyright law, additional reproduction, distribution, or transmission in either print or digital form is not permitted without ASHRAE's prior written permission.

ASHRAE

STANDARD

ANSI/ASHRAE Standard 52.2-2017

(Supersedes ANSI/ASHRAE Standard 52.2-2012)

Includes ANSI/ASHRAE addenda listed in Appendix H

Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size

- ANSI/ASHRE Standard 52.2-2017
- Size dependent collection efficiency from 0.3-10 μm
- Pressure drop and loading as well

Filter Ratings

HEPA: 99.97% Efficient

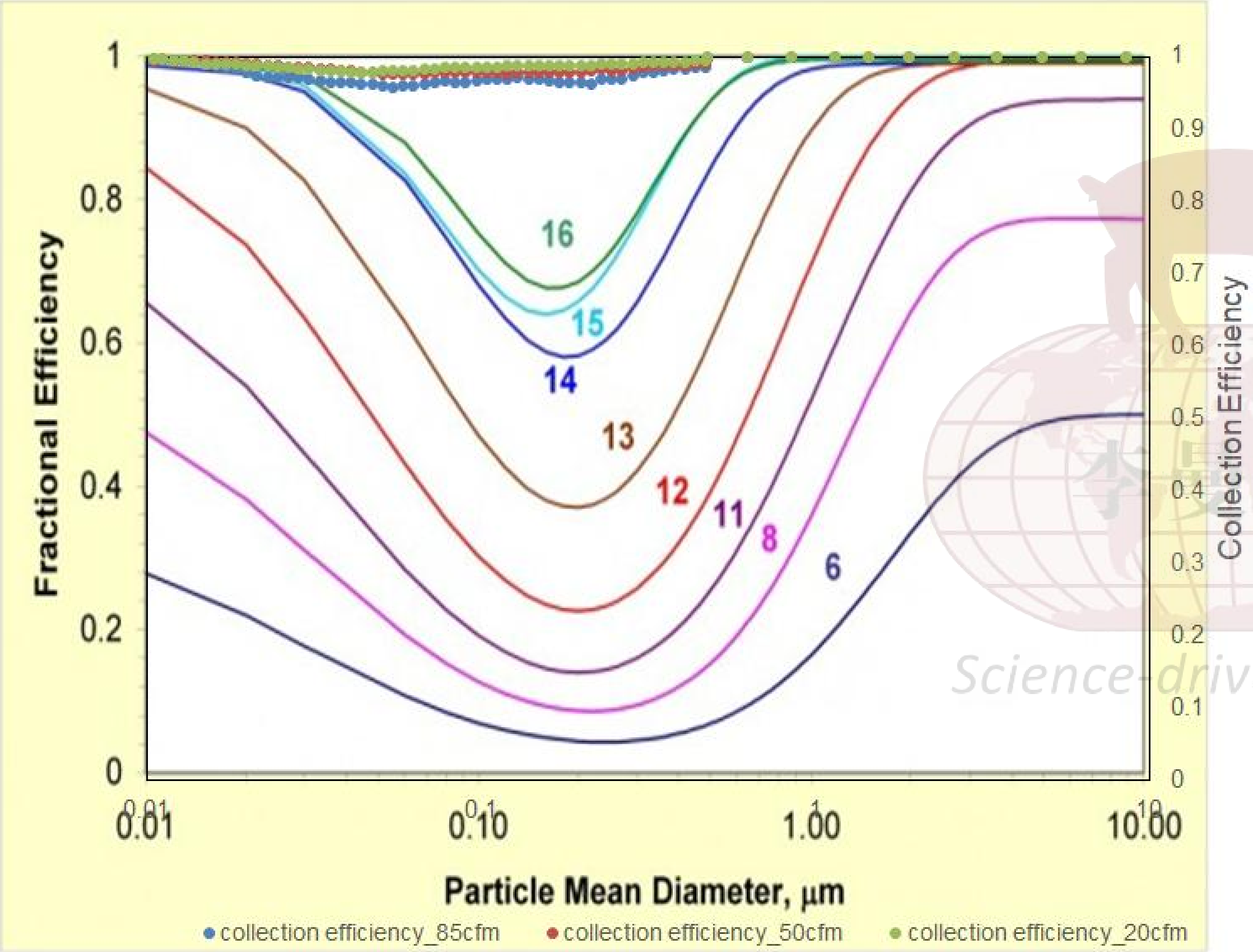


Table 12-1 Minimum Efficiency Reporting Value (MERV) Parameters

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, µm			
	Range 1 0.30 to 1.0	Range 2 1.0 to 3.0	Range 3 3.0 to 10.0	Average Arrestance, %
1	N/A	N/A	$E_3 < 20$	$A_{avg} < 65$
2	N/A	N/A	$E_3 < 20$	$65 \le A_{avg}$
3	N/A	N/A	$E_3 < 20$	$70 \le A_{avg}$
4	N/A	N/A	$E_3 < 20$	$75 \le A_{avg}$
5	N/A	N/A	$20 \le E_3$	N/A
6	N/A	N/A	$35 \le E_3$	N/A
7	N/A	N/A	$50 \le E_3$	N/A
8	N/A	$20 \le E_2$	$70 \le E_3$	N/A
9	N/A	$35 \le E_2$	$75 \le E_3$	N/A
10	N/A	$50 \le E_2$	$80 \le E_3$	N/A
11	$20 \le E_1$	$65 \le E_2$	$85 \le E_3$	N/A
12	$35 \le E_1$	$80 \le E_2$	$90 \le E_3$	N/A
13	$50 \le E_1$	$85 \le E_2$	$90 \le E_3$	N/A
14	$75 \le E_1$	$90 \le E_2$	$95 \le E_3$	N/A
15	$85 \le E_1$	$90 \le E_2$	$95 \le E_3$	N/A
16	$95 \le E_1$	$95 \le E_2$	$95 \le E_3$	N/A

MERV Ratings are not linear

Table 12-1 Minimum Efficiency Reporting Value (MERV) Parameters

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, μm			
	Range 1 0.30 to 1.0	Range 2 1.0 to 3.0	Range 3 3.0 to 10.0	Average Arrestance, %
1	N/A	N/A	$E_3 < 20$	$A_{avg} < 65$
2	N/A	N/A	$E_3 < 20$	$65 \le A_{avg}$
3	N/A	N/A	$E_3 < 20$	$70 \le A_{avg}$
4	N/A	N/A	$E_3 < 20$	$75 \le A_{avg}$
5	N/A	N/A	$20 \le E_3$	N/A
6	N/A	N/A	$35 \le E_3$	N/A
7	N/A	N/A	$50 \le E_3$	N/A
8	N/A	$20 \le E_2$	$70 \le E_3$	N/A
9	N/A	$35 \le E_2$	$75 \le E_3$	N/A
10	N/A	$50 \le E_2$	$80 \le E_3$	N/A
11	$20 \le E_1$	$65 \le E_2$	$85 \le E_3$	N/A
12	$35 \le E_1$	$80 \le E_2$	$90 \le E_3$	N/A
13	$50 \le E_1$	$85 \le E_2$	$90 \le E_3$	N/A
14	$75 \le E_1$	$90 \le E_2$	$95 \le E_3$	N/A
15	$85 \le E_1$	$90 \le E_2$	$95 \le E_3$	N/A
16	$95 \le E_1$	$95 \le E_2$	$95 \le E_3$	N/A

Common MERV Filters used

Lower Grade filters

Common Residential Filters

Higher grade filters

MERV Ratings are not linear

Table 12-1 Minimum Efficiency Reporting Value (MERV) Parameters

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Composite Average Particle Size Efficiency, % in Size Range, µm			
	Range 1 0.30 to 1.0	Range 2 1.0 to 3.0	Range 3 3.0 to 10.0	Average Arrestance, %
1	N/A	N/A	$E_3 < 20$	$A_{avg} < 65$
2	N/A	N/A	$E_3 < 20$	$65 \le A_{avg}$
3	N/A	N/A	$E_3 < 20$	$70 \le A_{avg}$
4	N/A	N/A	$E_3 < 20$	$75 \le A_{avg}$
5	N/A	N/A	$20 \le E_3$	N/A
6	N/A	N/A	$35 \le E_3$	N/A
7	N/A	N/A	$50 \le E_3$	N/A
8	N/A	$20 \le E_2$	$70 \le E_3$	N/A
9	N/A	$35 \le E_2$	$75 \le E_3$	N/A
10	N/A	$50 \le E_2$	$80 \le E_3$	N/A
11	$20 \le E_1$	$65 \le E_2$	$85 \le E_3$	N/A
12	$35 \le E_1$	$80 \le E_2$	$90 \le E_3$	N/A
13	$50 \le E_1$	$85 \le E_2$	$90 \le E_3$	N/A
14	$75 \le E_1$	$90 \le E_2$	$95 \le E_3$	N/A
15	$85 \le E_1$	$90 \le E_2$	$95 \le E_3$	N/A
16	$95 \le E_1$	$95 \le E_2$	$95 \le E_3$	N/A

"Pre-filters"

Used to collect large particles only

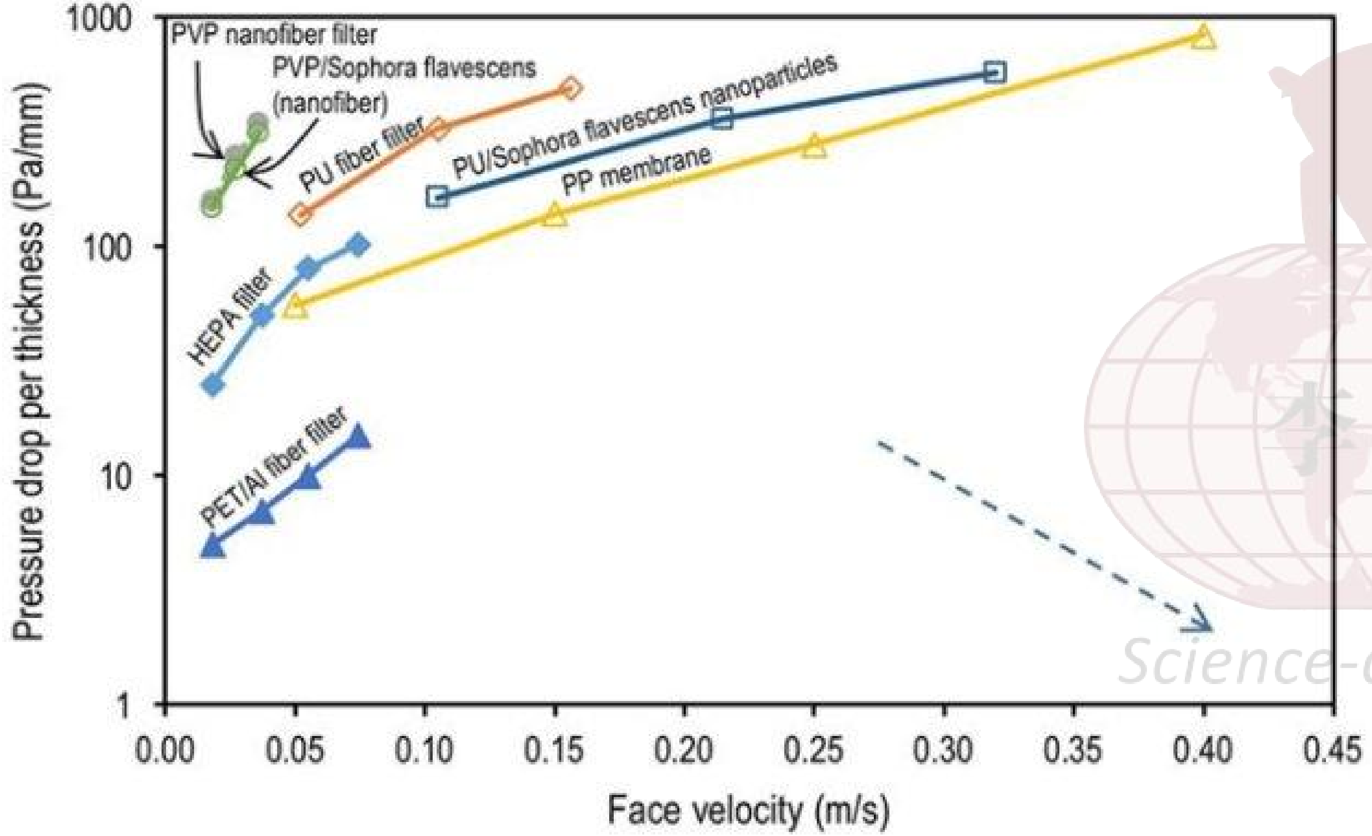
Pre-filter + Higher MERV Filter

Pre-filter (low MERV rating)

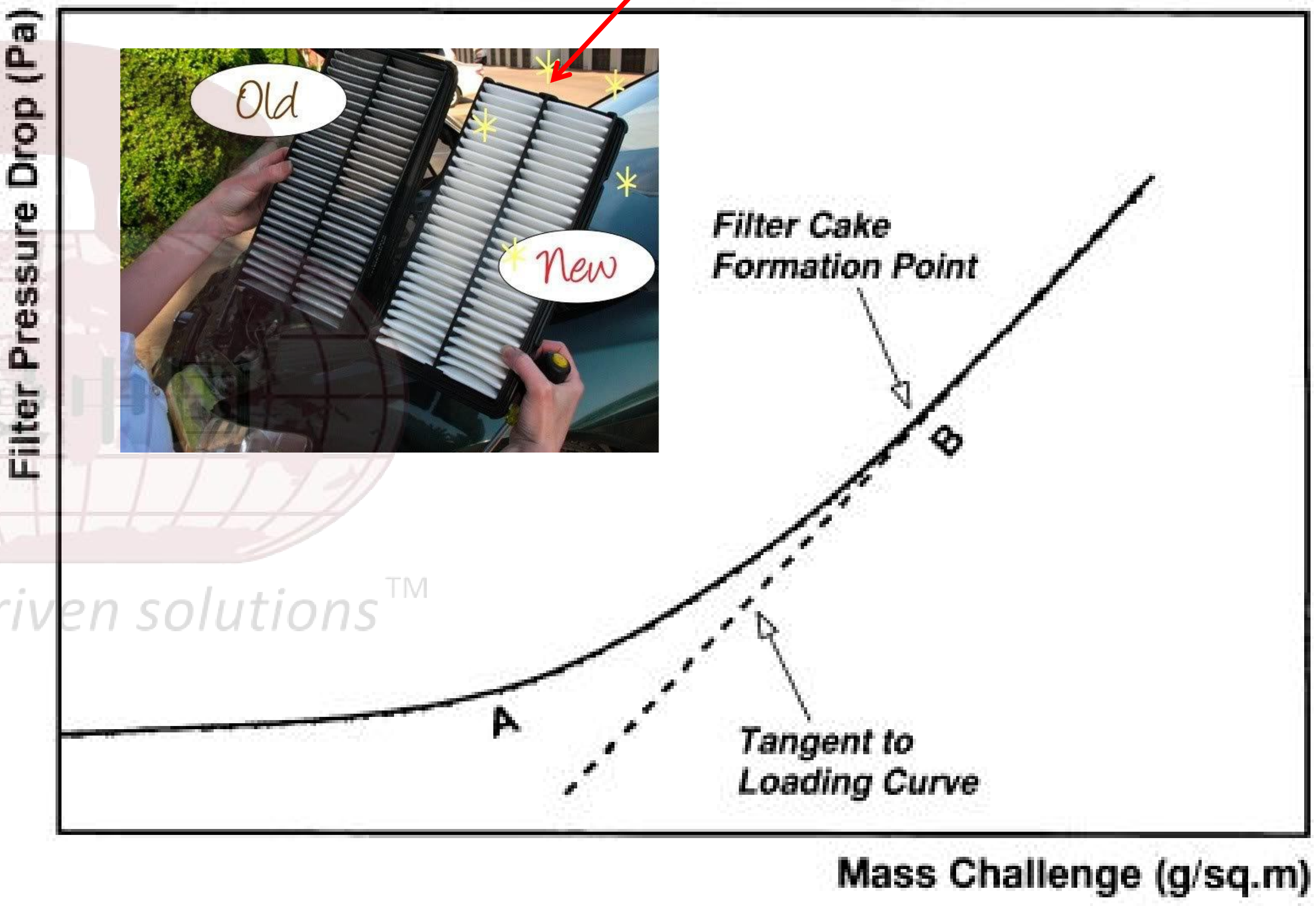
Main filter (higher MERV rating)

Filter Pressure Drop

Filter Pleating



Recent advances in antimicrobial air filter, 2017



Tailor et al, Buidling & Environment, 1998

Filtration in Barns

Filters require regular replacement

Filter cost

- Filter baseline costs are the annual replacement costs of the filters
- Additional energy costs
  - Energy used (Watts): Pressure Drop x Ventilate Rate/Fan Efficiency

Summary

- Aerosol particles span a wide size range
- Small particles have long lifetimes in the air
- Small particles can carry infectious pathogens
- Filtration can be used to reduce barn-to-barn pathogen aerosol transport
- Filters have size-dependent collection efficiencies
  - MERV ratings