

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

Novel Nanofiber Technologies  
for Environmental Applications

**Prof. Wallace Leung, ScD (MIT)**

# Contents

## Nanofiber + Production

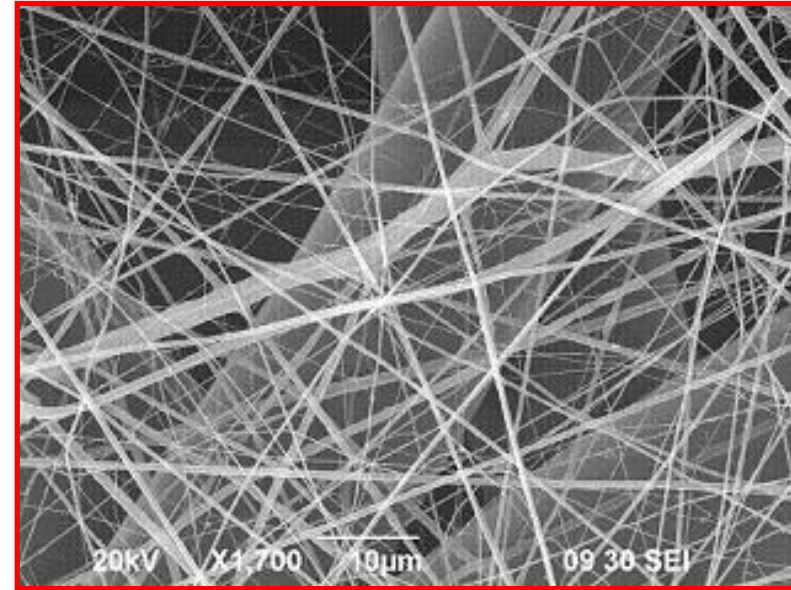
- Nanofibers
- Needle and Needle-less production

## Environment

- (a) Aerosols Removal
- (b) Removal of Harmful Gas in Air
- (c) Removal of Harmful Organics in Water

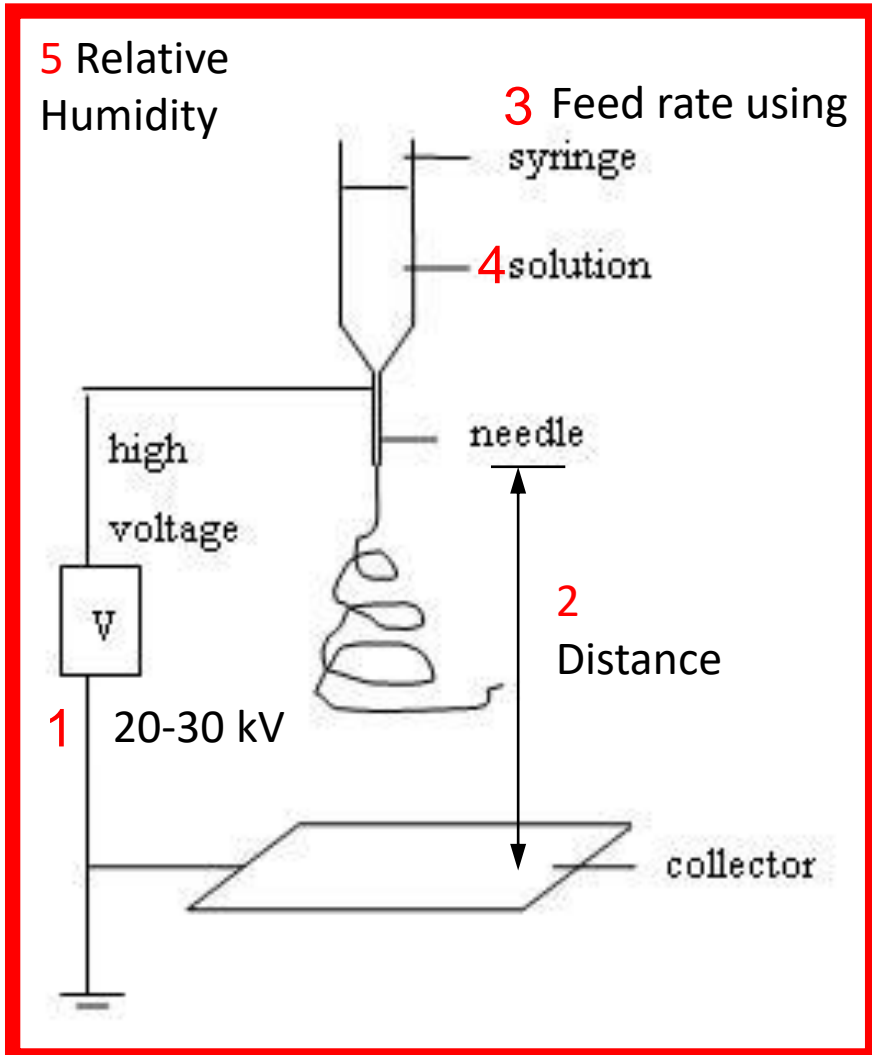
# Nanofibers

- Fiber diameter less than  $1\ \mu\text{m}$  (1000 nm)
- Length  $\geq \mu\text{m}$
- Materials:
  - Organic
  - Inorganic
  - Natural materials
- **Applications –Environment, Energy, Health, Sensing, etc.**

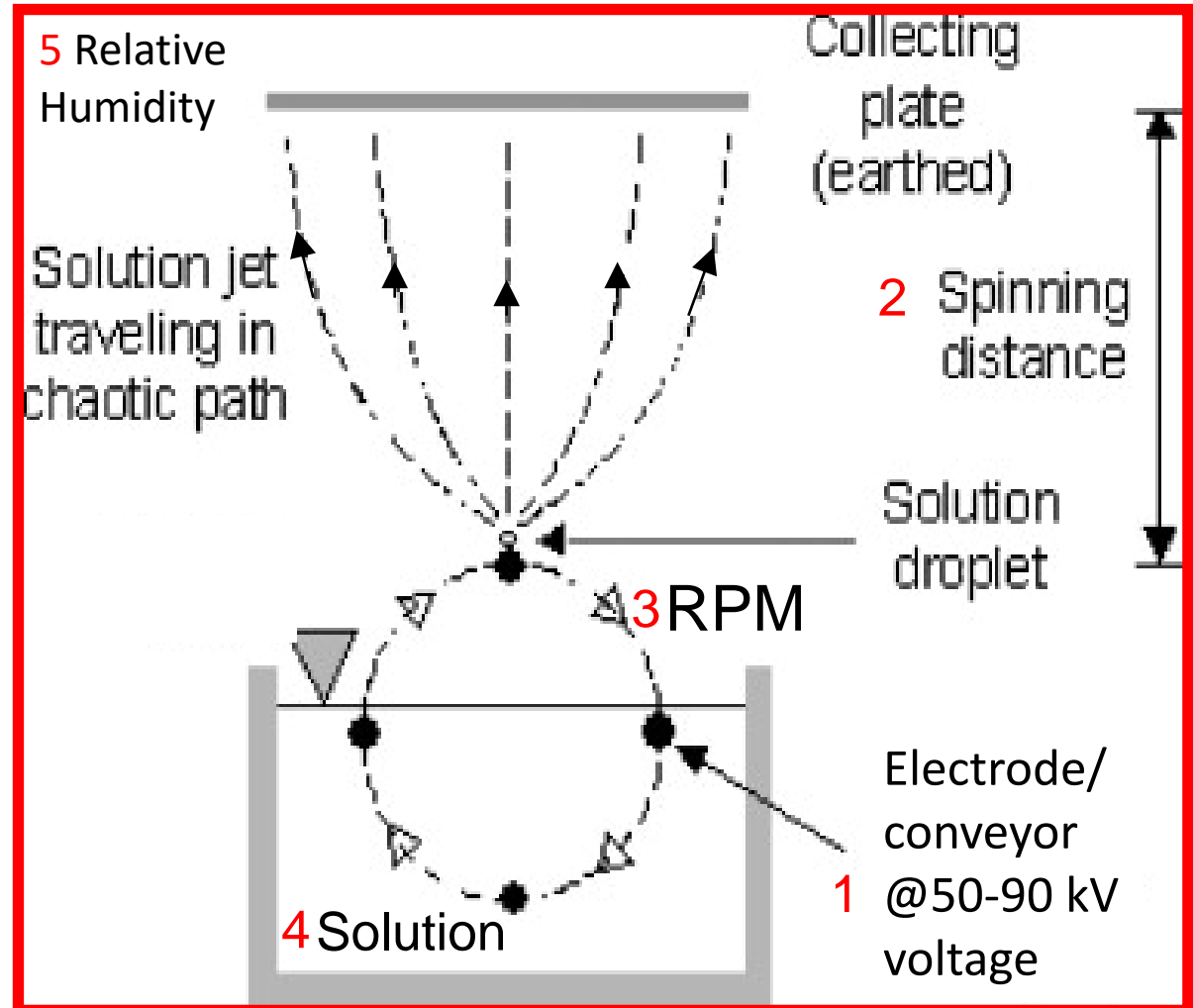


# Solution Electrospinning

## 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 ( $\leq 100$  nm, i.e. PM0.1)
- Harmful gases

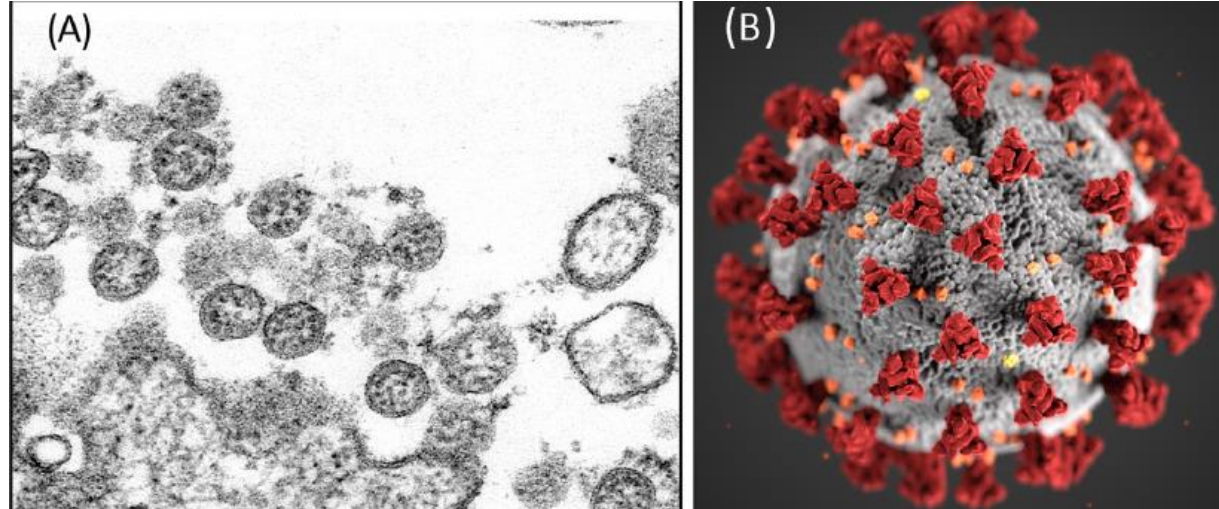
PM2.5=270 $\mu\text{g}/\text{m}^3$  (10X WHO concentration limit\*)

\*Note: World Health Organization Standard PM2.5, 25  $\mu\text{g}/\text{m}^3$



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

Courtesy of CDC

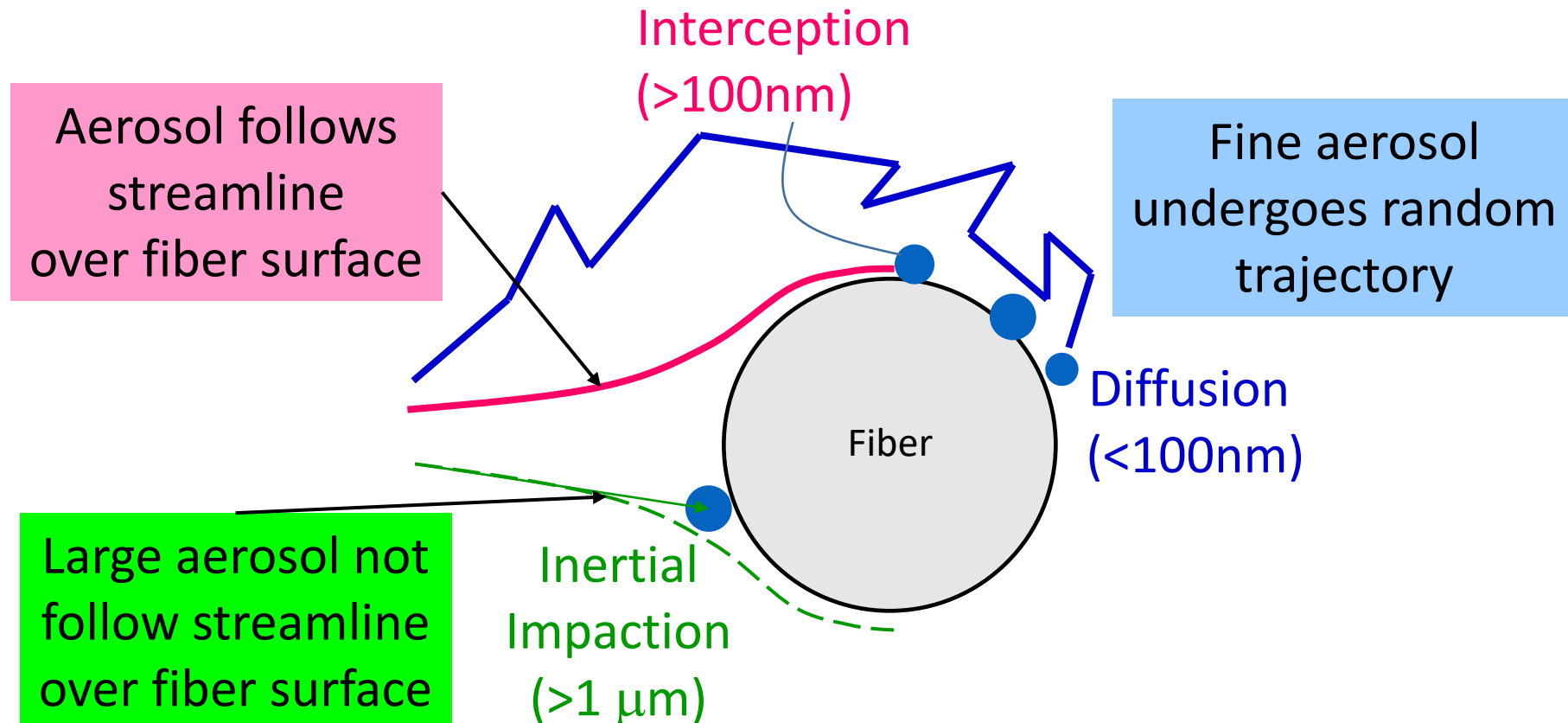


**SARS-CoV-2 virus  
60-140nm**

**Viruses same size range as pollutants!!**

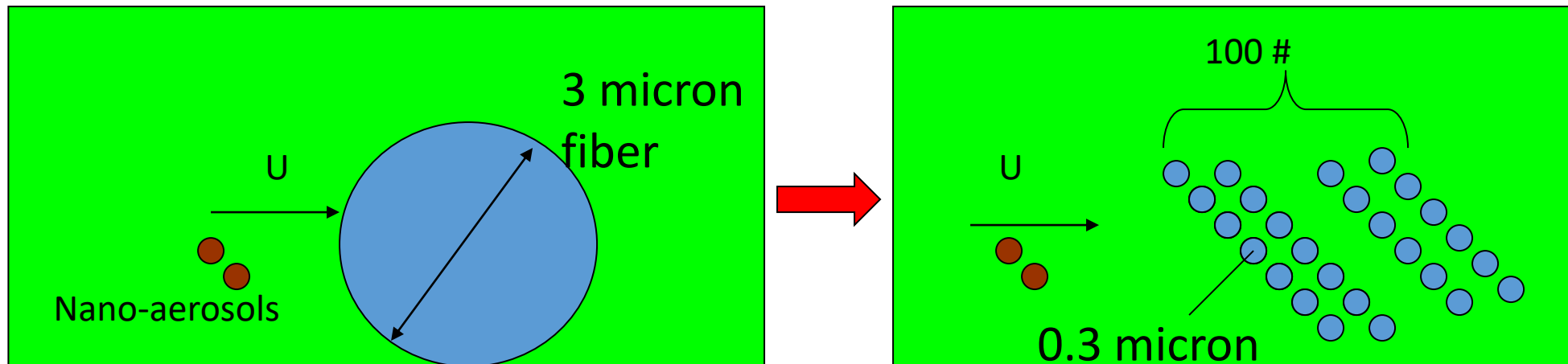
# Filtration - Mechanical Capture

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



# Increase fiber number & area with nanofibers

- 3- $\mu\text{m}$  microfiber  $\Rightarrow$  reduced diameter to 0.3- $\mu\text{m}$  nanofiber  $\Rightarrow$  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  $\Delta p$  (see solution later)

# Grade Efficiency and Quality Factor

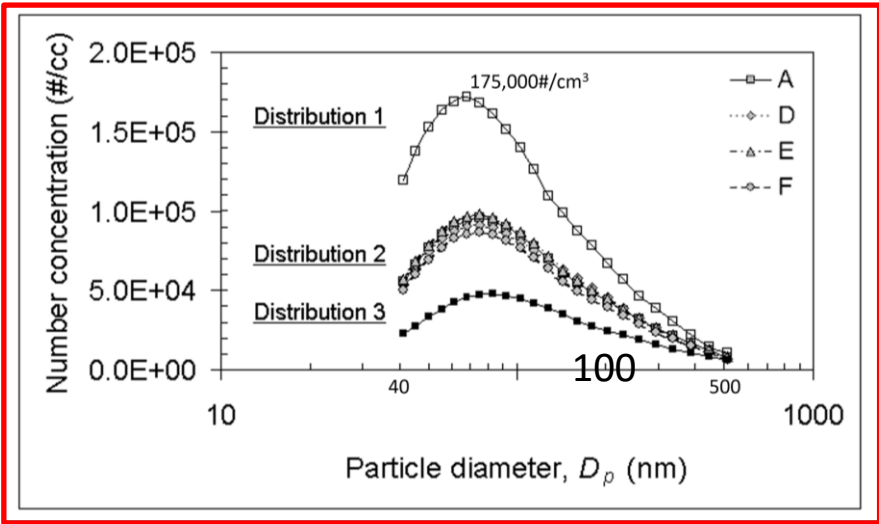
Filtration grade  
efficiency:

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

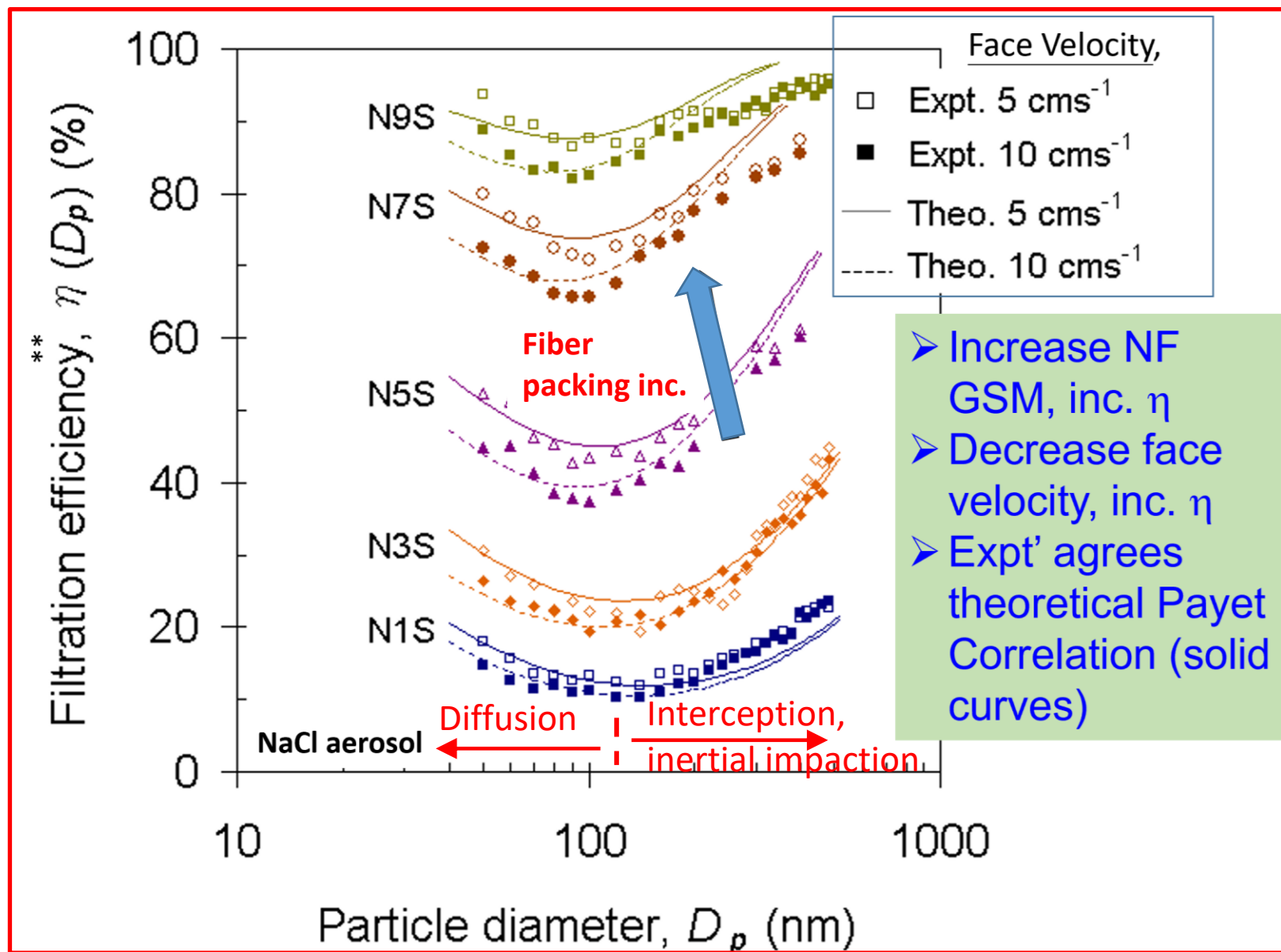
Quality factor  
(benefit-to-cost):

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

# NaCl aerosols Monodispersed, round shape

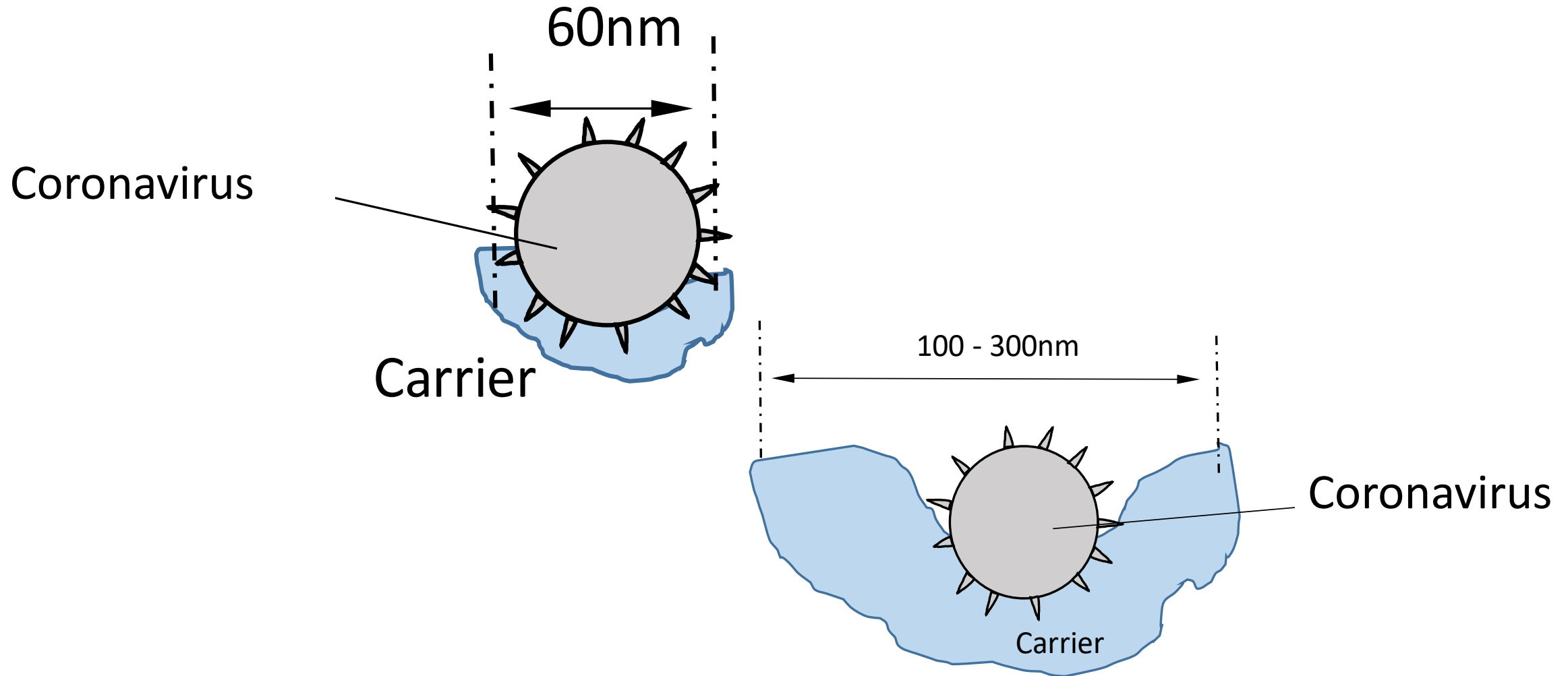


Leung et al. Sep. & Purif. Tech (2010)  
IF=8.6, 359 Citations



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

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

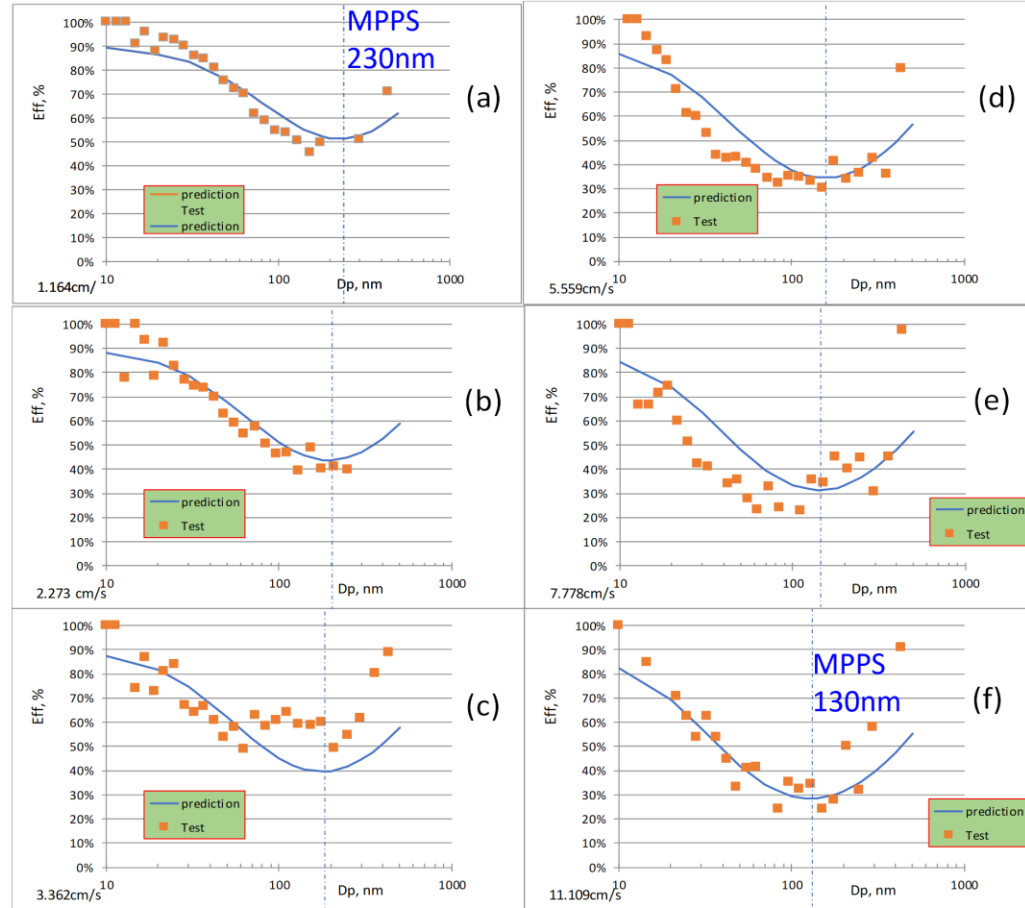


# Portable filter tester on Real Aerosols

Real  
Aerosols\*  
(street level)

$U=1.16 \rightarrow$   
11.1 cm/s,  
MPPS=230  
 $\rightarrow$ 130 nm

\*Fractal shaped

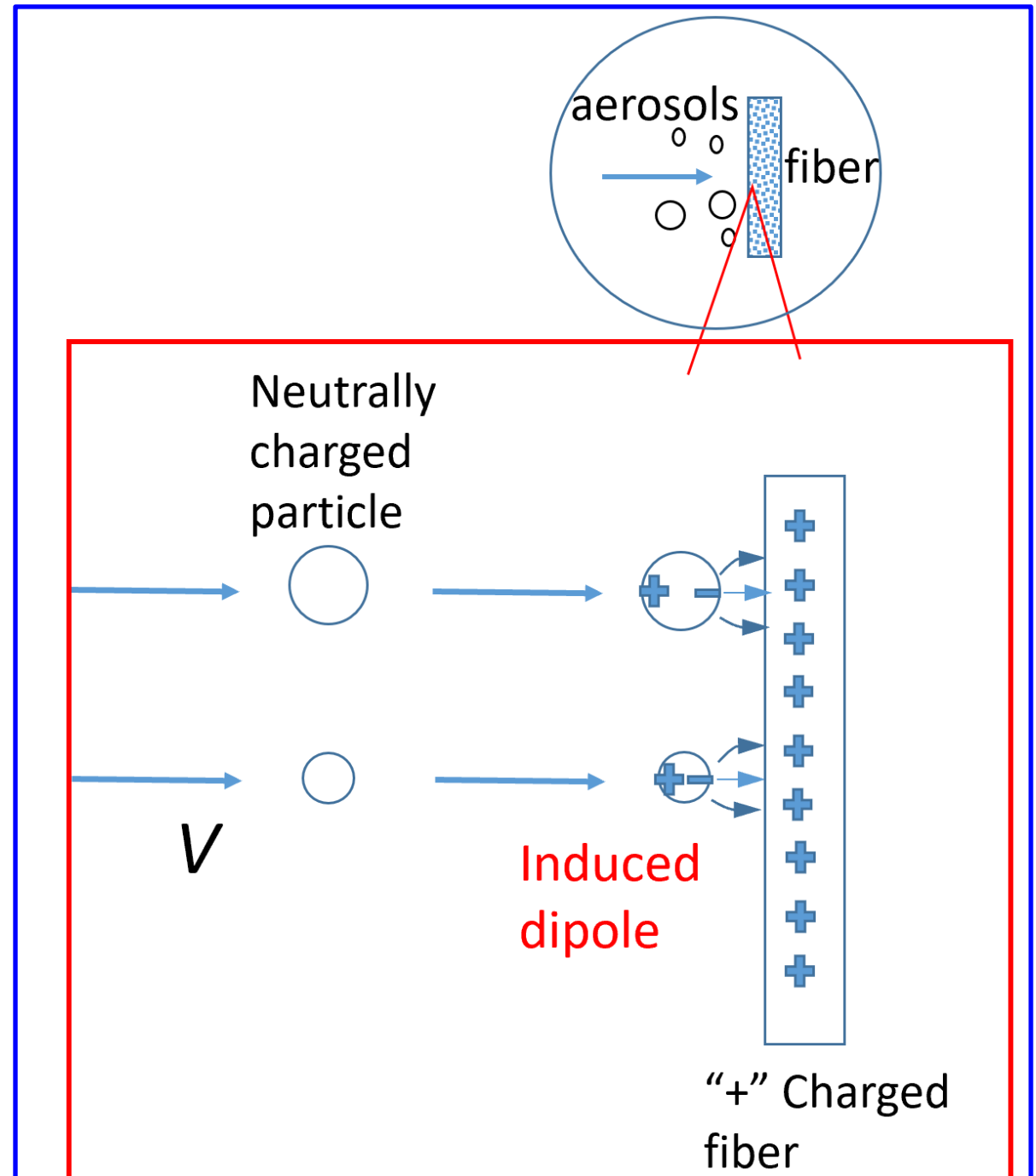


# Nanofiber Electret – Electrostatic mechanism

## Deficiencies:

- Electric field not as strong with large diameter microfibers
- Charges on charged nanofibers decay rapidly

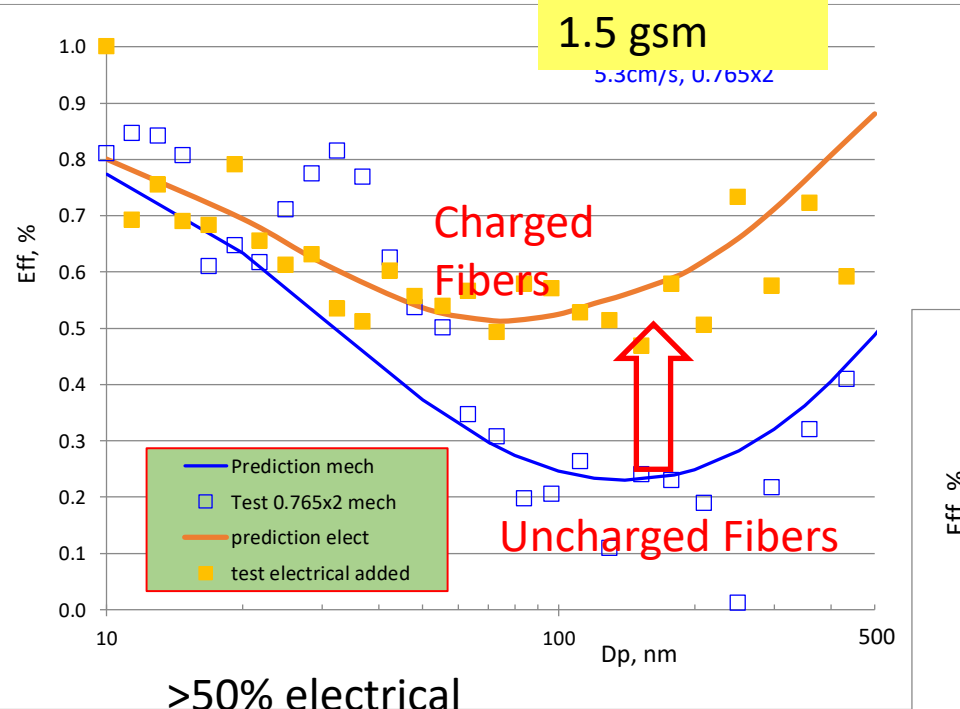
Sun, Leung, Sep. &  
Purif. Tech. J. 212  
(2019) 854–876



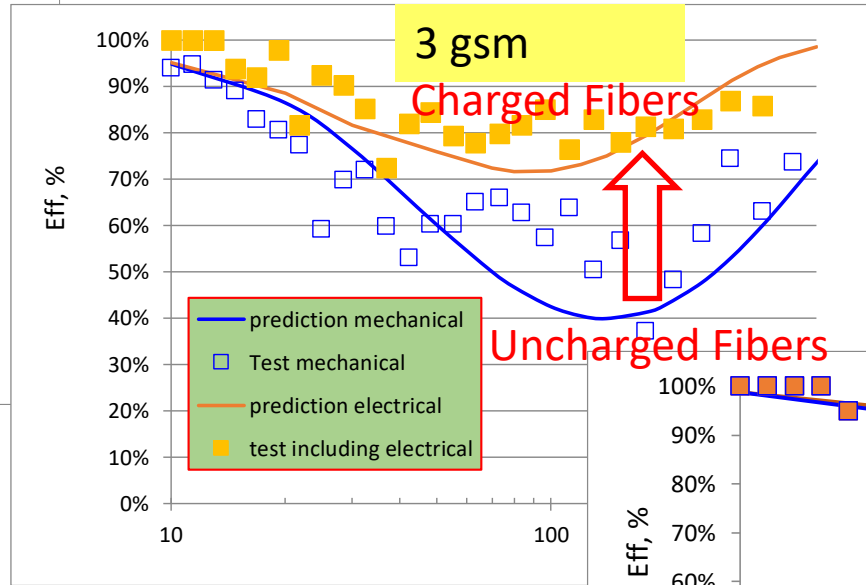


# Real Aerosols simulating Airborne SARS virus captured by Charged and Uncharged nanofibers (5.3 cm/s)

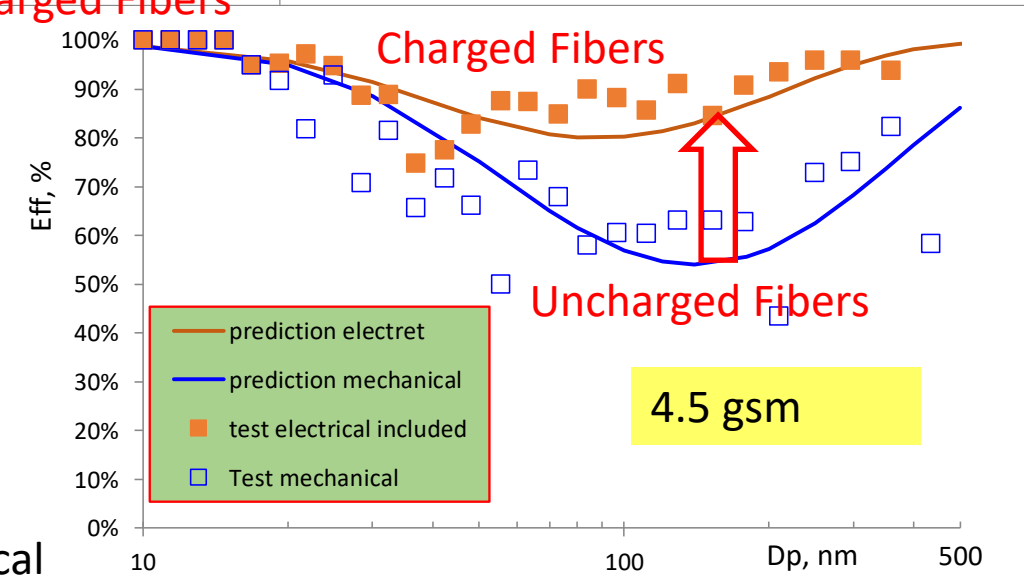
Leung and Sun, Sep. & Purif. Tech (2020b) **IF=9.136**,  
93 Citations in 2 years



>50% electrical  
>25% mechanical



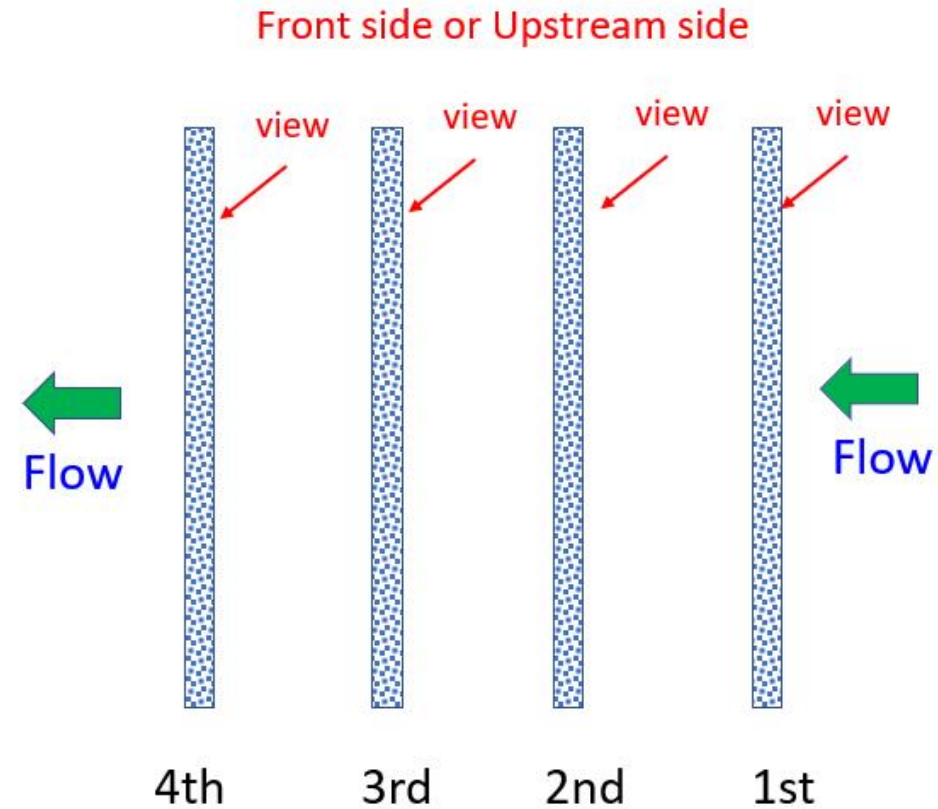
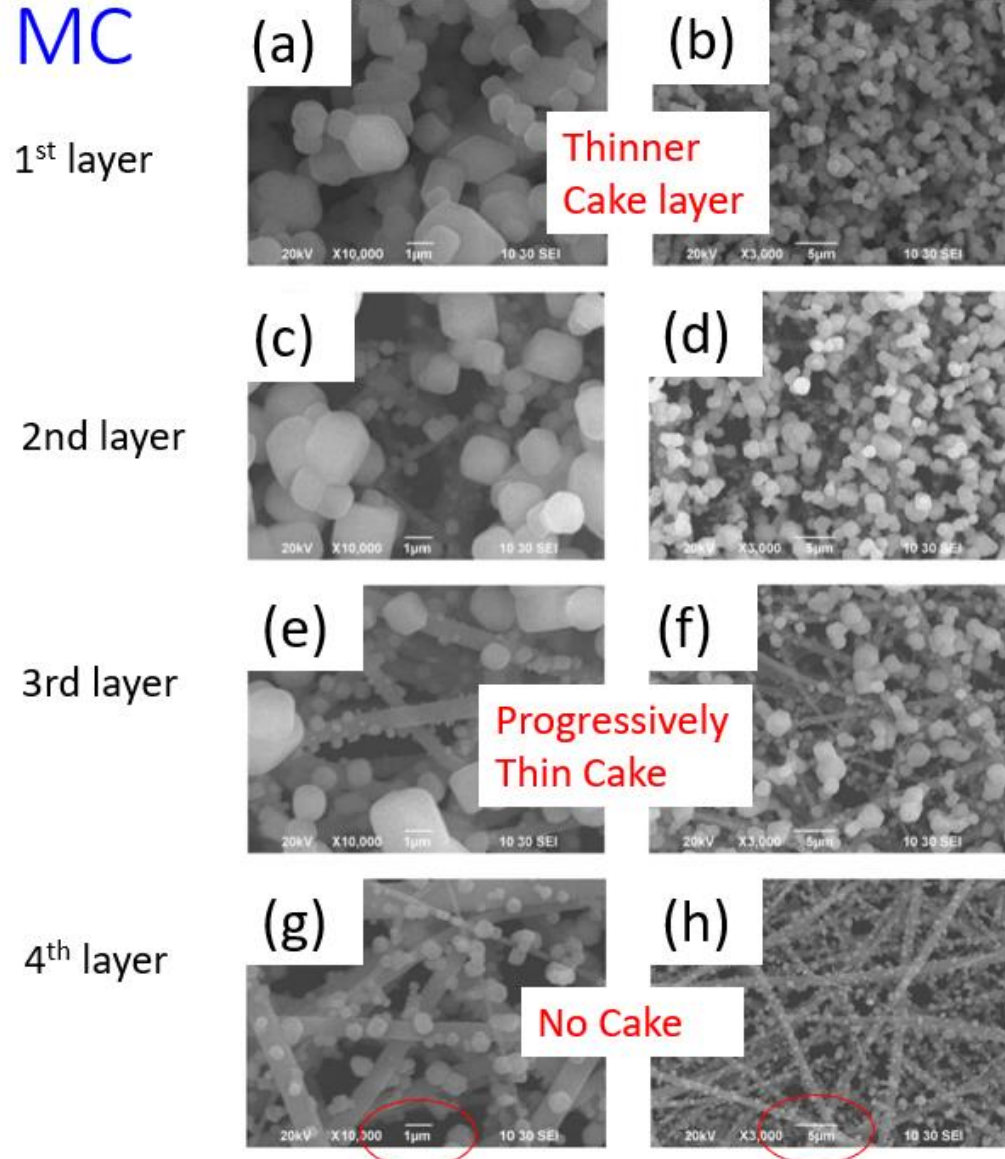
>80% electrical  
>50% mechanical



>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

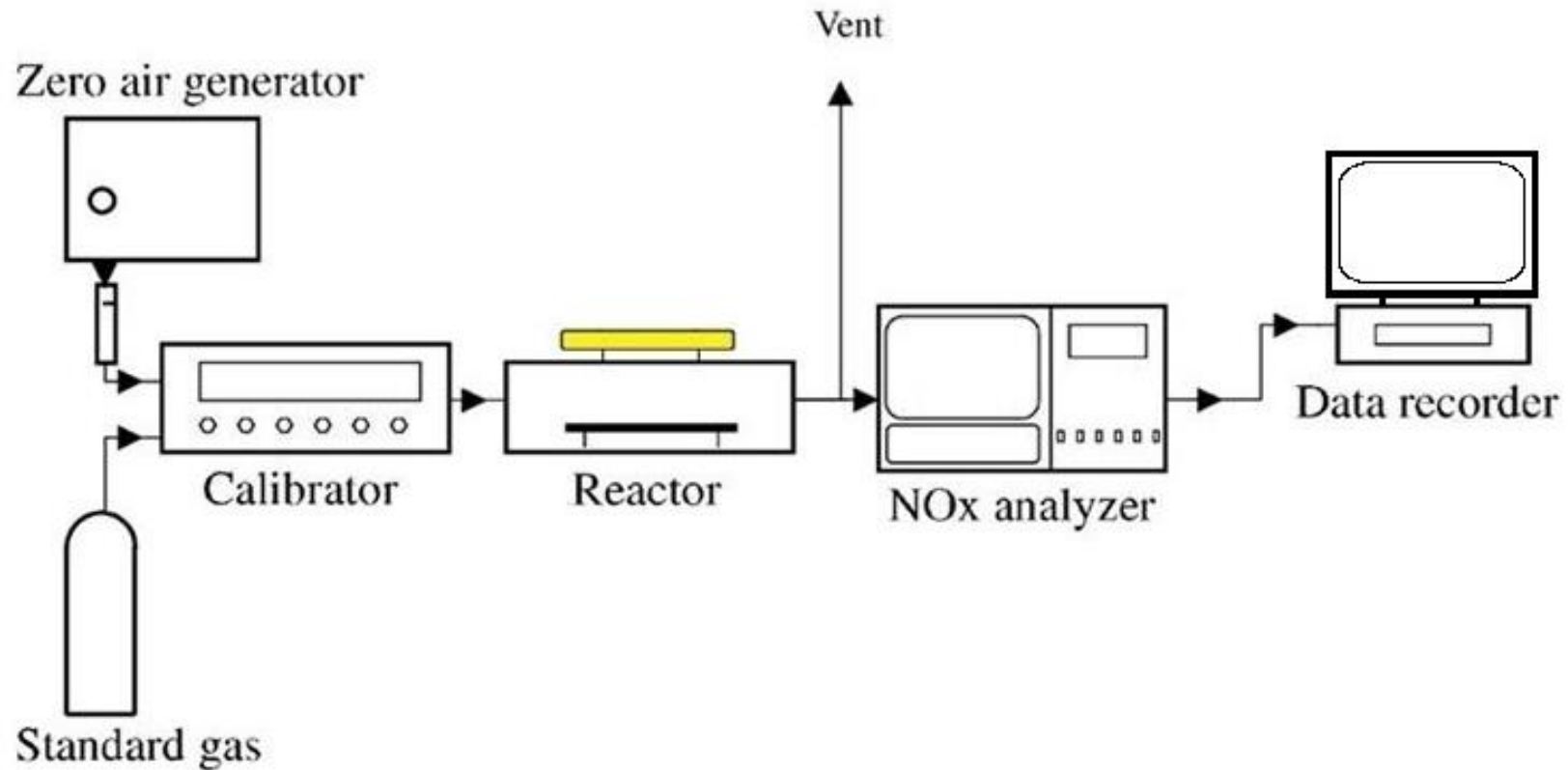
$D_p$ , nm	CNF Batch process	CNF Continuous process	Charged Melt-blown media (3 samples)	CNF Optimized Continuous process
AVG All Sizes	0.26	0.22	0.11	0.38
	1			1.46X
		1		1.73X
			1	3.45X

# Charge retention of our Charged PVDF Nanofiber filter

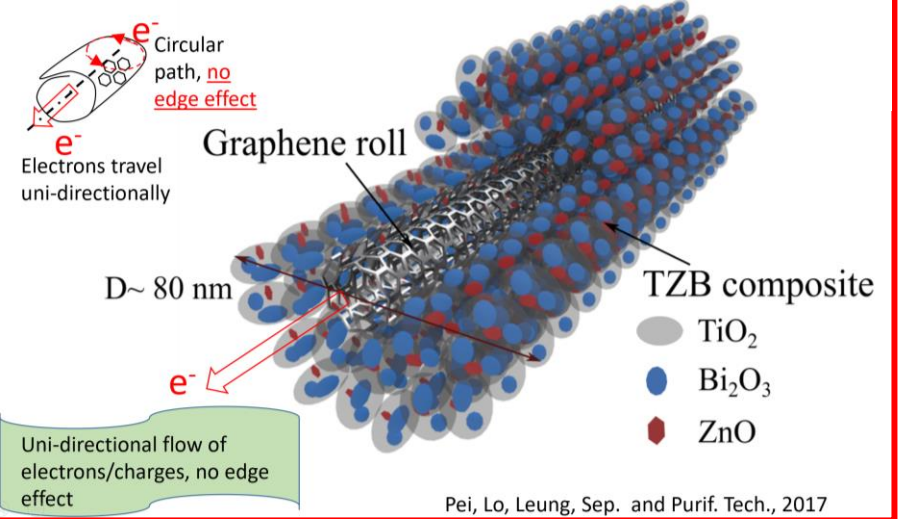
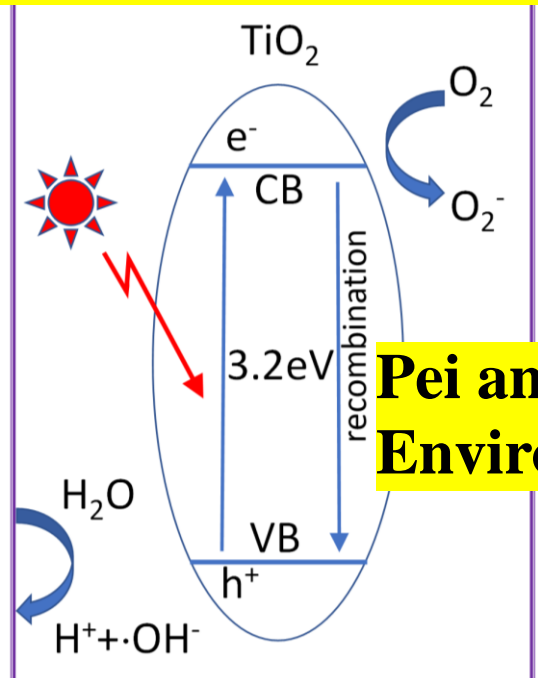
- Filter efficiency @150 nm NaCl aerosols is the same, at 99.62% after 5 month duration

# Photodegradation – Gas Purification and Disinfection

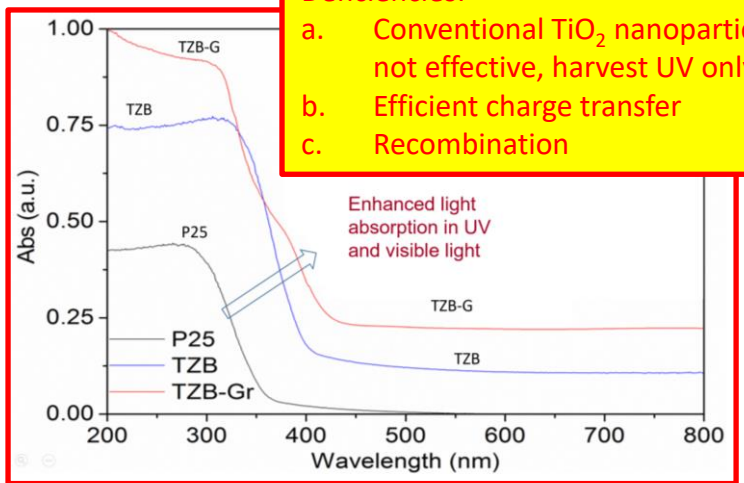
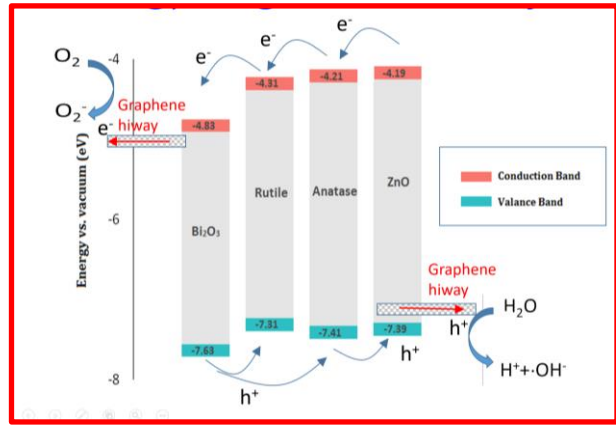
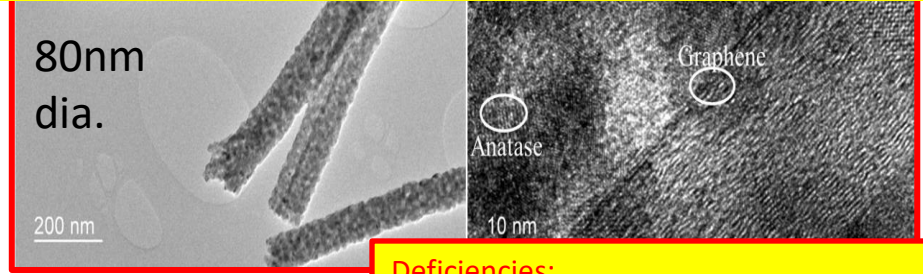
# Flow through photo-reactor for converting harmful test gas (NO<sub>x</sub>, Formaldehyde, O-xylene, etc.)



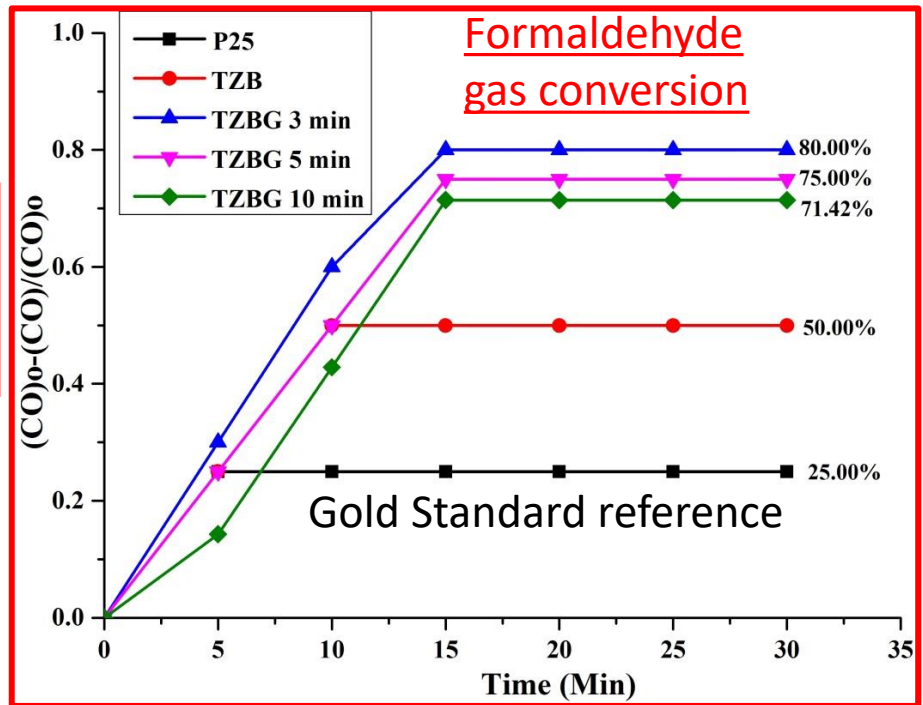
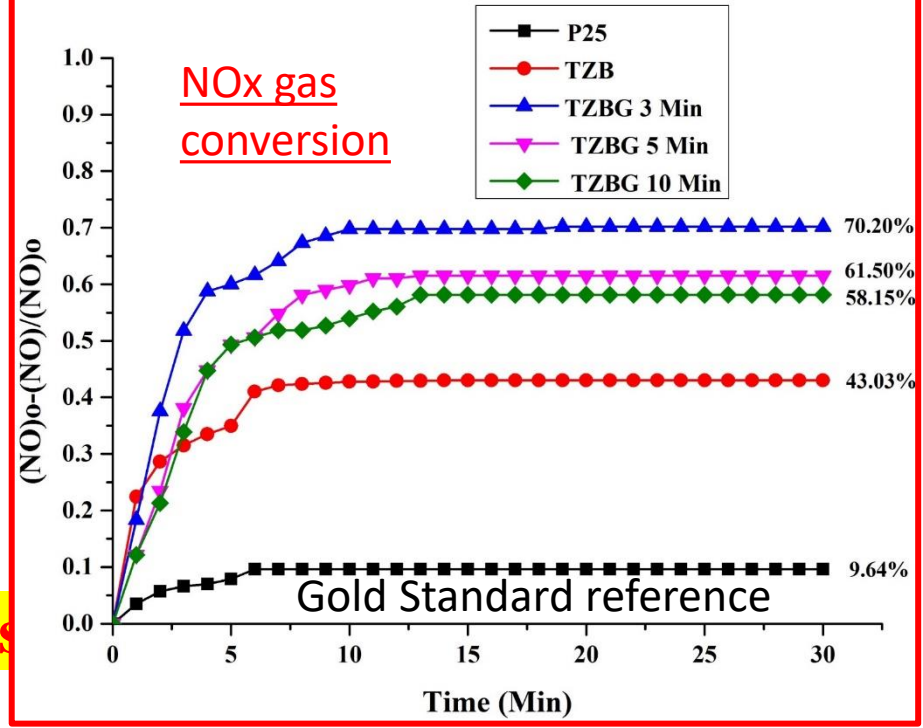
# NF Photocatalyst – Purify Air



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

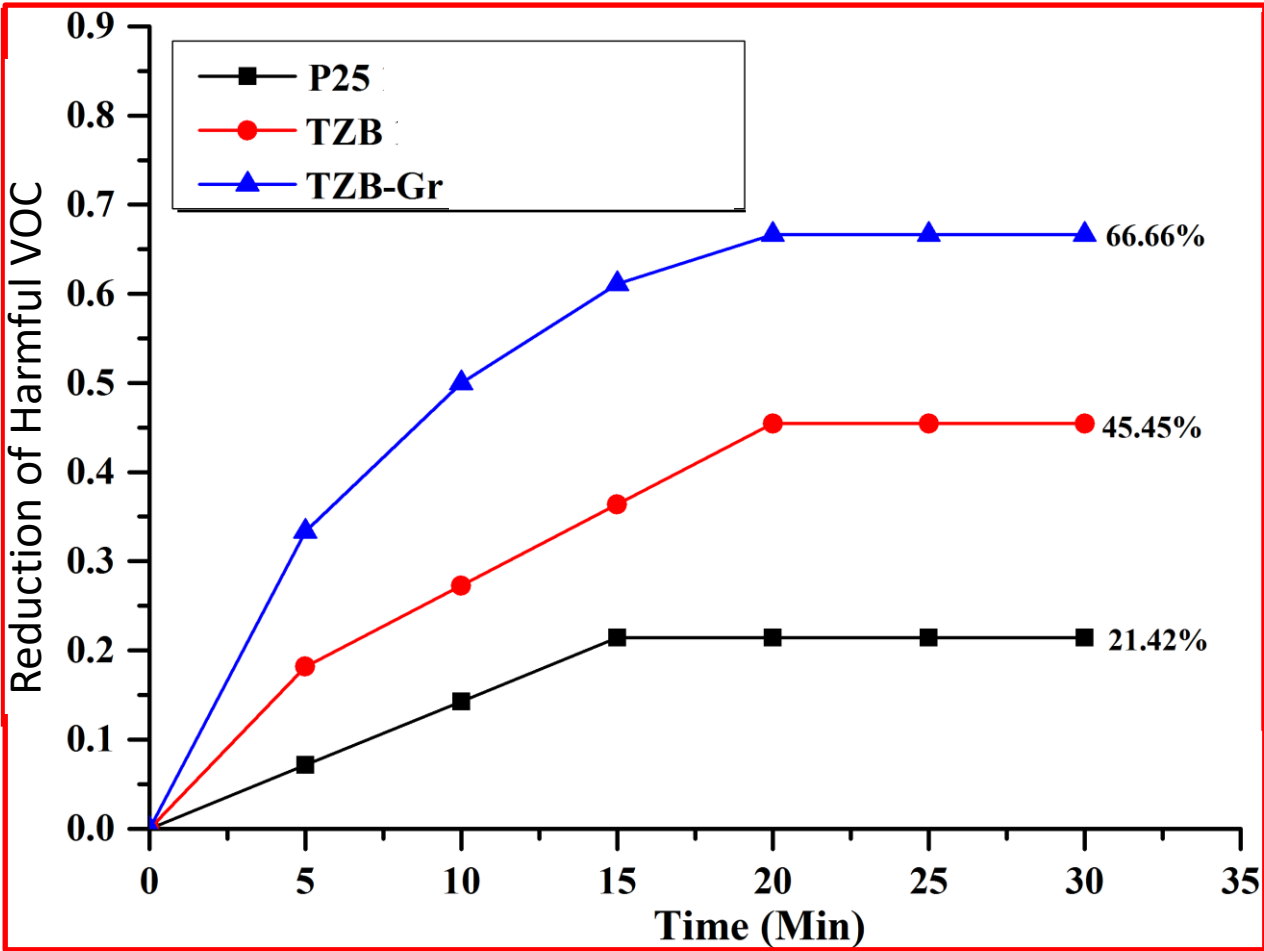


- Deficiencies:**
- Conventional TiO<sub>2</sub> nanoparticles not effective, harvest UV only
  - Efficient charge transfer
  - Recombination



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

# Whitewash - Photocatalyst nanofibers in coating

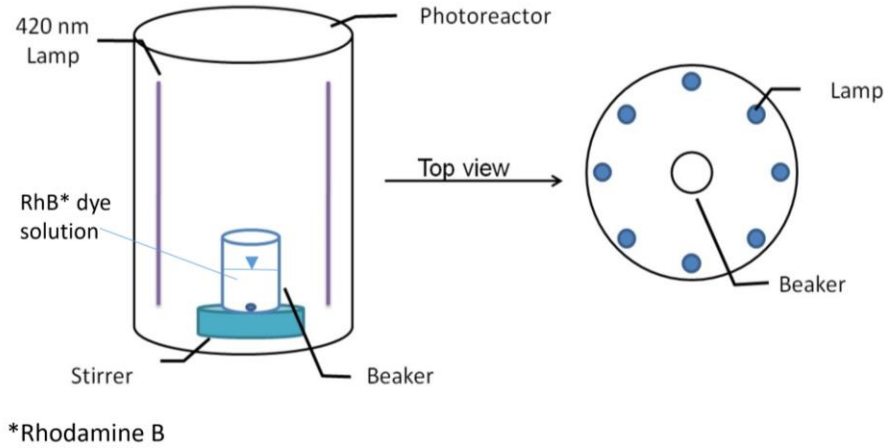




# Water Purification

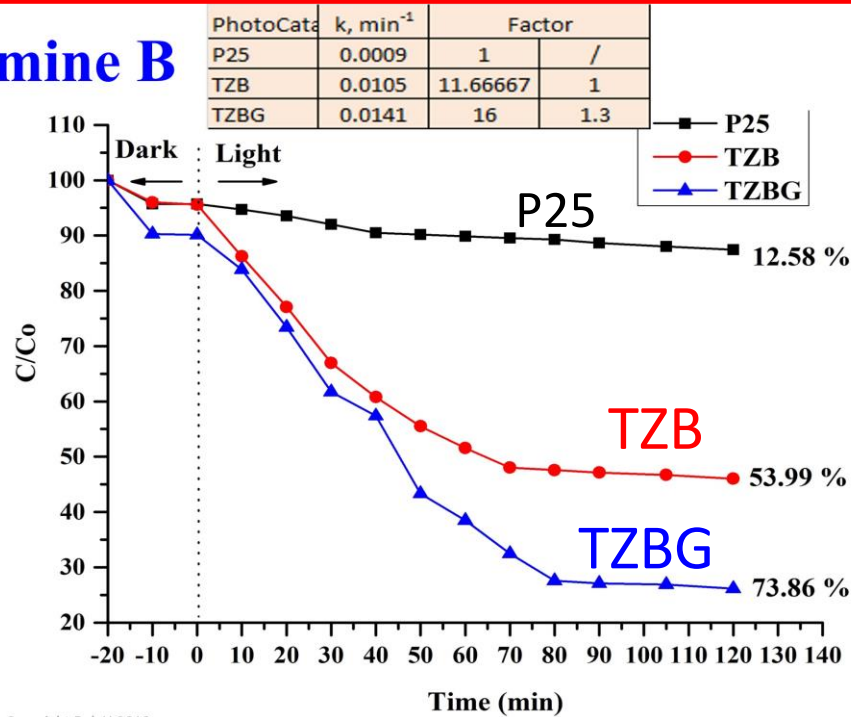
NF Photocatalyst –  
Water Purification  
(breaking dissolved  
organics, dye  
herbicides,  
pesticides etc. )

Batch Photo-reactor for Photocatalyst tests on Dye Solution

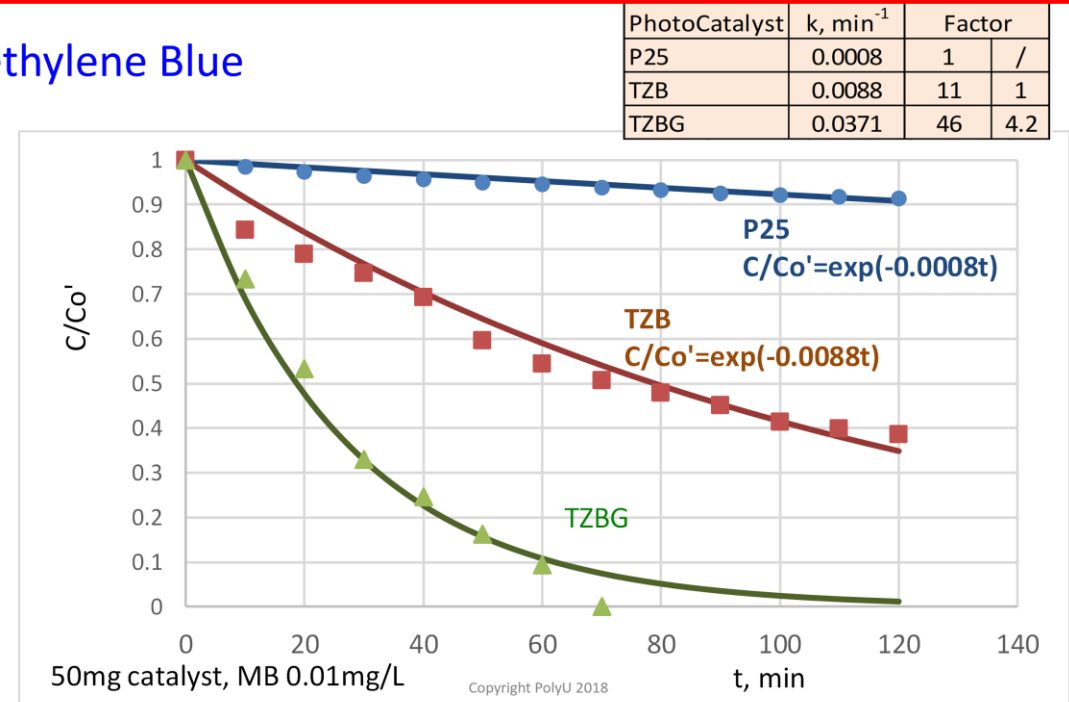


Free/loose  
Catalyst (need to  
be recovered by  
centrifugation  
after purification)

Rhodamine B



Methylene Blue



# 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<sub>2</sub> on NO<sub>x</sub> (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 ( $\text{TiO}_2$ , ....) and highly conductive *graphene inside* that can be used for
  - Solar Cells
  - Photocatalyst
  - Sensors\*
  - Battery\*
  - Others

---

\*Note: to be explored



**COVID-19**  
Global literature on coronavirus disease

العربية | 中文(中国) | english | français | Русский | español | português

News/Update/Help

Advanced Search ?

Title, abstract, subject

Home / Search / Chapter one - Introduction to submicron aerosols and nanoaerosols

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

## Nanofiber Filter Technologies for Filtration of Submicron Aerosols and Nanoaerosols

Wallace Woon-Fong Leung

- Describes technologies with insight and use basic engineering principles to build-up technologies
- Includes extensive clear and understandable figures and tables to enhance key concepts
- Uses examples throughout to explain engineering principles and interdisciplinary concepts
- The only book in the market focusing on nanofiber filter technologies for filtering submicron aerosols and nanoaerosols.





*Nanofiber Filter technologies for Filtration of Submicron Aerosols and Nanoaerosols (NFT)* covers the nanoaerosols (less than 100 nanometers) to larger submicron aerosols due mostly to pollution, which are present in high number concentration in our surroundings. People are breathing these nanoaerosols daily without being aware of it. Airborne viruses from flu to coronaviruses are also nanoaerosols. During the COVID-19 pandemic, it took a long time for health authorities and the General Public to recognize the airborne transmission mode of the virus. This leads to inadequate protection and ineffective virus control strategies resulting in high infection and death rates. The book cites evidence and observations pointing to the airborne transmission mode of the coronavirus. It also discusses different filtration technologies using nanofibers to capture these aerosols for short-term filtration, where aerosols are trapped in the filter (depth filtration), and long-term filtration, where aerosols are trapped in the growing filter cake (cake filtration). This book provides a good understanding on how nanofibers, which is of size 1/1000 times that of a normal human hair, can effectively filter these tiny aerosols. NFT, organized in four sections – fundamentals, deep understanding, technologies, and application, covering comprehensively on the subject, is a valuable resource for undergraduates and graduates, engineers, researchers and practitioners in related industries.

### Nanofiber Filter Technologies for Filtration of Submicron Aerosols and Nanoaerosols

Fundamentals	Deep Understanding	Technologies	Applications
Submicron Aerosols and Nanoaerosols (CN1)	Depth, Intermediate, Cake Filtration (CN4)	Multilayer/Multilayer Nanofiber Filter in Depth Filtration (CN5)	Aerosol Aerosols (CN12)
Filtration of Aerosols (CN2)	Skin Layer in Cycle Loading/Cleaning (CN3)	Composite Filter in Cake Filtration (CN2)	Nanofiber Filter Applications (CN13)
Nanofiber Production (CN3)	Numerical Modeling (CN6)	Charged Nanofibers (CN4)	
Fiber Testing and Standards (CN4)		Backpulse/Backblow Cleaning (CN10)	
		Future Tech (CN14)	

Ch1-Chapter

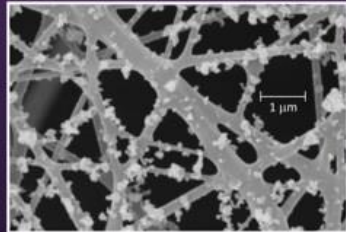
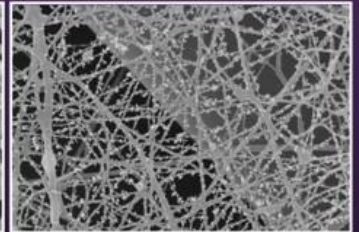
**About the Author**  
**Dr. Wallace Woon-Fong Leung** is a Distinguished Research Professor from The Hong Kong Polytechnic University. He has been working on development of nanofiber filter technologies on filtering submicron- and nanoaerosols for 16 years. He has 38 SCI publications and 9 US patents on nanofiber technologies. He has delivered numerous plenaries and keynotes in Europe, North America, Asia, and Middle East, respectively. He is also a multidisciplinary engineer, scientist, and educator with international academic and industrial experiences. During the COVID-19 pandemic, he has deployed his invented nanofiber technologies in mass production of highly protective, highly breathable facemasks for the public railroad.


elsevier.com/books-and-journals

9 780120 244685

ELSEVIER

ELSEVIER

Nanofiber Filter Technologies for Filtration of Submicron Aerosols and Nanoaerosols

Leung

# Nanofiber Filter Technologies for Filtration of Submicron Aerosols and Nanoaerosols

Wallace Woon-Fong Leung



*Thank God  
For Clean  
Environment You  
have Provided*

Thank you all for listening!