Introduction to Hong Kong's Nonwoven Industry and its Product Advantages:

Novel Nanofiber Technologies for Environmental Applications

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Contents

Nanofiber + Production

- Nanofibers
- Needle and Needle-less production

Environment

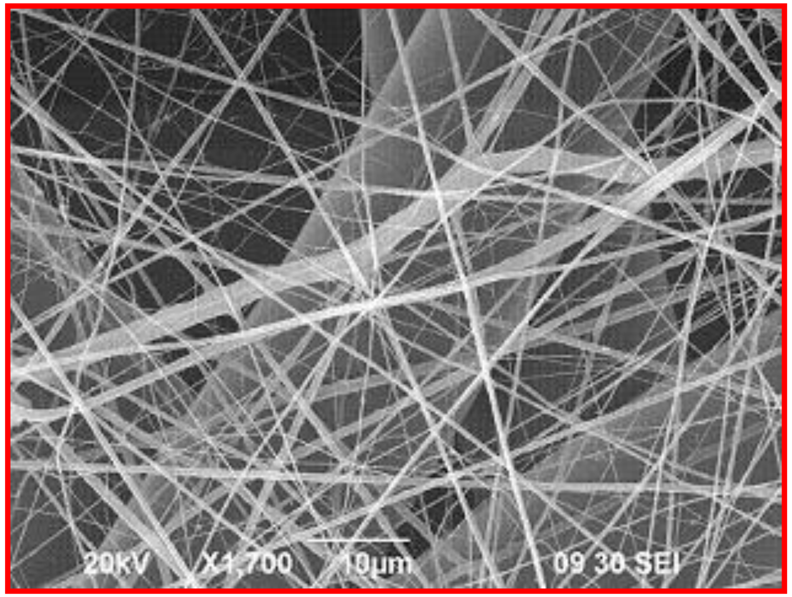
(a) Aerosols Removal

(b) Removal of Harmful Gas in Air

(c) Removal of Harmful Organics in Water

Nanofibers

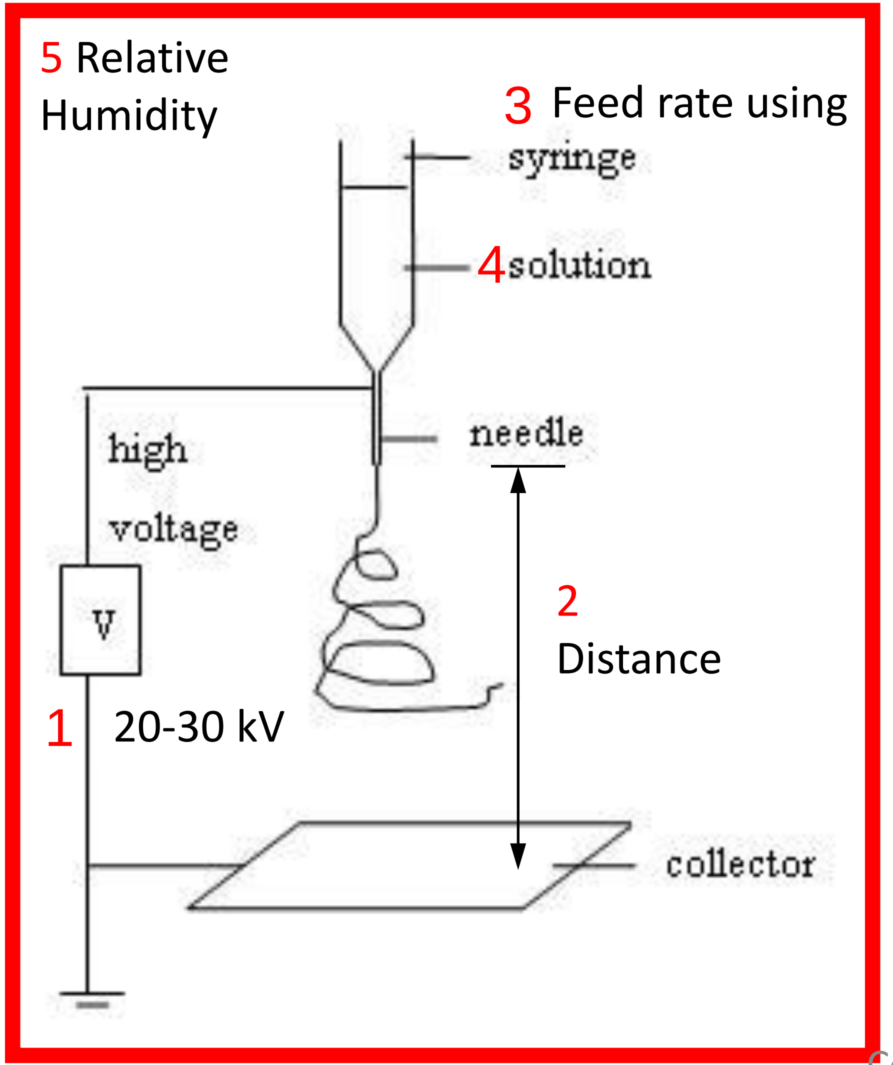
- Fiber diameter less than 1 μm (1000 nm)
- Length ≥μm
- Materials:
  - Organic
  - Inorganic
  - Natural materials



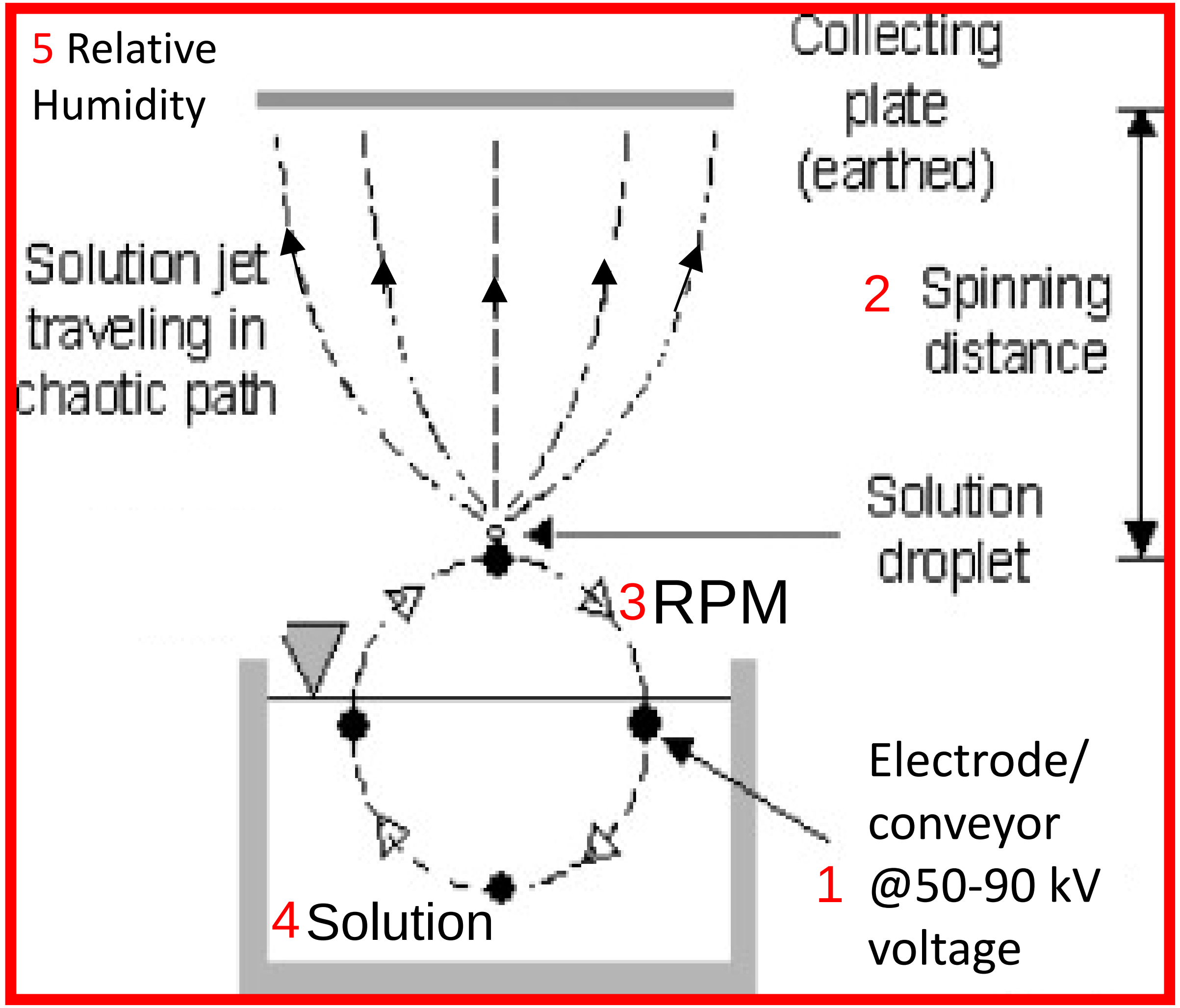
- **Applications –Environment,** Energy, Health, Sensing, etc.

Solution Electrospinning

Needle Electrospinning



Needle-less Electrospinning



Needle Electrospinning Machine

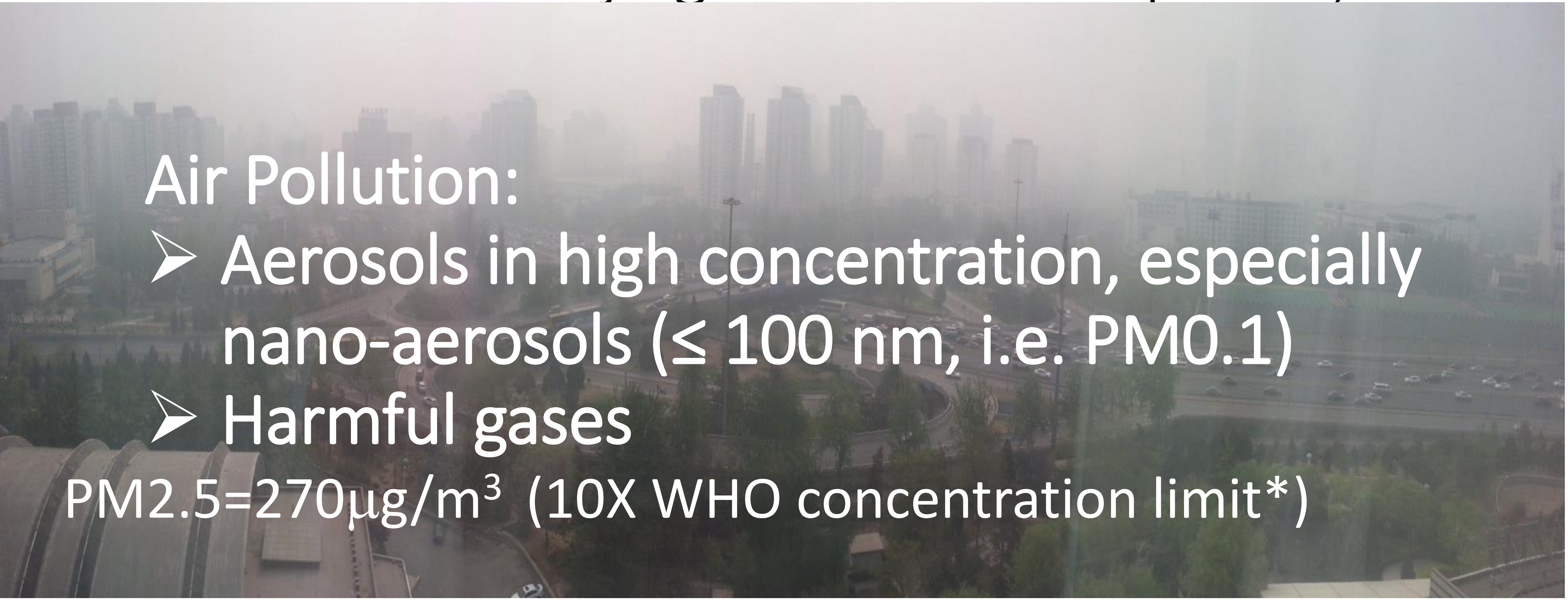
2 Moving Needles, substrate on rotating drum for uniform fiber coating

Needleless Electrospinning

Continuous electrospinning units produces
“Infinite number of fibers” deposited on moving/stationary substrate collector

Aerosol Removal

Air Pollution in Beijing - 9 am Mon April 14, 2014



Air Pollution:

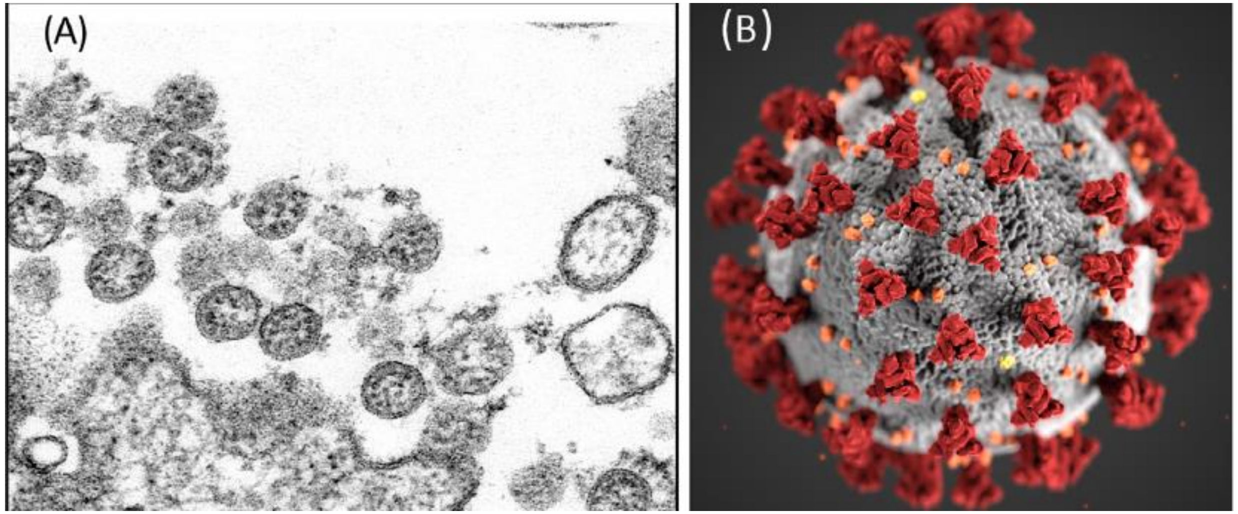
- Aerosols in high concentration, especially nano-aerosols (≤ 100 nm, i.e. PM0.1)
- Harmful gases

PM2.5=270μg/m^3 (10X WHO concentration limit*)

*Note: World Health Organization Standard PM2.5, 25 μg/m^3

Virus Size: 50-100 nm (Virus are attached to nuclei sites/droplets)

Courtesy of CDC

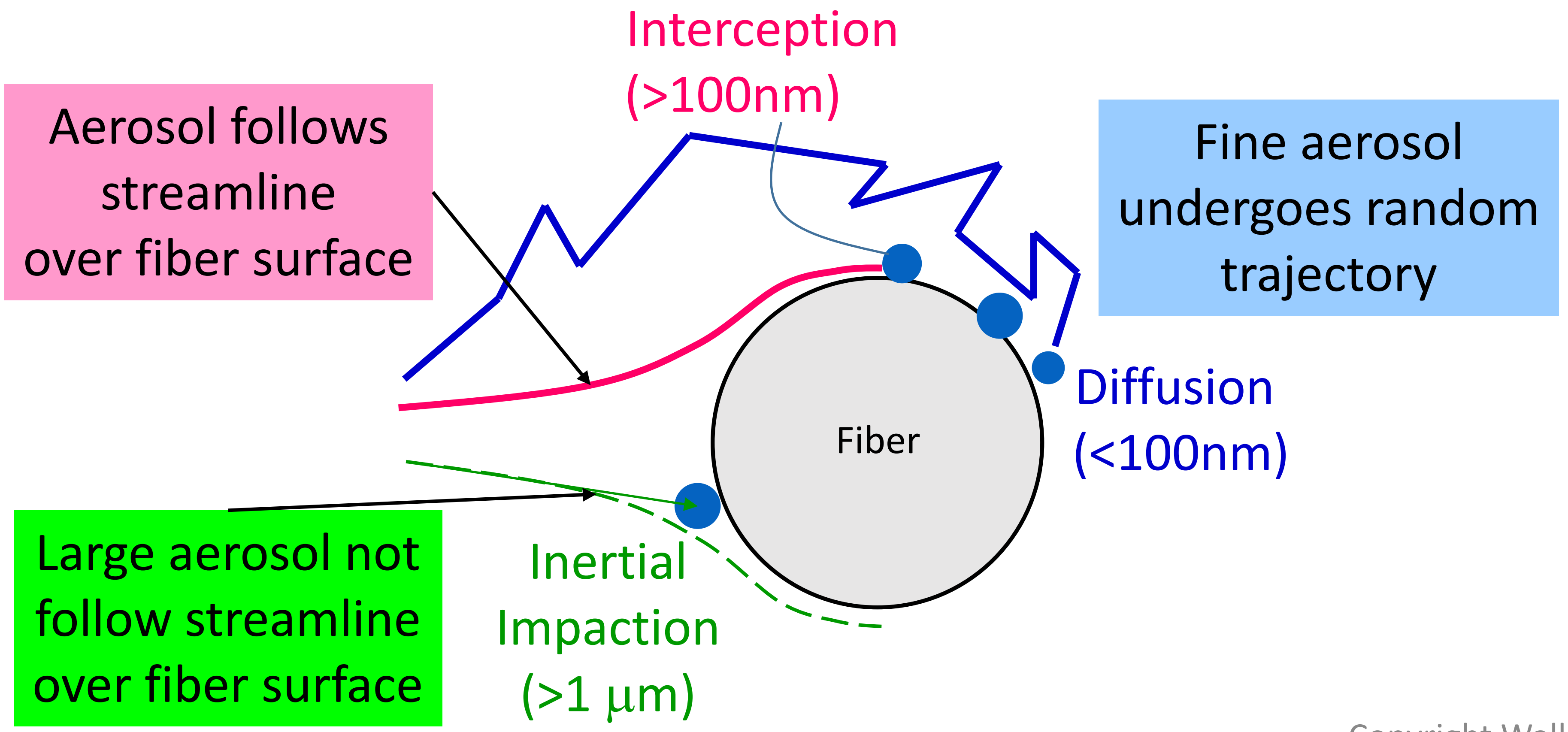


SARS-CoV-2 virus
60-140nm

Viruses same size range as pollutants!!

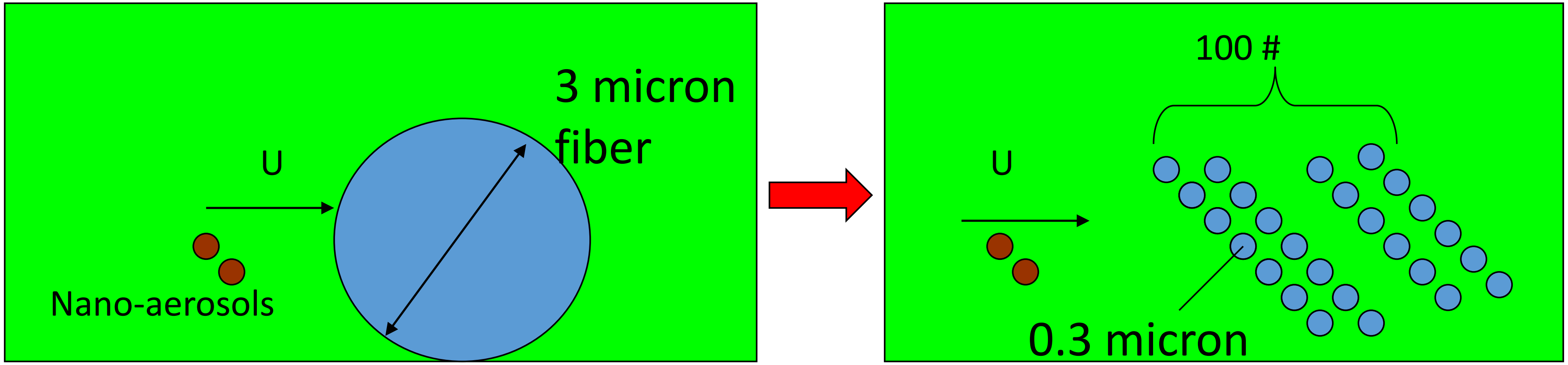
Filtration - Mechanical Capture

- **Mechanical** filtration: diffusion, interception, inertial impaction
- **Nano-aerosols filtration** dominated by **diffusion** & **interception**



Increase fiber number & area with nanofibers

- 3-μm microfiber ⇒ reduced diameter to 0.3-μm nanofiber ⇒ 100 fibers (same length)!
- Increase surface area only by 10X
  - ❑**Enhance interception** (D_p>100 nm)
  - ❑**Enhance diffusion** (D_p<100 nm).



❑Bad news: Increases Δp *(see solution later)*

Grade Efficiency and Quality Factor

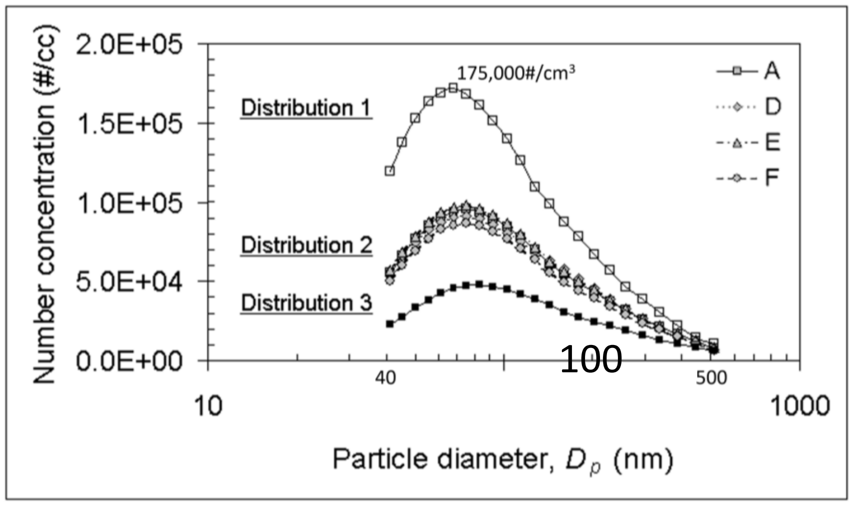
Filtration grade efficiency:

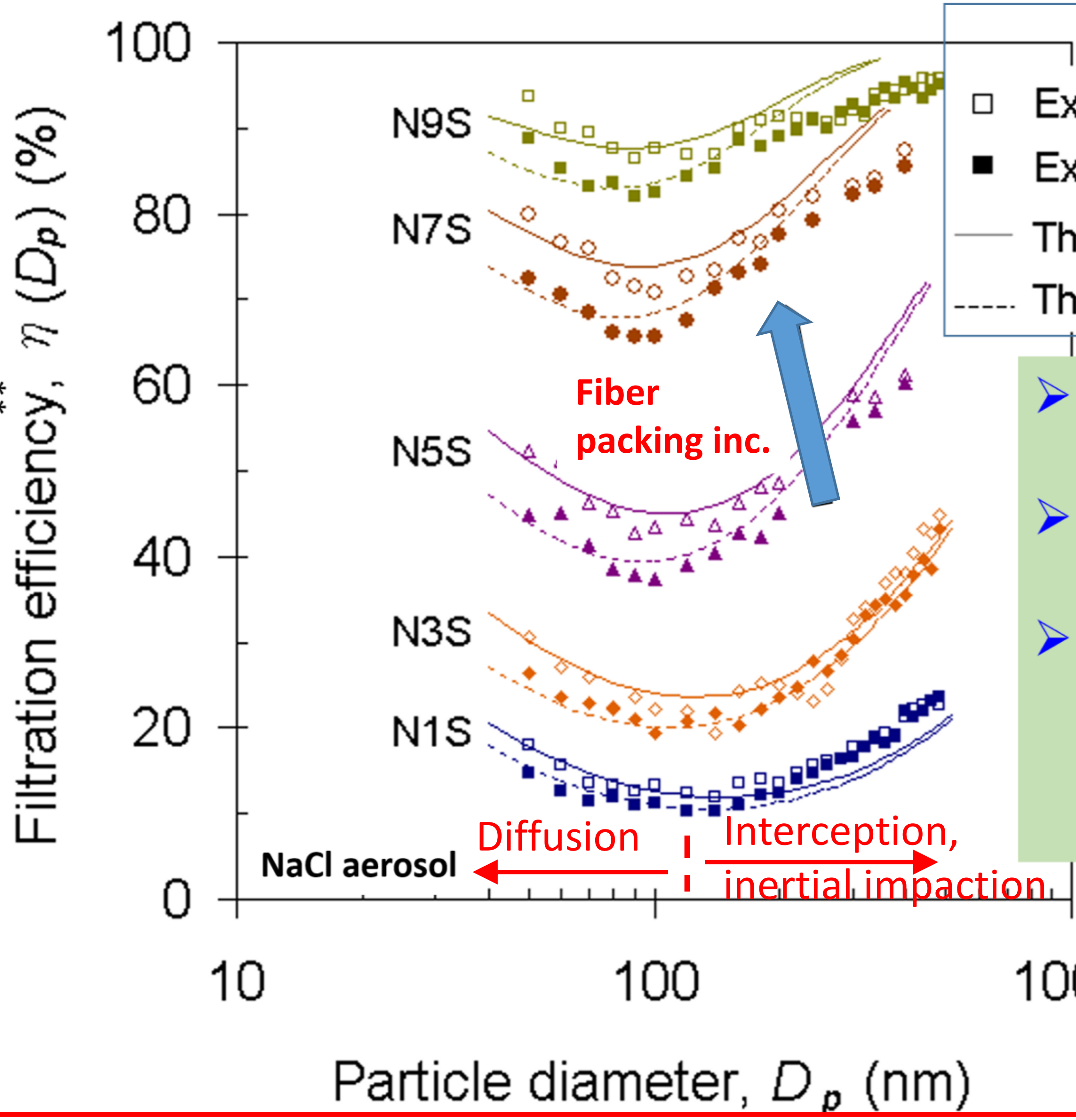
$$\eta = 1 - \frac{c_{out}(d_p)}{c_{in}(d_p)}$$

Quality factor (benefit-to-cost):

$$QF = \frac{-\ln(1 - \eta)}{\Delta p}$$

NaCl aerosols Monodispersed, round shape

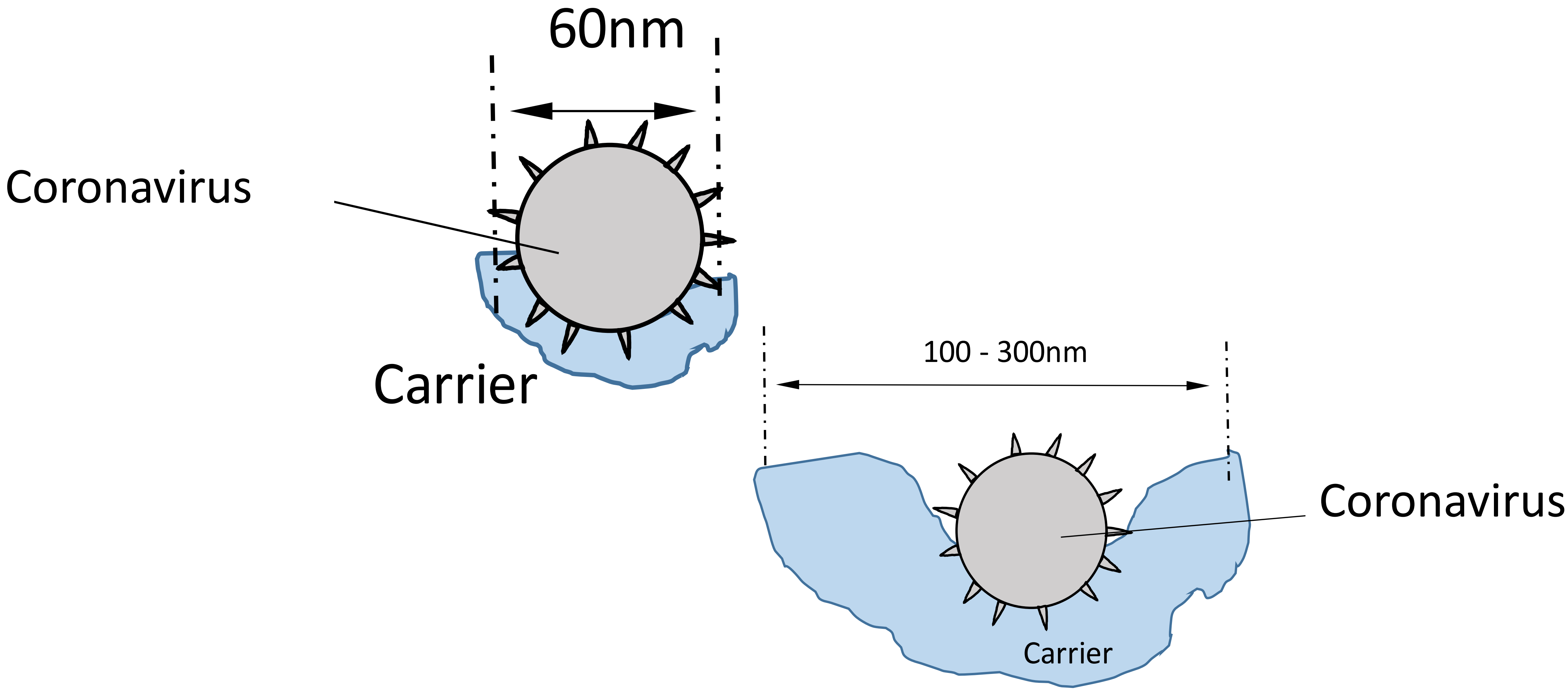




- Increase NF GSM, inc. η
- Decrease face velocity, inc. η
- Expt' agrees theoretical Payet Correlation (solid curves)

Leung et al. Sep. & Purif. Tech (2010) IF=8.6, 359 Citations

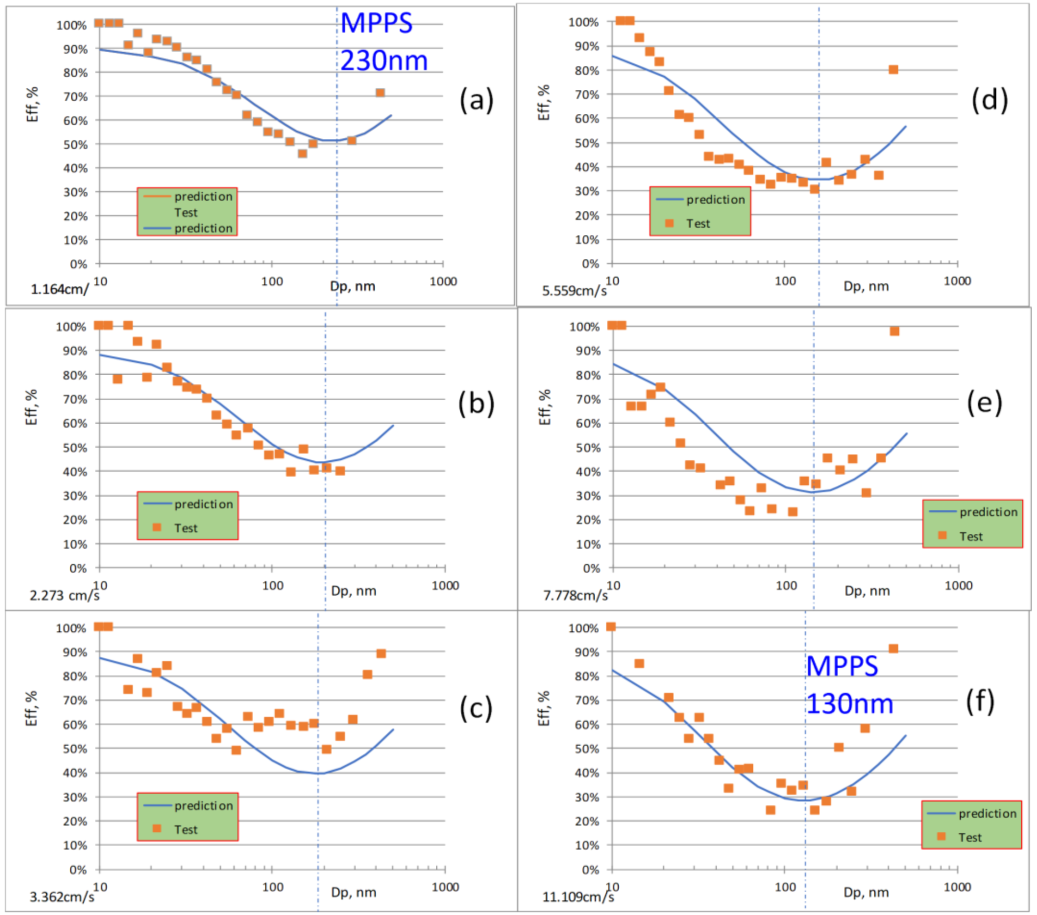
Airborne novel coronavirus (60-140 nm) simulated by ambient aerosols, typically 100 nm



Portable filter tester on Real Aerosols

Real Aerosols* (street level)

U=1.16 → 11.1 cm/s, MPPS=230 →130 nm



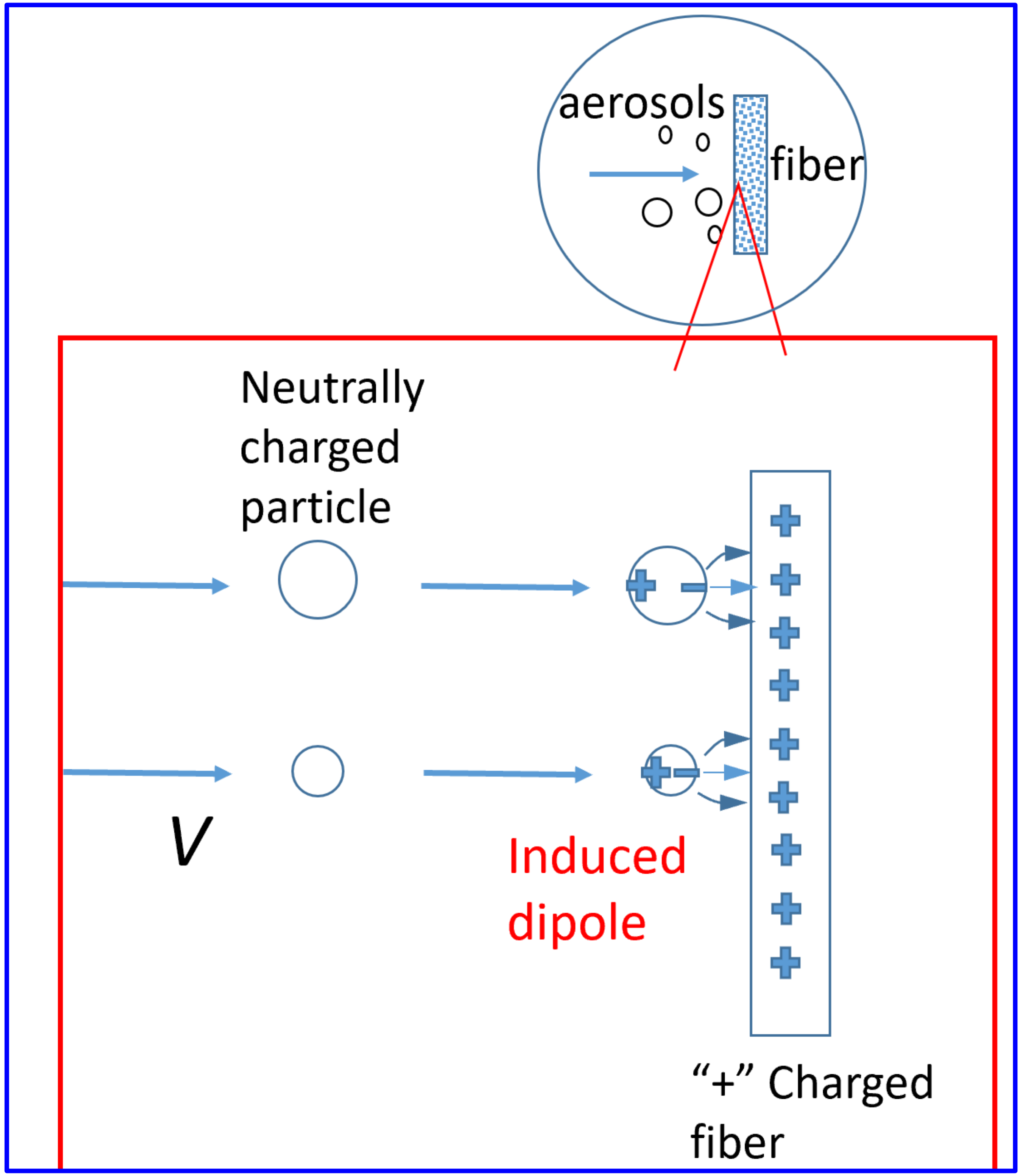
*Fractal shaped

Nanofiber Electret – Electrostatic mechanism

Deficiencies:

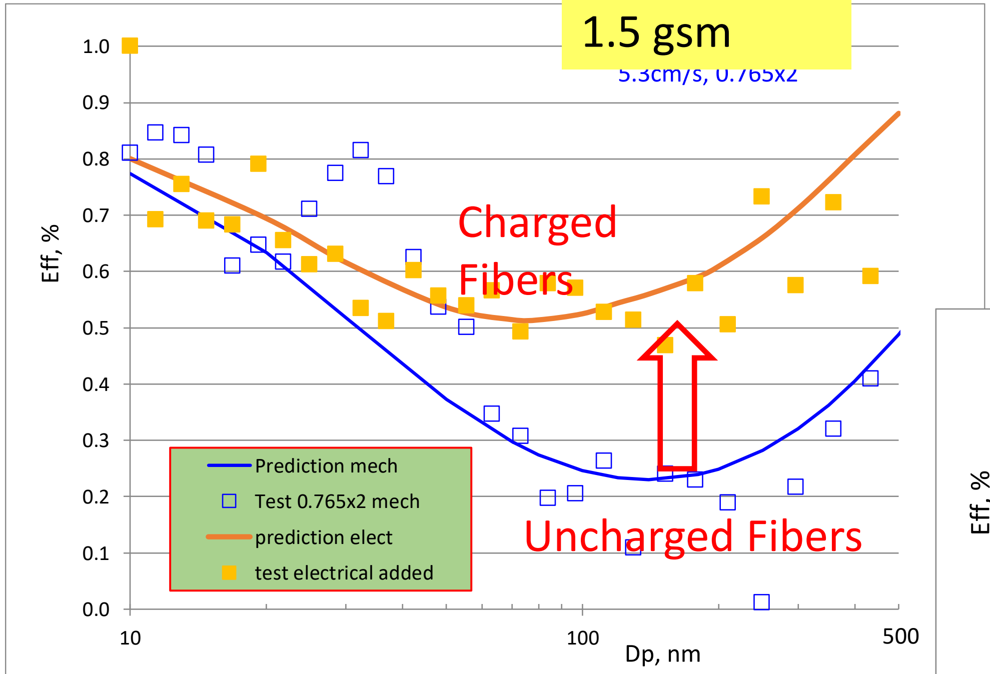
a. Electric field not as strong with large diameter microfibers
b. Charges on charged nanofibers decay rapidly

Sun, Leung, Sep. & Purif. Tech. J. 212 (2019) 854–876

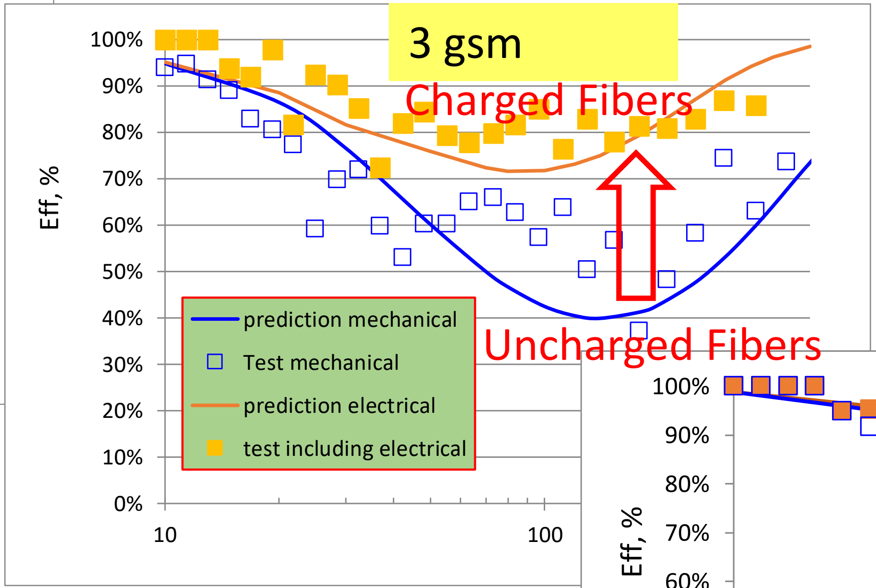


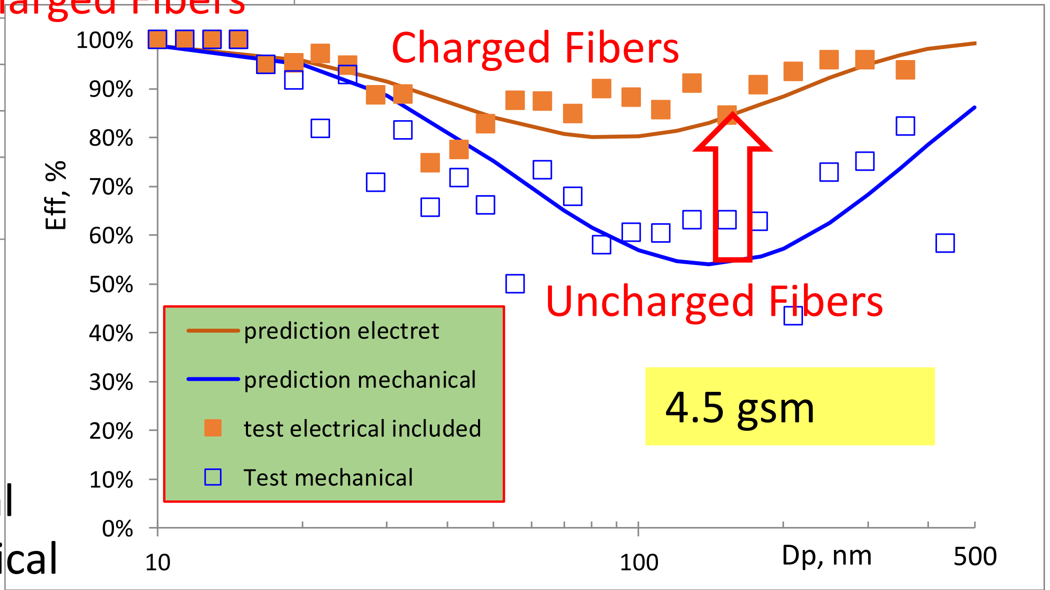
Real Aerosols simulating Airborne SARS virus captured by Charged and Uncharged nanofibers (5.3 cm/s)

Leung and Sun, Sep. & Purif. Tech (2020b) **IF=9.136**, 93 Citations in 2 years



>50% electrical
>25% mechanical



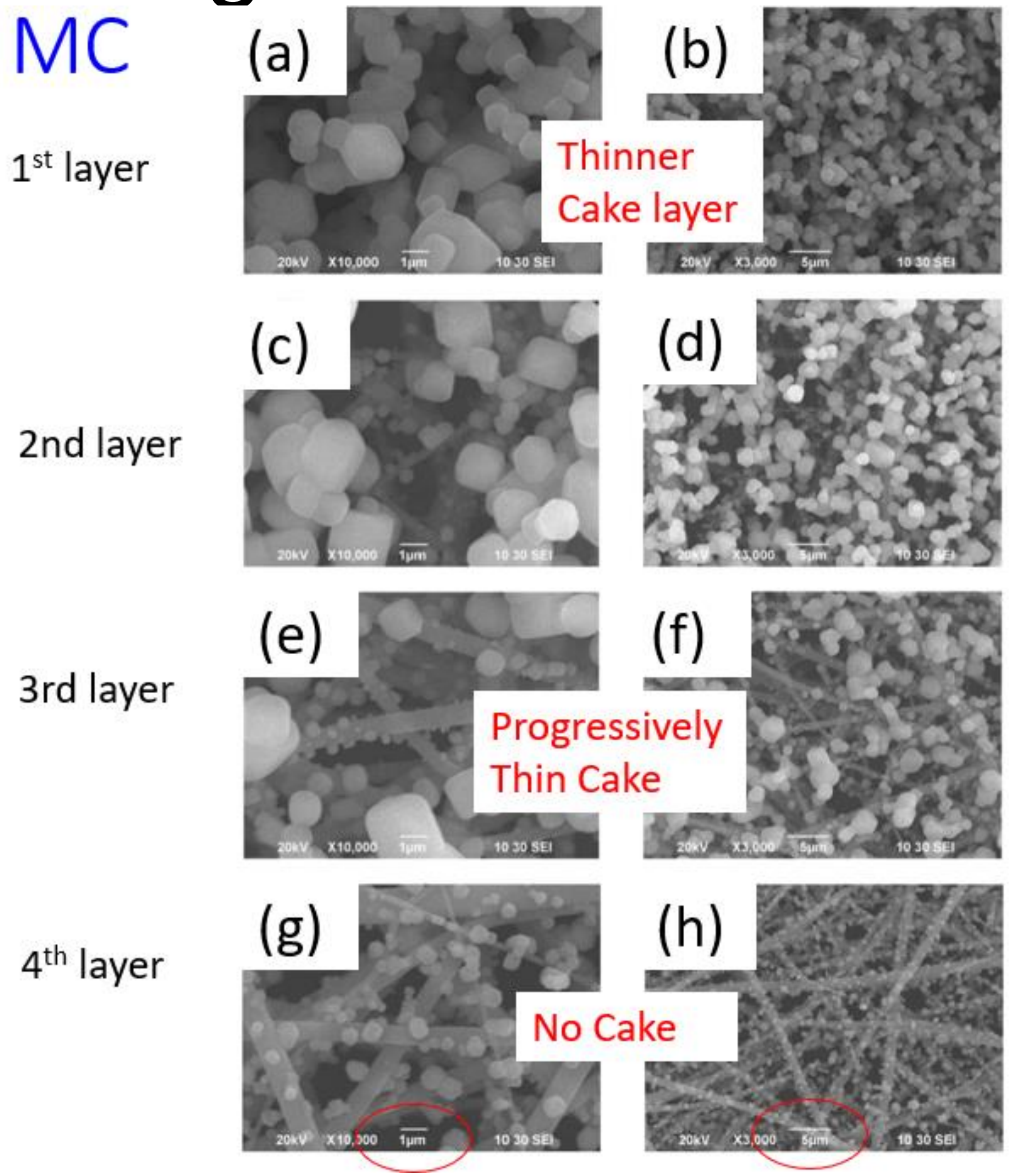


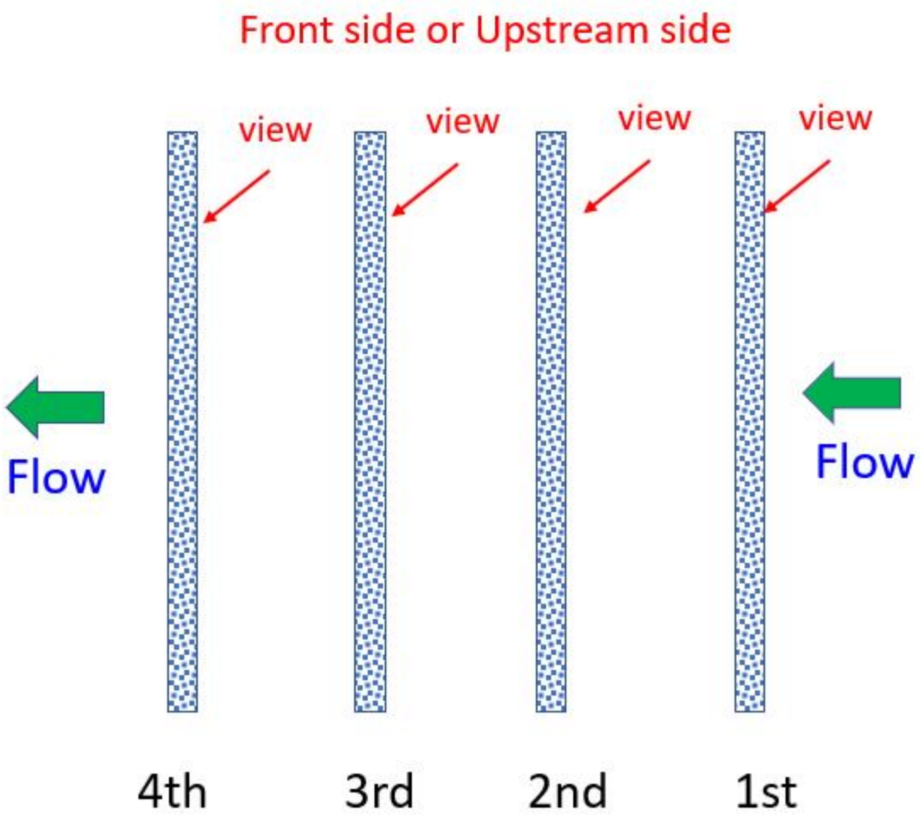
>80% electrical
>50% mechanical

>90% electrical
>65% mechanical

Note: 525 nm nanofiber diameter

SEM images of charged 4-layer filter after aerosol loading as viewed from filter upstream





QF, 1/Pa for average of all test charged nanofiber (CNF) filters

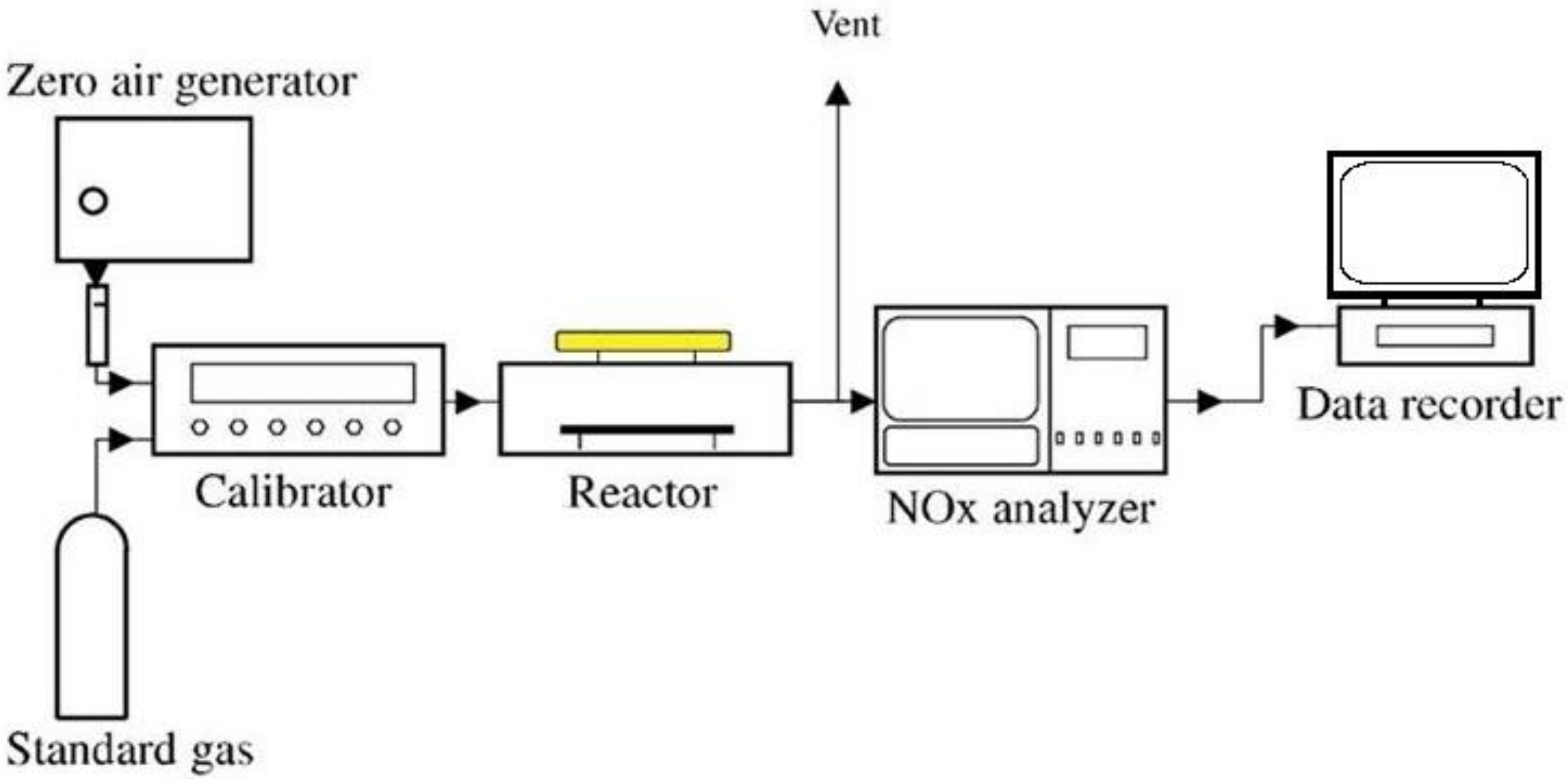
D_p, nm	CNF Batch process	CNF Continuous process	Charged Melt-blown media (3 samples)	CNF Optimized Continuous process
AVG All Sizes	0.26	0.22	0.11	0.38
	1			1.46X
		1		1.73X
			1	3.45X

Charge retention of our Charged PVDF Nanofiber filter

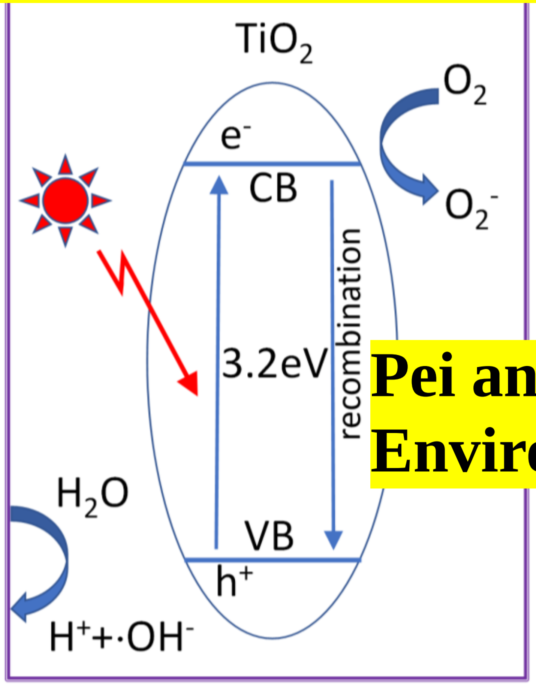
- Filter efficiency @150 nm NaCl aerosols is the same, at 99.62% after 5 month duration

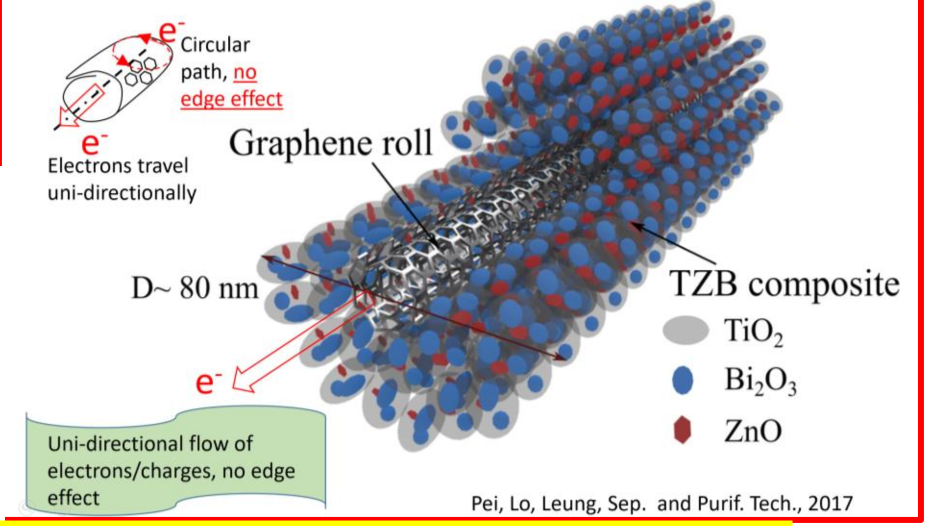
Photodegradation – Gas Purification and Disinfection

Flow through photo-reactor for converting harmful test gas (NOx, Formaldehyde, O-xylene, etc.)

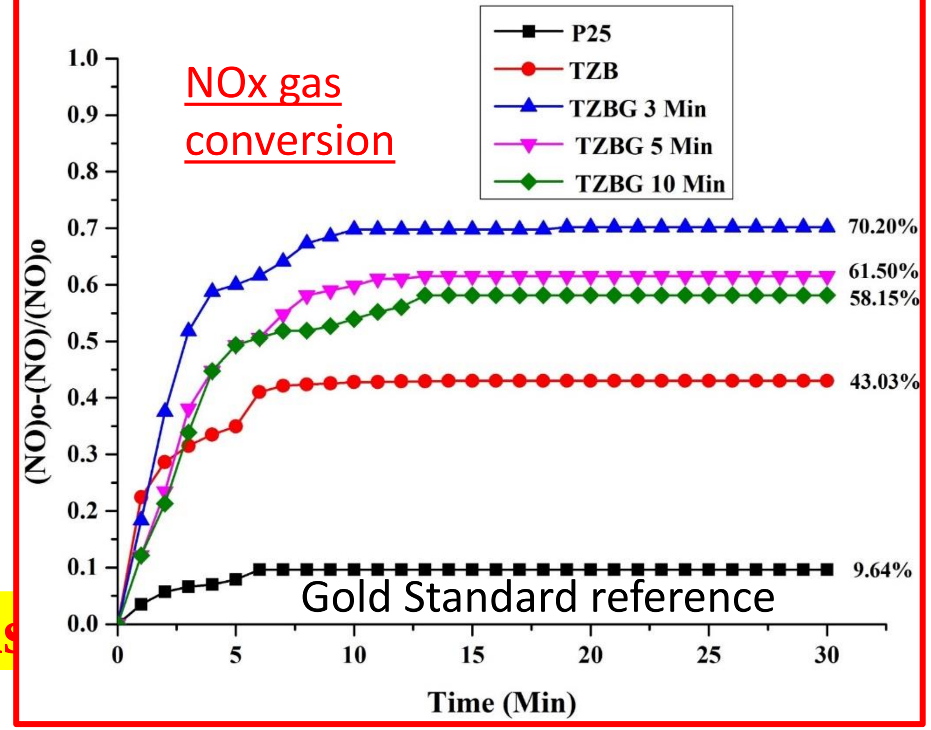


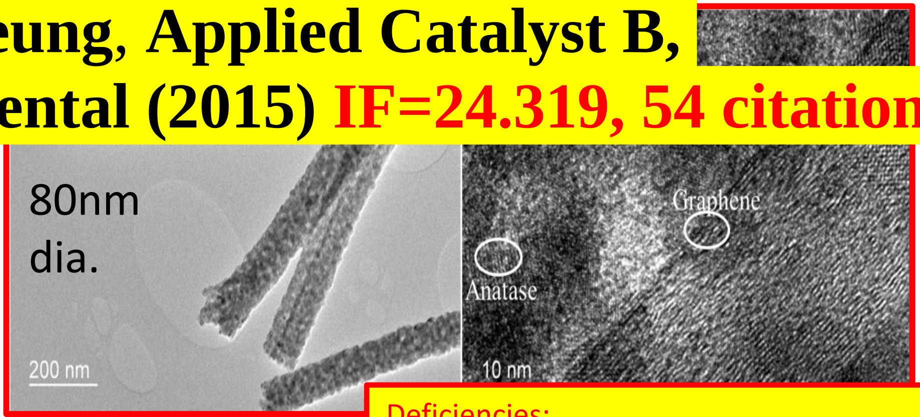
NF Photocatalyst – Purify Air

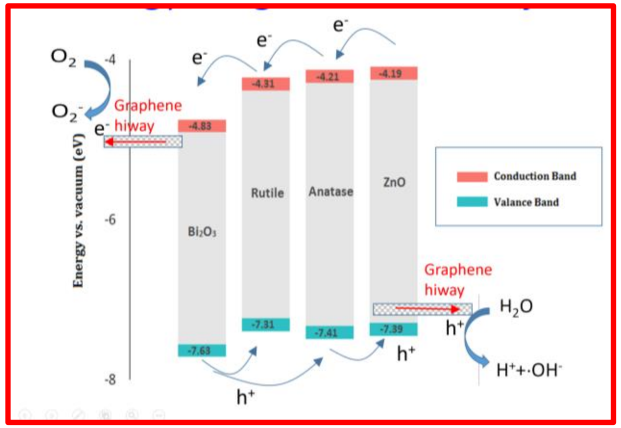




Pei and Leung, Applied Catalyst B, Environmental (2015) IF=24.319, 54 citations

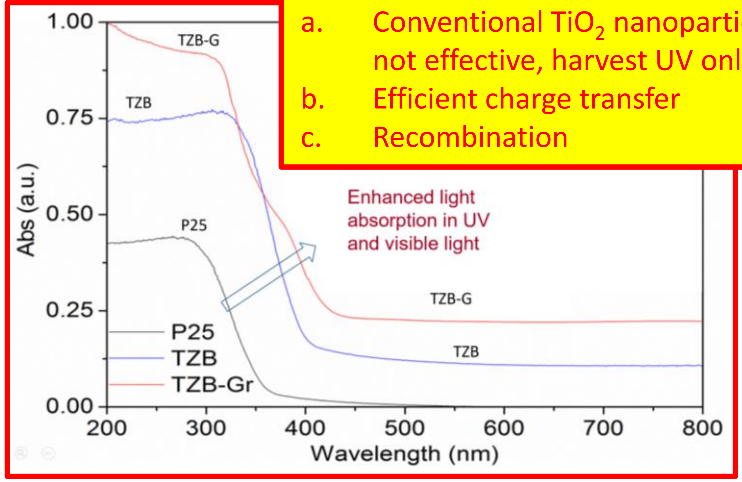


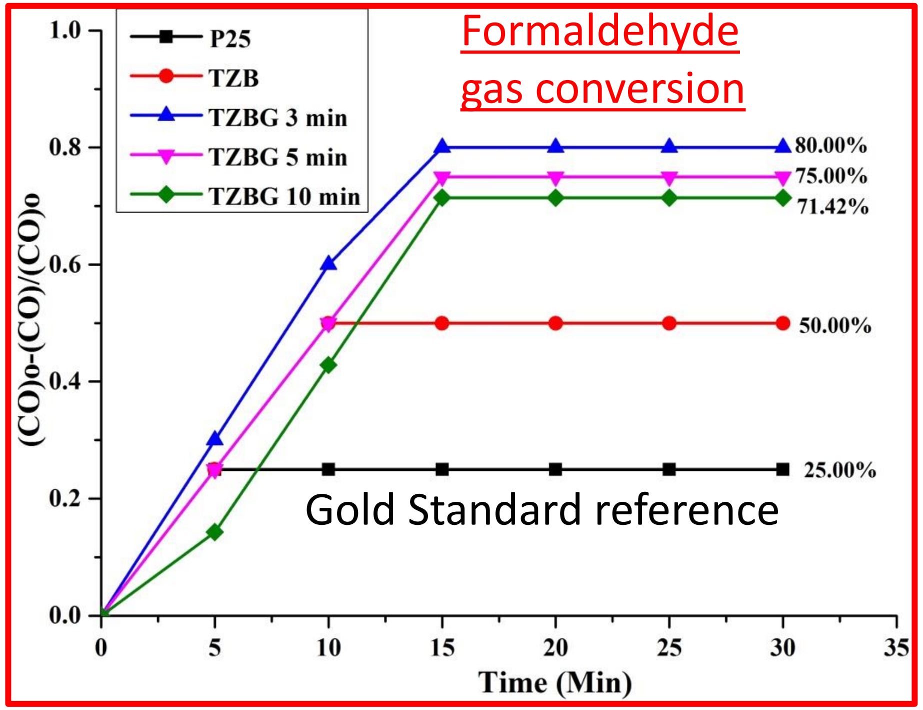




Deficiencies:

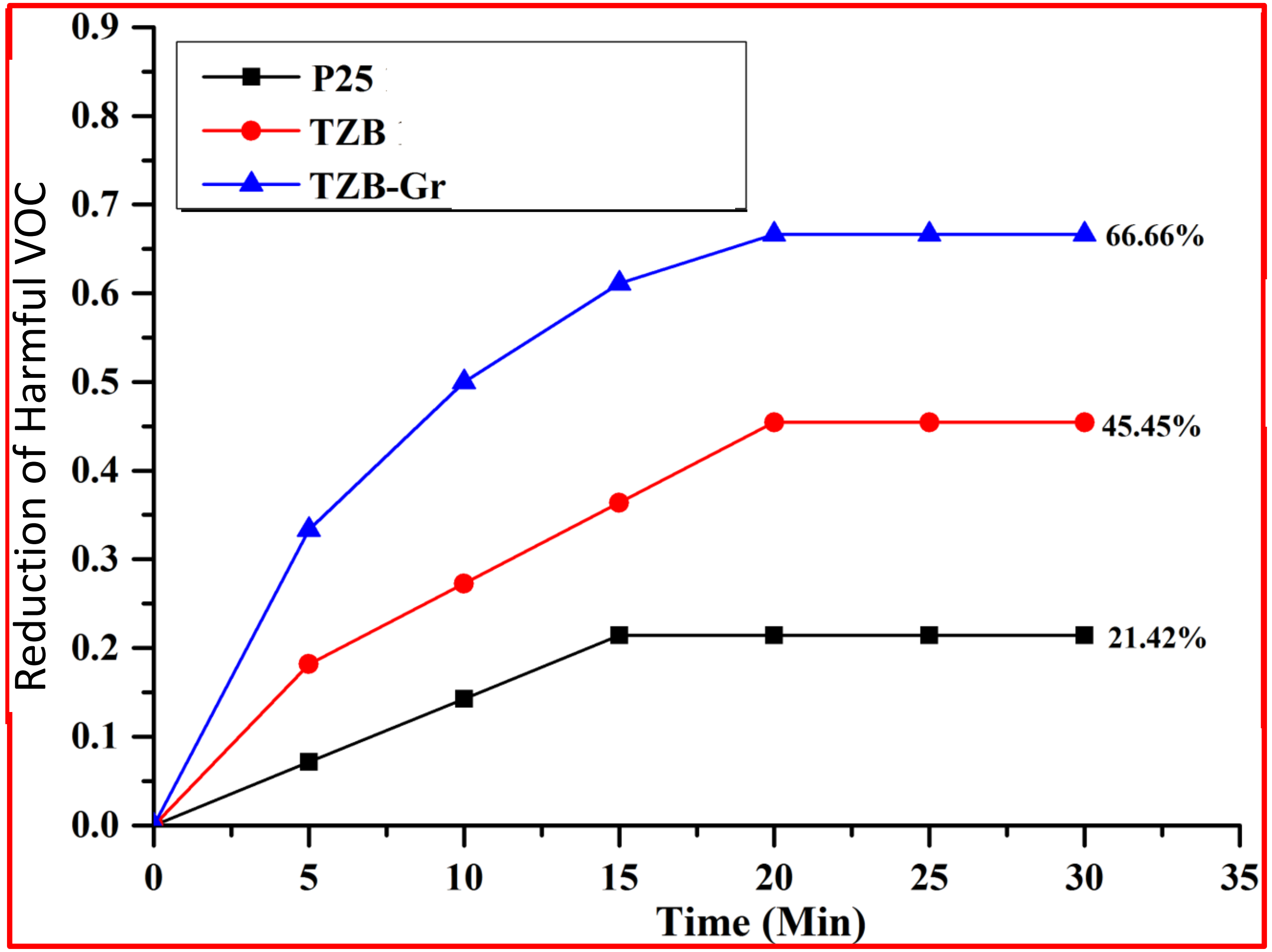
a. Conventional TiO_2 nanoparticles not effective, harvest UV only
b. Efficient charge transfer
c. Recombination





- Leung et al. US patent 2015
- Muzafar & Leung, Ceramics Int., 2019

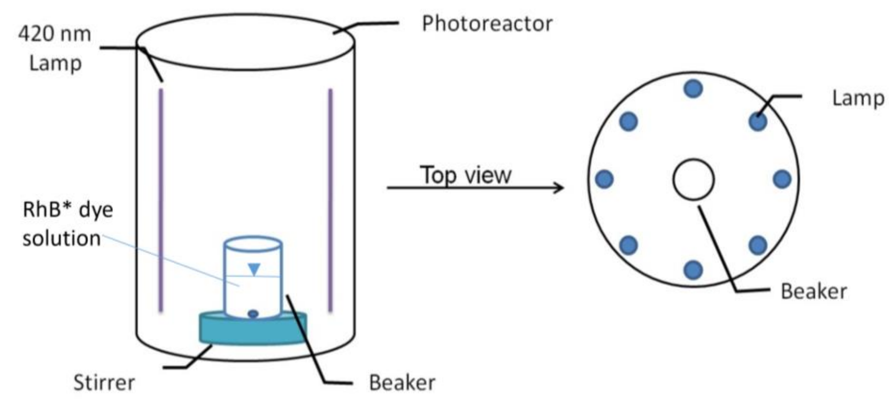
Whitewash - Photocatalyst nanofibers in coating



Water Purification

NF Photocatalyst – Water Purification (breaking dissolved organics, dye herbicides, pesticides etc.)

Batch Photo-reactor for Photocatalyst tests on Dye Solution

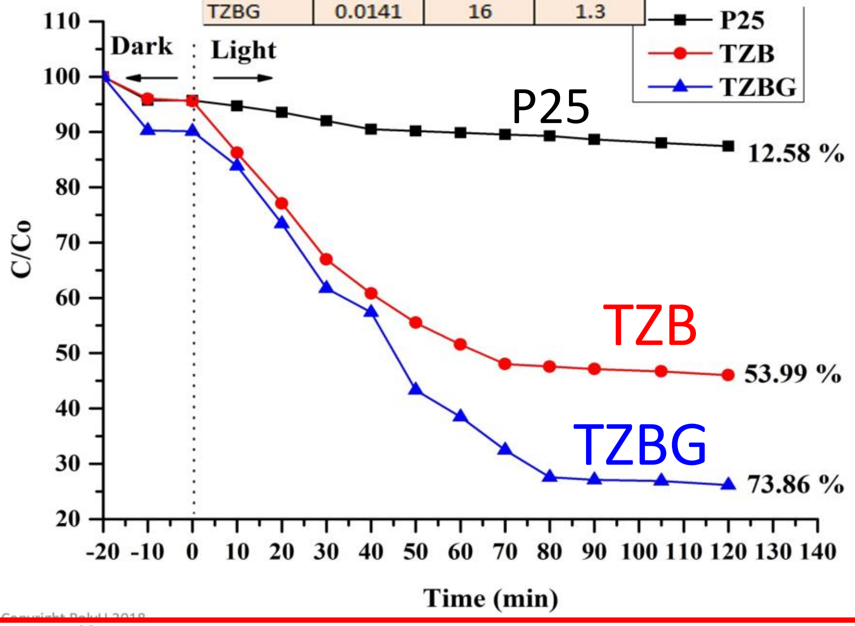


*Rhodamine B

Free/loose Catalyst (need to be recovered by centrifugation after purification)

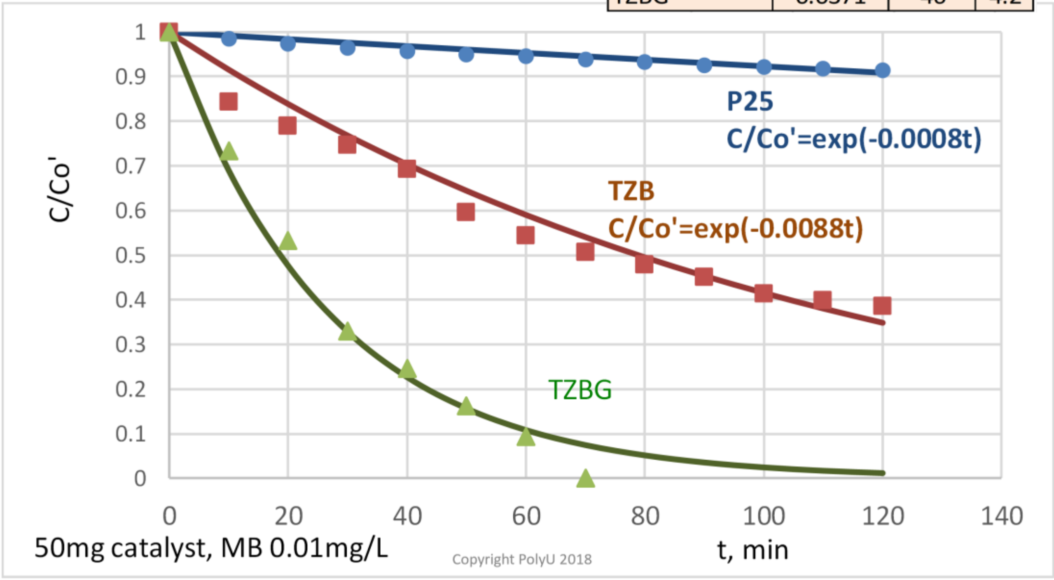
Rhodamine B

PhotoCata	k, min^{-1}	Factor	
P25	0.0009	1	/
TZB	0.0105	11.66667	1
TZBG	0.0141	16	1.3



Methylene Blue

PhotoCatalyst	k, min^{-1}	Factor	
P25	0.0008	1	/
TZB	0.0088	11	1
TZBG	0.0371	46	4.2



Conclusions

AIR FILTER

- **High efficiency, pressure drop and Capacity**
- **Multilayer NF arrangement** provides high filtration efficiency and minimal pressure drop
- **Electret filter (large-scale production)** developed for both light and heavy aerosol loading (high capacity). Filter fully utilized for aerosol loading on every fiber 360 degrees and entire filter from upstream to downstream fully utilized.

AIR/WATER PURIFICATION

- Novel NF photocatalyst solve common problem with current photocatalyst in (i) **harvesting visible light** and (ii) **reducing recombination** by **hierarchy structure** and (iii) **improving charge transport** via **1D NF** and **highly conductive graphene in NF**.
- **TZBG provides fast degradation/conversion better than gold standard** 25nm TiO_2 on **NOx (outdoors)** and **formaldehyde (indoor VOC) in air**; and dissolved organics (**Methylene Blue and Rhodamine) in water**.
- **Embedding nanofibers in coating (Whitewash)** provide effective **indoors/outdoors use, and reuse without losing/replenishing fibers**.

New Application Prospects

- Developed *optimized* PVDF *charged nanofibers*. Fiber mat highly permeable with well controlled fiber packing density
  - Large-scale roll-to-roll production demonstrated, life time at least 5 months
  - Filters with low power consumption, disinfectant filter, breathable respirators (N95, N99) and facemask
  - Transdermal drug delivery*
  - Protein transfer in 2D gel analysis*
  - Others
- Developed a new material that has both semiconductor properties (TiO_2, ….) and highly conductive ***graphene inside*** that can be used for
  - Solar Cells
  - Photocatalyst
  - Sensors*
  - Battery*
  - Others

*Note: to be explored

New book 570 pages, 317 figures, 47 tables, Elsevier, 1st ed., 2021, included in WHO literature on Coronavirus

World Health Organization

COVID-19
Global literature on coronavirus disease

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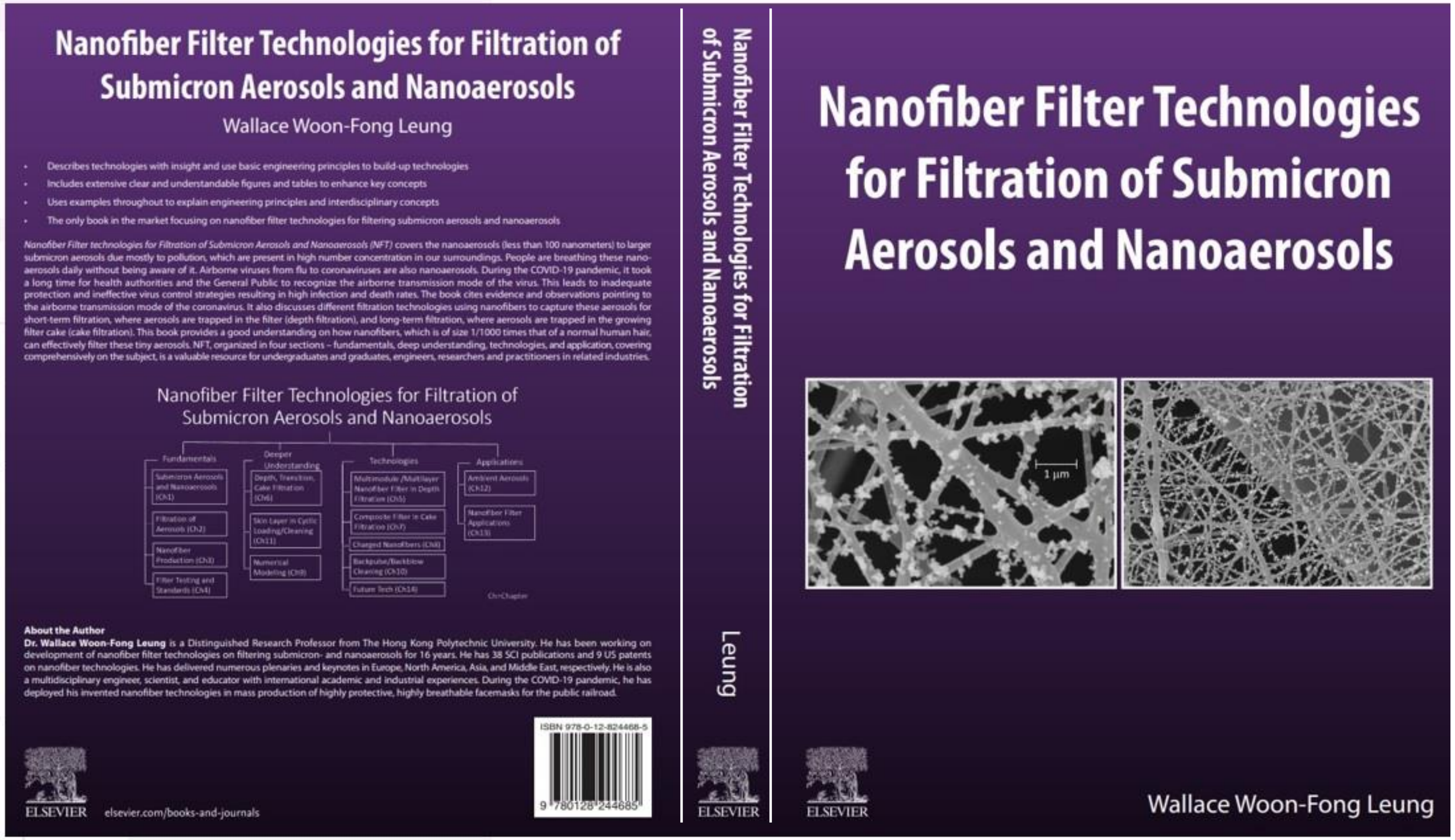
Chapter one - Introduction to submicron aerosols and nanoaerosols
Woon-Fong Leung, Wallace.
Nanofiber Filter Technologies for Filtration of Submicron Aerosols and Nanoaerosols ; : 1-44, 2022.
Article in English | ScienceDirect | ID: covidwho-1499569

ABSTRACT

Aerosols are fine particles of liquid and/or solid, which are airborne. Aerosols can settle in reasonable distance when they are over 10µm. For aerosols less than 10µm, they take progressively longer time for the aerosol to settle. For aerosols less than 5 µm, they are practically unsettleable. For aerosols less than 1µm (i.e., submicron aerosols), they practically stay airborne indefinitely, and people can easily inhale these submicron aerosols through the respiratory system. By virtue of their small size, they can pass to the vascular circulation to different organs causing potential chronic and acute diseases. This is even more so for nanoaerosols (NAs), less than 100nm. Unfortunately, we are surrounded by submicron aerosols and nanoaerosols in our daily environment. In indoors, a common source of these tiny aerosols can be found in cooking simple breakfast, such as toasting bread, to more sophisticated broiling and frying. Tobacco smoking, burning candles and incense, using cleaning detergents, and wearing perspiration suppresser can release these tiny aerosols in the air. In outdoors, these aerosols can be present in high concentrations from emissions of road traffic, power plants, biomass plants, and commercial kitchen exhaust to incineration plants. Not only these submicron aerosols and nanoaerosols might have harmful chemical ingredients but they can also carry viruses and tiny bacteria. The severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) virus and its variants (such as Delta variant which are highly contagious and infectious) are good examples showing wide-spread human-to-human infection as a result of airborne transmission of the virus. Unfortunately, this aspect has escaped attention by the public authorities in early part of the coronavirus (COVID-19) pandemic and even to some extent as of today. In environment with low relative humidity, the liquid content from droplet aerosol can




Thank God
For Clean
Environment You
have Provided
Thank you all for listening!