MB Web Properties and Electrostatic Charging of Webs

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The University of Tennessee
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for

Asian Filtration Conference

Outline

- Respirators against viruses
- Nonwoven properties and performance
- Ectrostatic charging techniques
- Filtration mechanisms
- Medical protective fabrics
- Respirator performance

Respirator (tight seal, L) and Mask (loose fit, R)

Variety of respirator shapes

Sara Turnbull, House Beautiful editor
Bra designer

Conventional MB electret for COVID-19 respirators

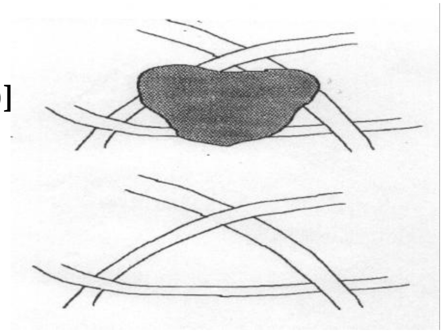
Excellent efficiency and perfect seal but unbearable breathability

Lack of oxygen: 21% at sea level, 15% inside N95, equivalent to 2,3000 meter above sea level

Argument: Can MB electret capture coronal virus?

In terms of size:

COVID virus – 0.08 microns
Pore size of a MB fabric for N95 - 20 microı



In terms of electrostatic attraction:

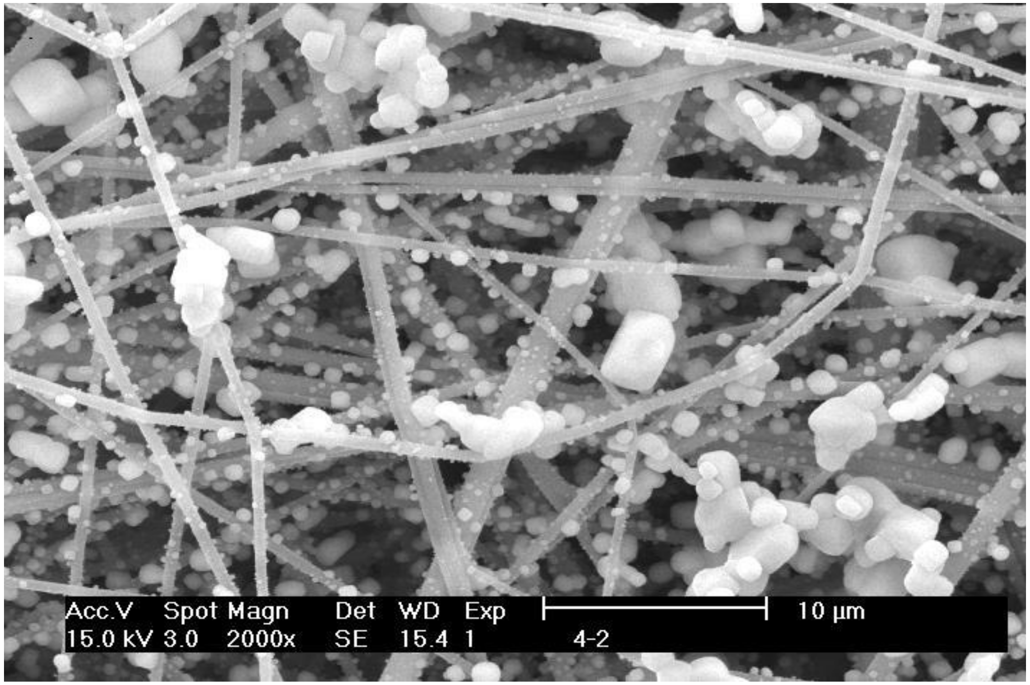
Virus is electrically neutral

SEM image of fine particles captured on the fiber surface by

vander waal forces (mechanical mechanisms)

Columbic force (positive charges attract negative particles and vice versa

Image force (attraction of neutral particles by polarization)



N95 Material – 熔噴加靜電布
Electrostatically-charged Meltblown Fabric

WWII- Biological Warfare Agent, Microglass fiber
1956 – MB process developed by US Naval Space Lab
1957 – Spuntik 1
1961 – NASA President JFK
1969 – Human landing on the moon
1970's – Mechanisms of air filtration by British Royal Science Academy

1980's – PT involved in the investigation of MB process

貧賤不能移（民）

Air Filtration Mechanisms

Inertial impaction
Direct interception
Brownian diffusion
Electrostatic attraction

Nonwoven web properties

Independent variables

Fiber Size, Packing Density

Dependent variables

Pore size

Quantity – Basis weight

Performance

Air Permeability (Pressure drop), Filtration efficiency, Fluid penetration (Hydrohead), Oil absorbency, etc.

Packing Density or Solidity (α)

$$\alpha = \frac{V_f}{V_{web}} = \frac{\frac{W_f}{\rho_f}}{tA} = \frac{Basis\ weight}{t\rho_f}$$

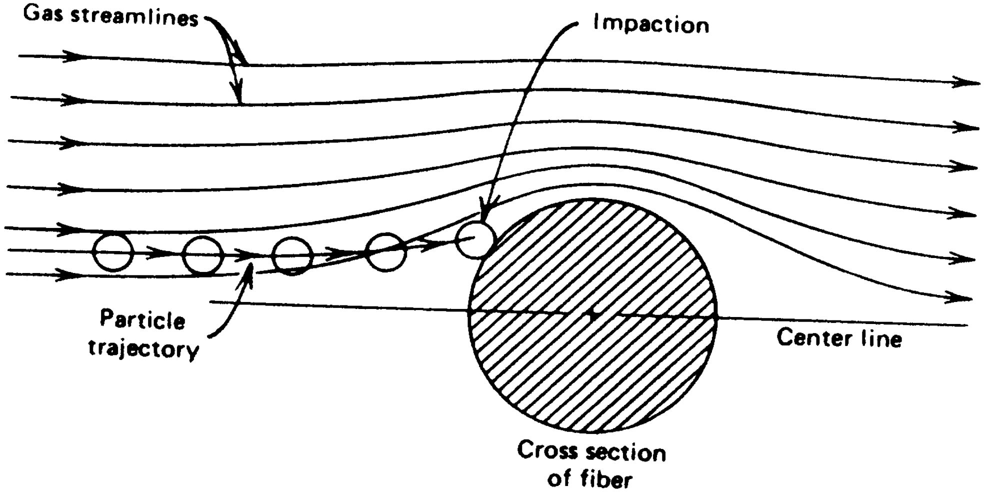
V_f – total volume of fibers

ρ_f – fiber density

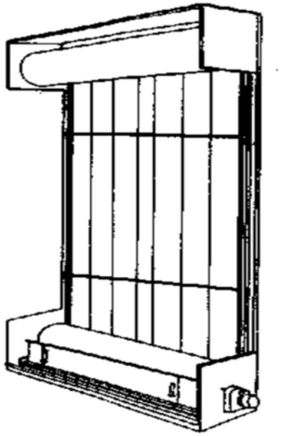
t – thickness of the web

A – area of the web

Inertia Impaction



Vertical Roll Filter



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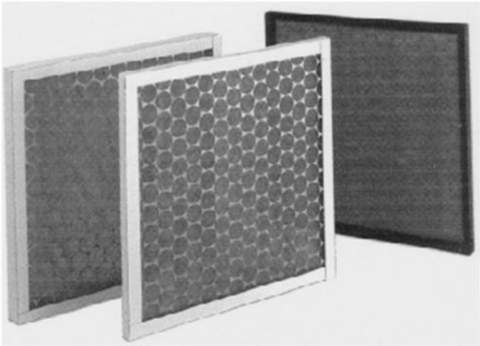
Flat Panel Filter



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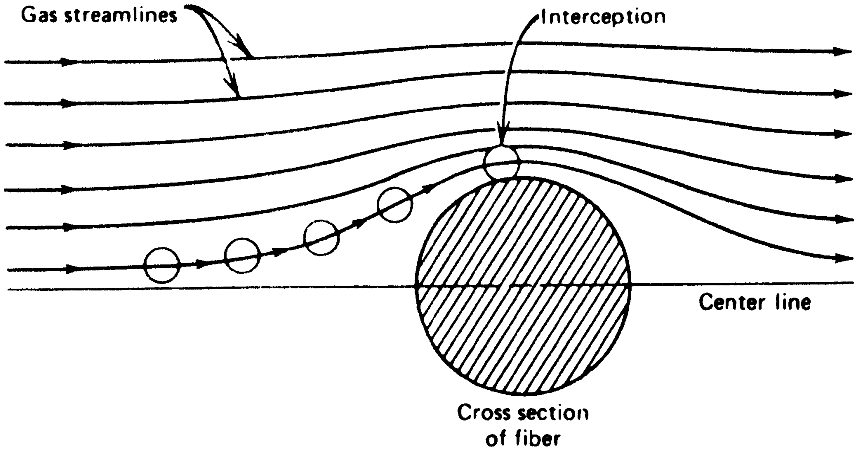
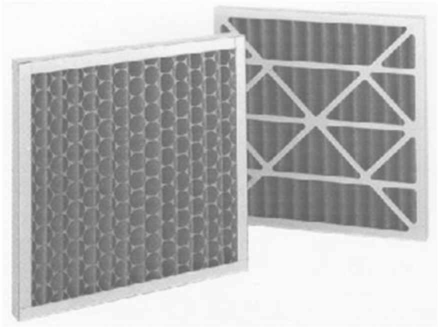
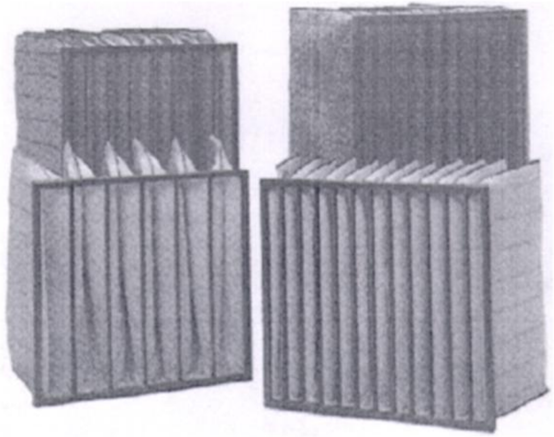
Direct Interception



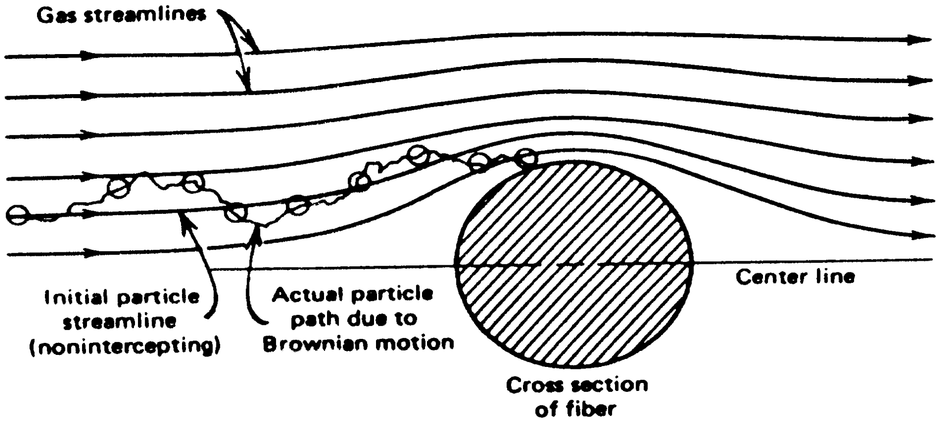
Pleated Panel Filter



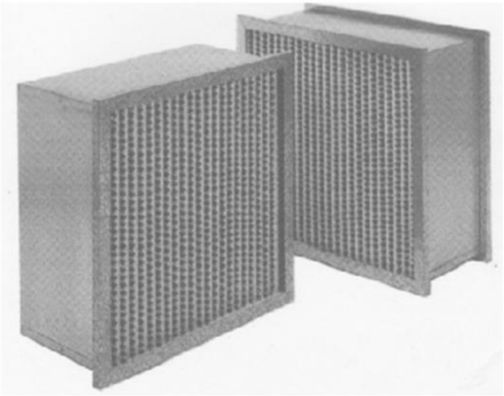
Pocket Filter



Brownian Diffusion



Alumnium-separated Filter



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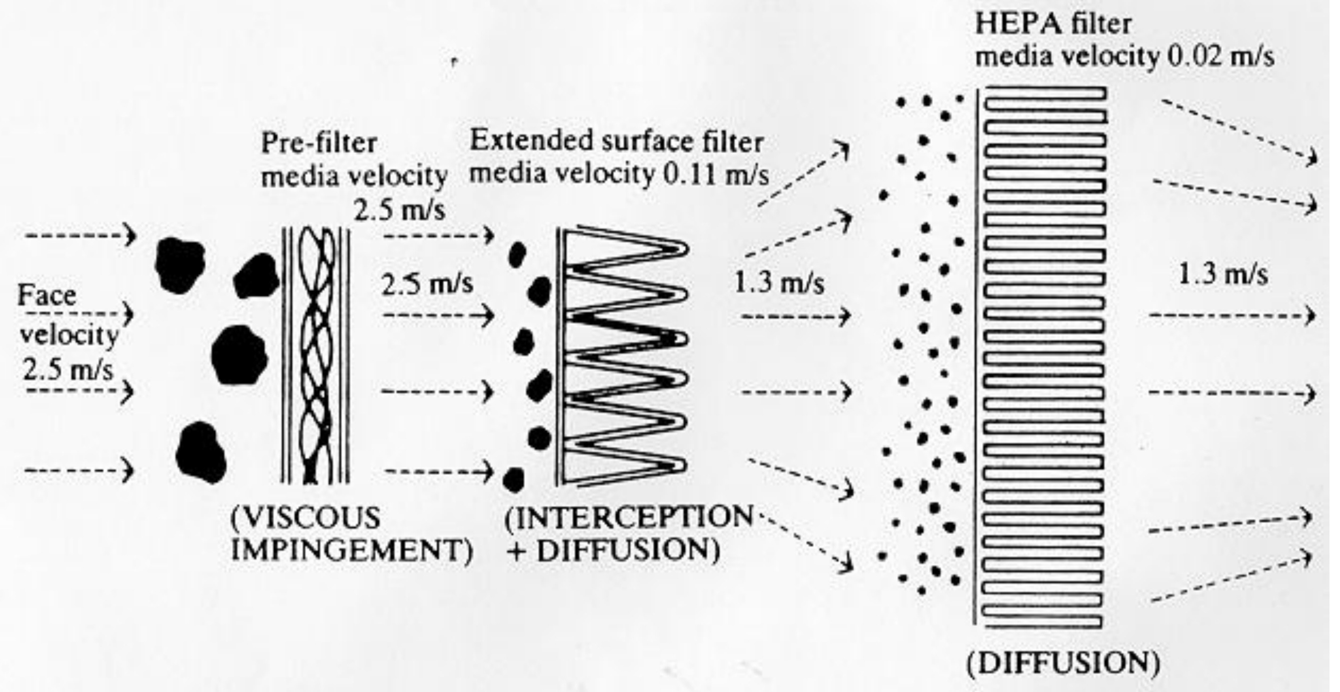
V-Bank Filter

A High Efficiency Filtration System



A system for effective particle removal from air

蔡秉燚（彝）
Peter Tsai

Optimization of filter media and filters

Increase of FE by increasing the total fiber surface area

$$FE = 1 - p = 1 - e^{-\eta S_f}$$

p = aerosol penetration through the filter media

η = single fiber efficiency (equations in the previous Introduction course)

s_f = fiber surface area.

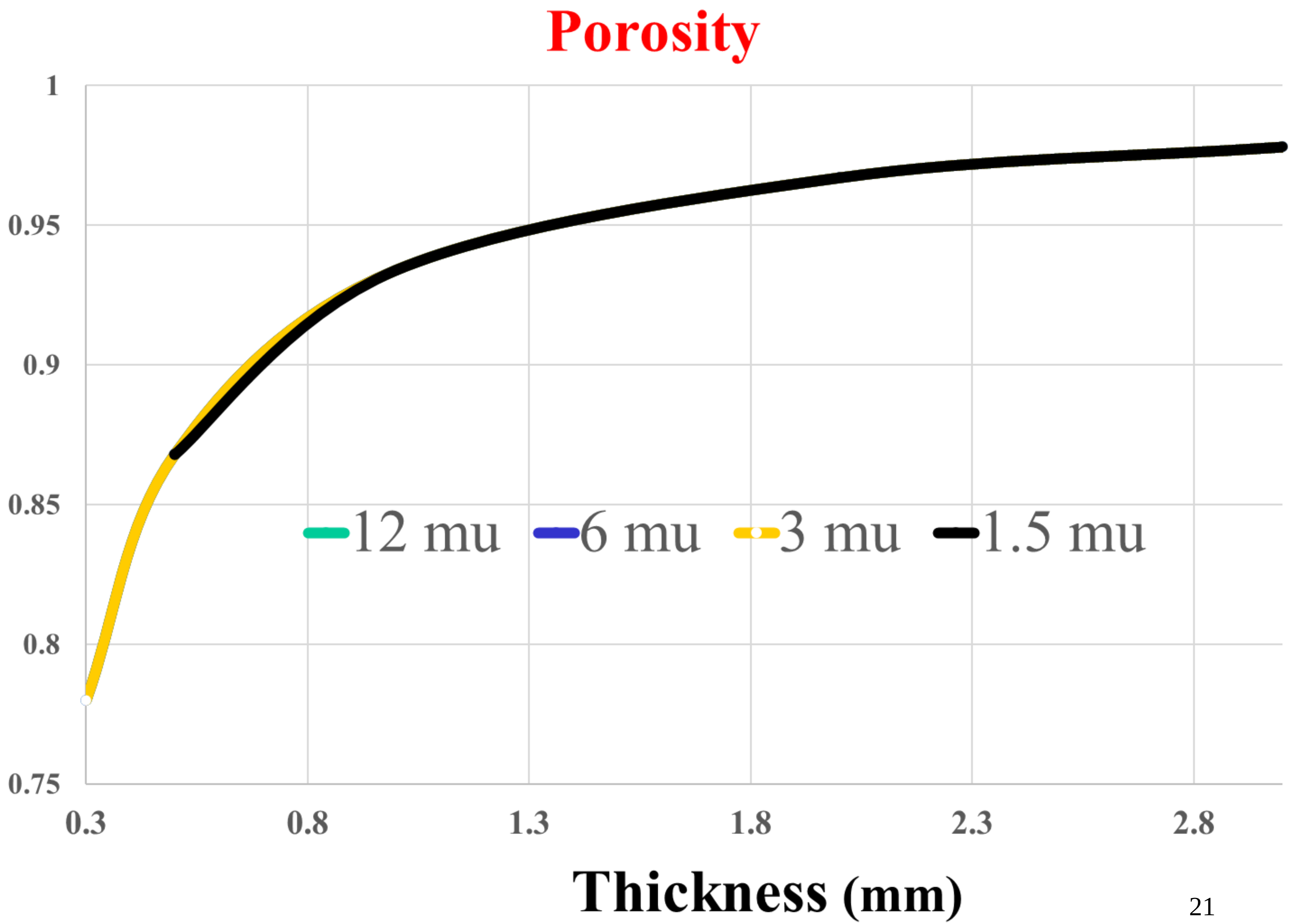
Fiber size and FE

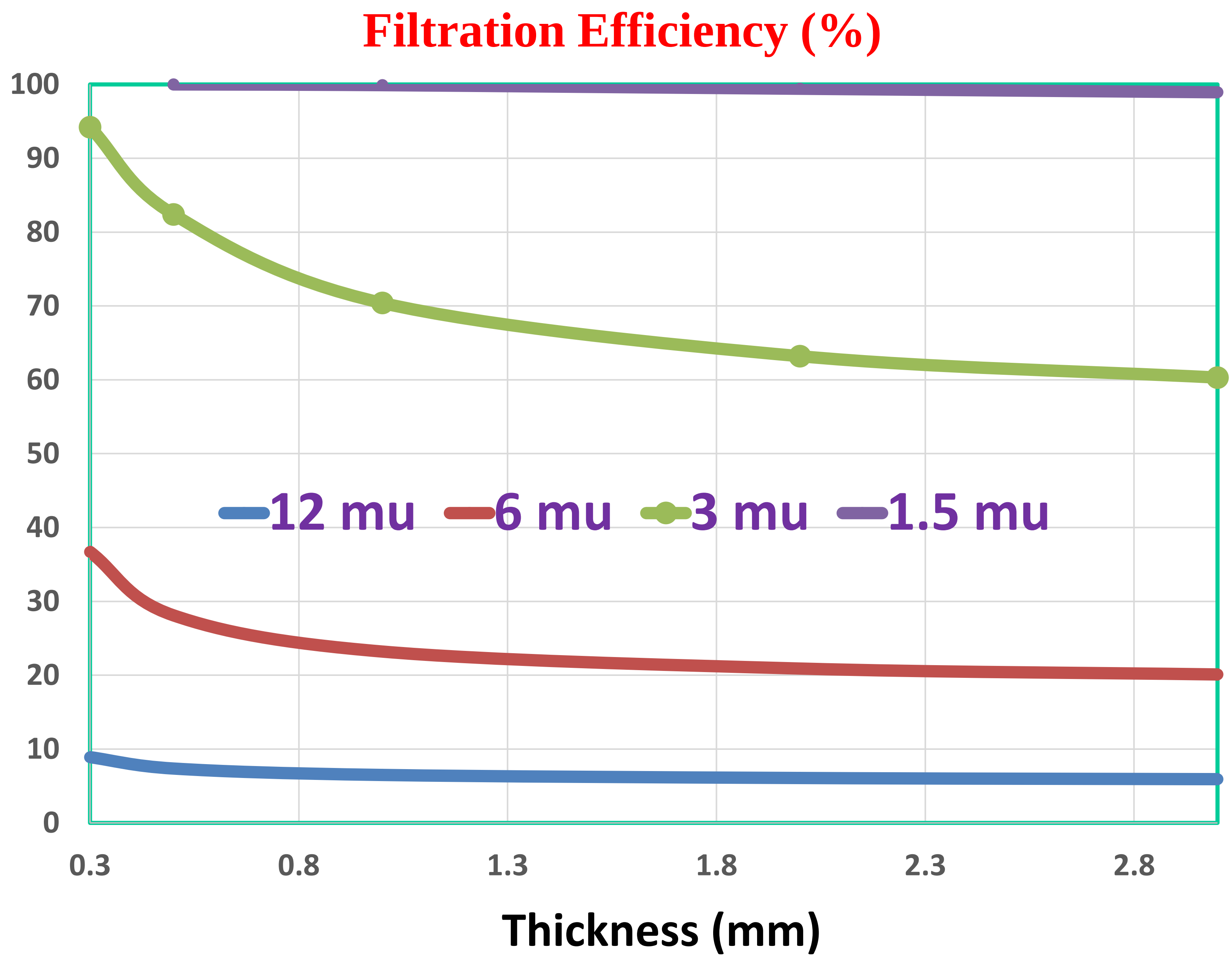
$$FE = 1 - P = 1 - e^{-\mu s}$$

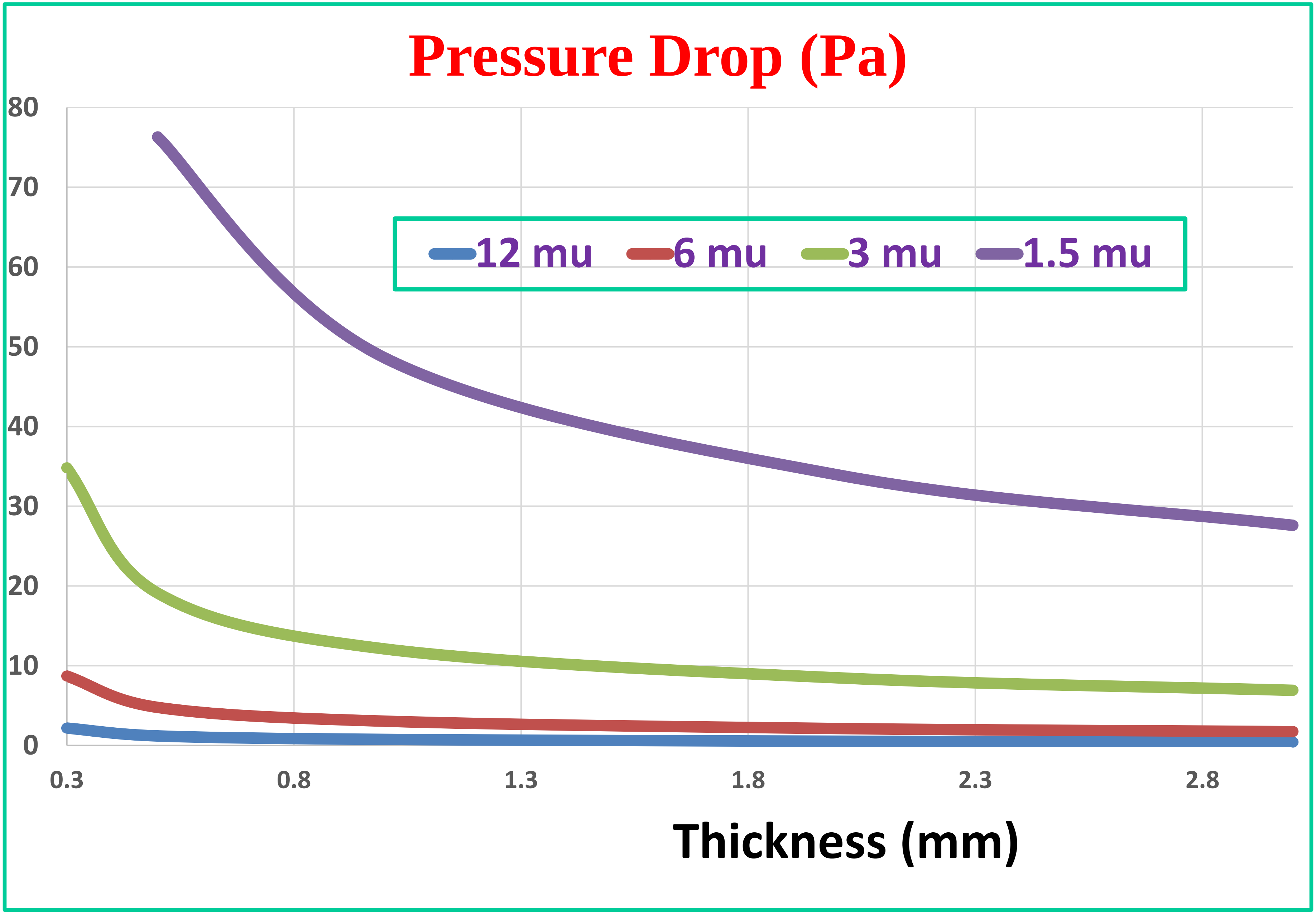
$$s = 2\pi r l$$

$$w = \pi r^2 l * \rho$$

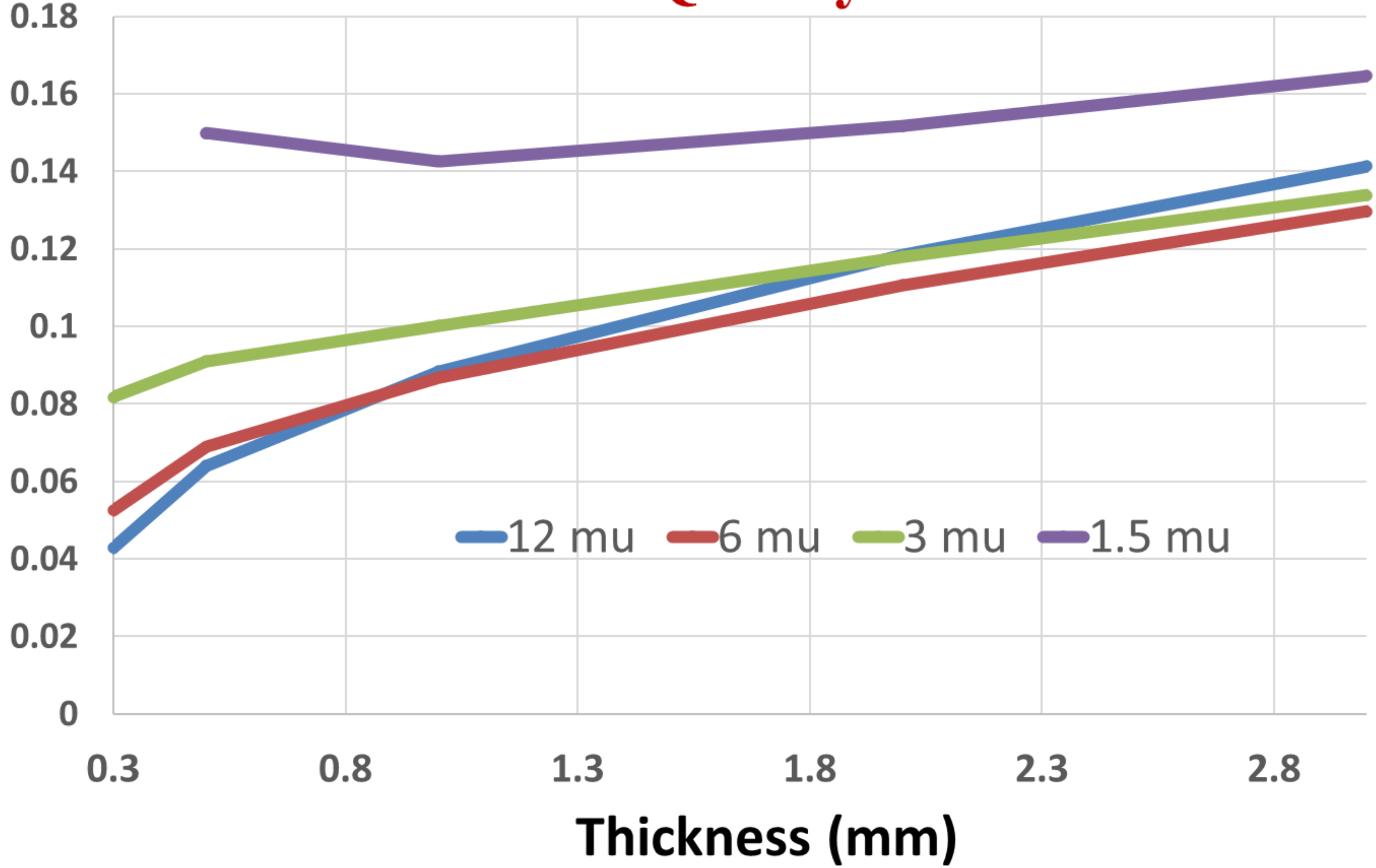
$$s = \frac{2w}{r \cdot \rho}$$

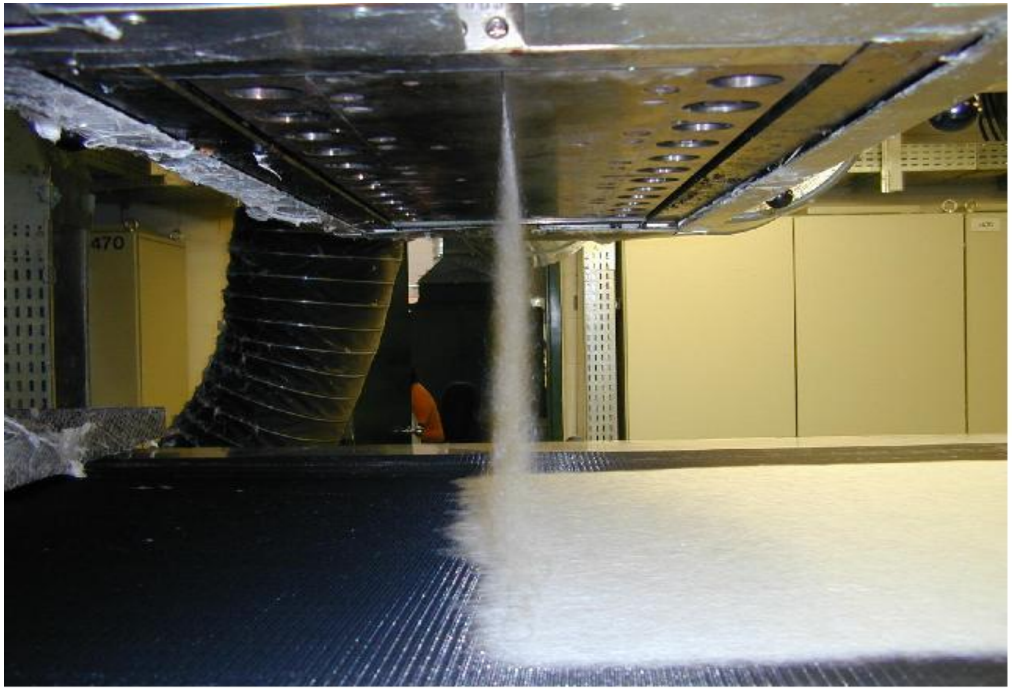

Porosity
1
0.95
0.9
0.85
0.8
0.75
0.3
0.8
1.3
1.8
2.3
2.8
12 mu
6 mu
3 mu
1.5 mu
Thickness (mm)


Filtration Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
12 mu
6 mu
3 mu
1.5 mu
0.3
0.8
1.3
1.8
2.3
2.8
Thickness (mm)


Pressure Drop (Pa)
80
70
60
50
40
30
20
10
0
12 mu
6 mu
3 mu
1.5 mu
0.3
0.8
1.3
1.8
2.3
2.8
Thickness (mm)

Filter Quality / mmH2O





Vertical

Horizontal

Electrostatic charging

Electrostatic charging

by Corona charging or
by Triboelectrification

Corona, a Plasma – the fourth state of matter

Saha equation – ionization temperature of hydrogen, about 10,000K

Efficiency of corona charged materials

Ten-fold higher than uncharged, meaning 1 ply of charged =10 plies of uncharged

e.g.,

35% - uncharged

98.6 - Charged

Electret - A counter term of Magnet

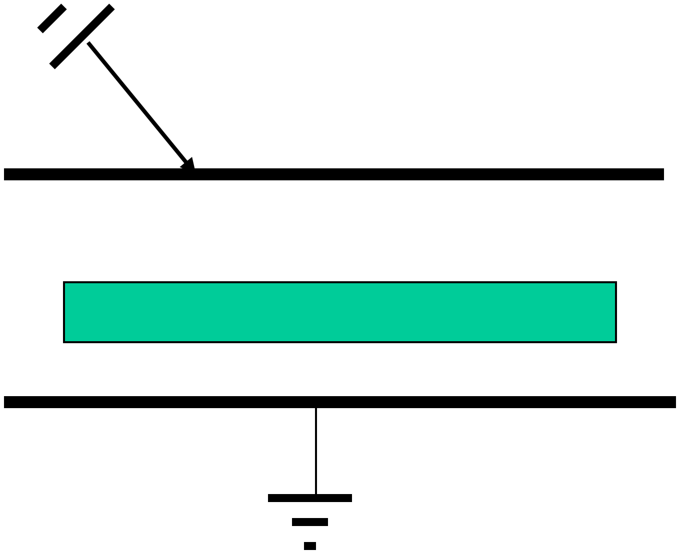
Magnet – A ferrous material that exhibits quasi-permanent magnetic field

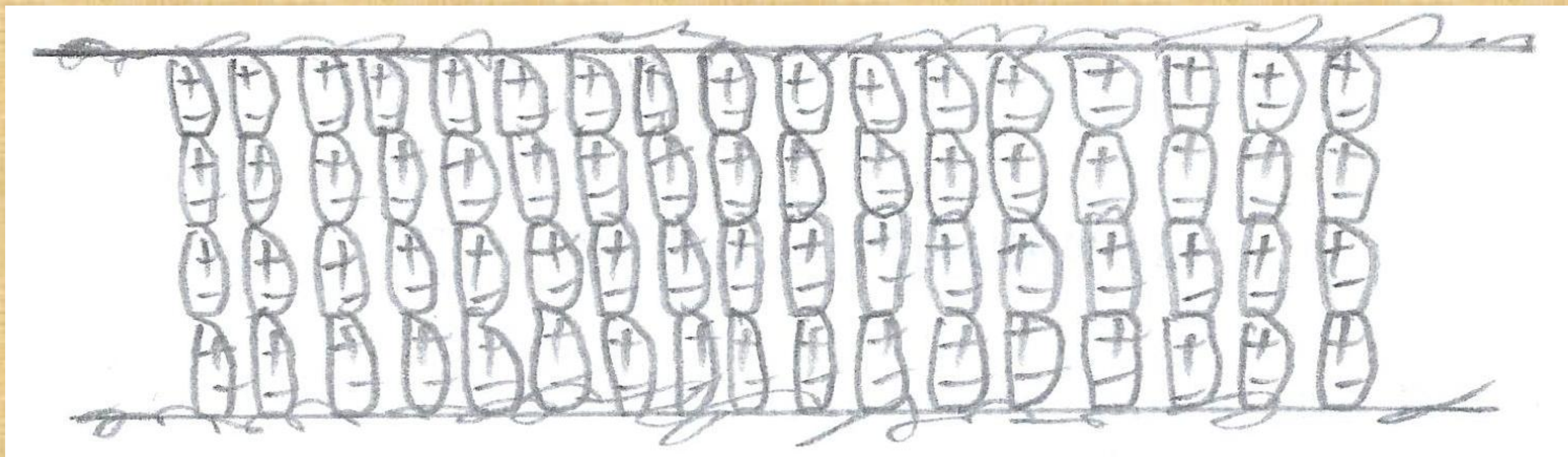
永磁体 磁铁

Electret – A dielectric material that exhibits quasi-permanent electric field

永电体 电塑

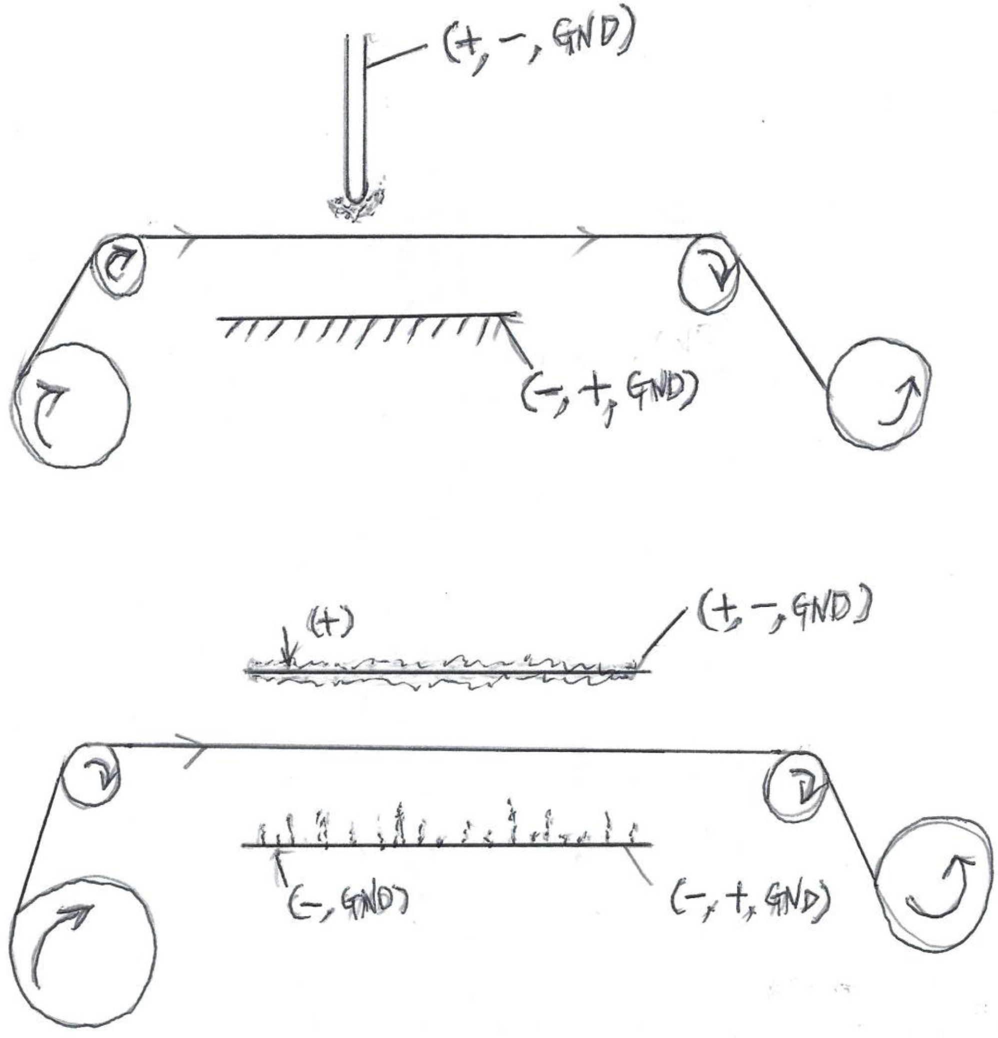
Electret by Polarization 驻极体



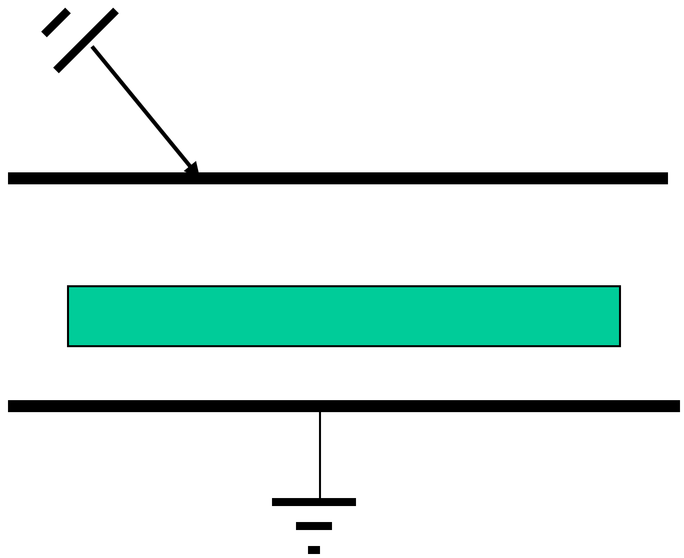


Corona Charging by Highly-Intensified Electric Field

E > 3 MV / m



Bulky net charge measurement



Measurement of net charge in a media using parallel plates

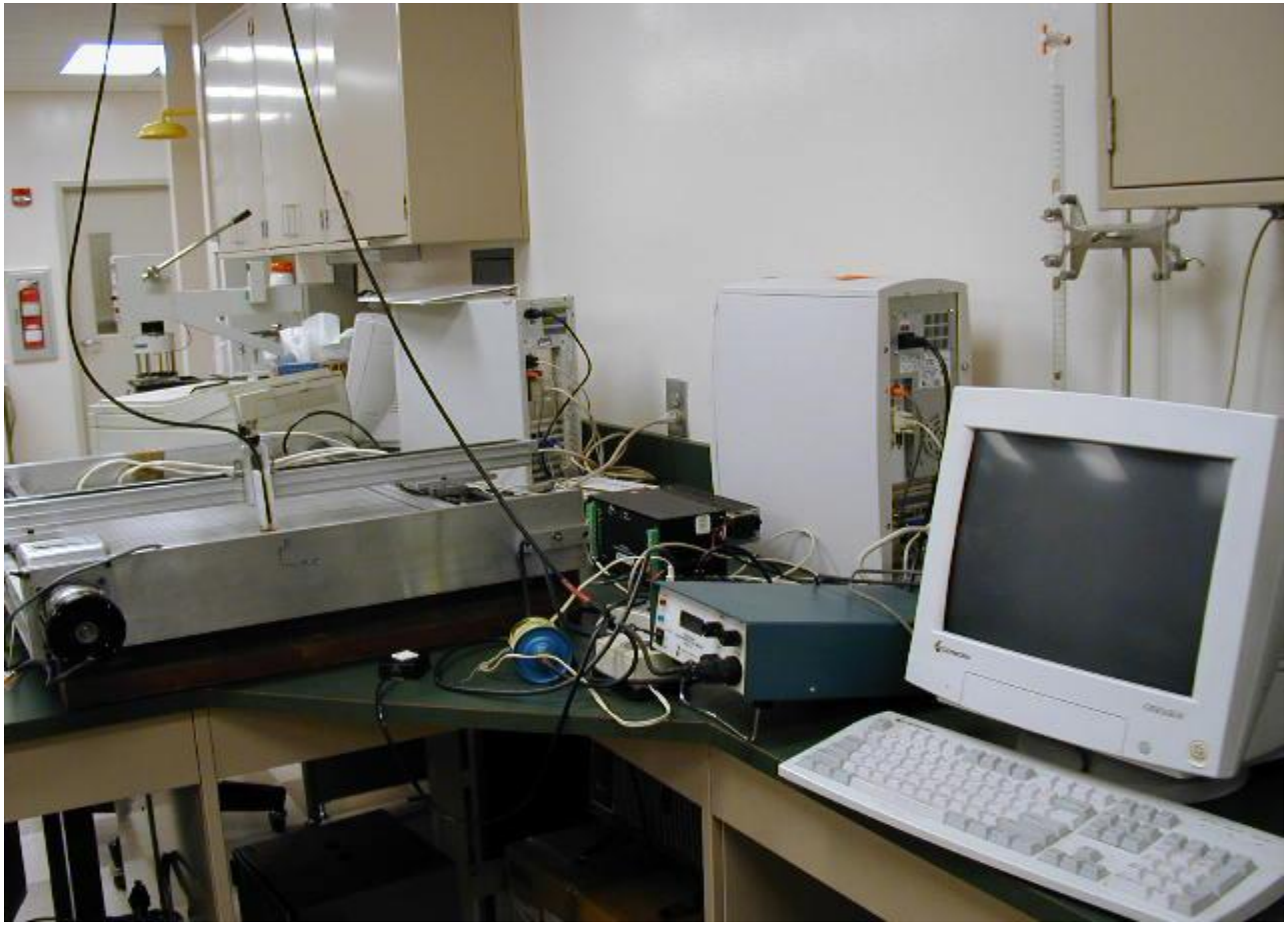
$$F_E = qE = q\frac{V}{d} \quad \text{- electrical field force on the media}$$

$$F_g = mg \quad \text{- gravity force or body force of the media}$$

$$F_E = q\frac{V}{d} = mg = F_g \quad \text{- when the media floats}$$

$$\text{so,} \quad q = \frac{mgd}{V}$$

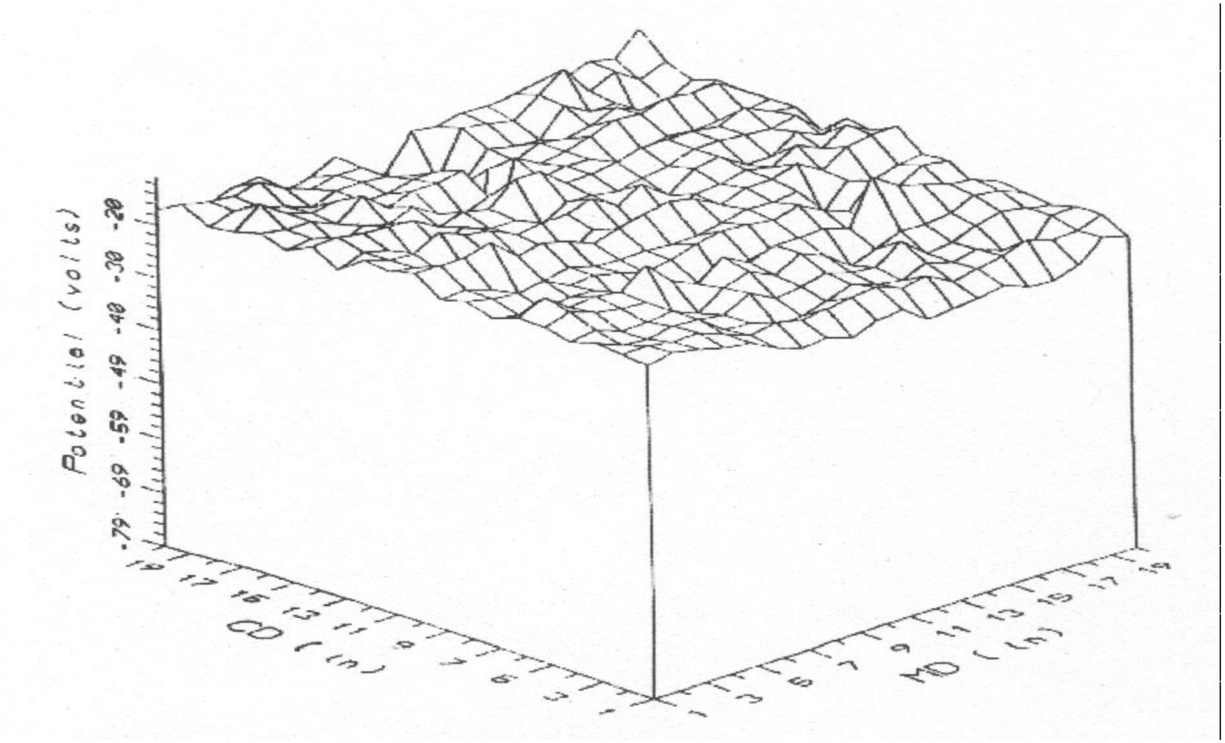
A Surface Charge Potential Measuring System



Surface Charge Potential of uncharged web

(face side, fluffy side)

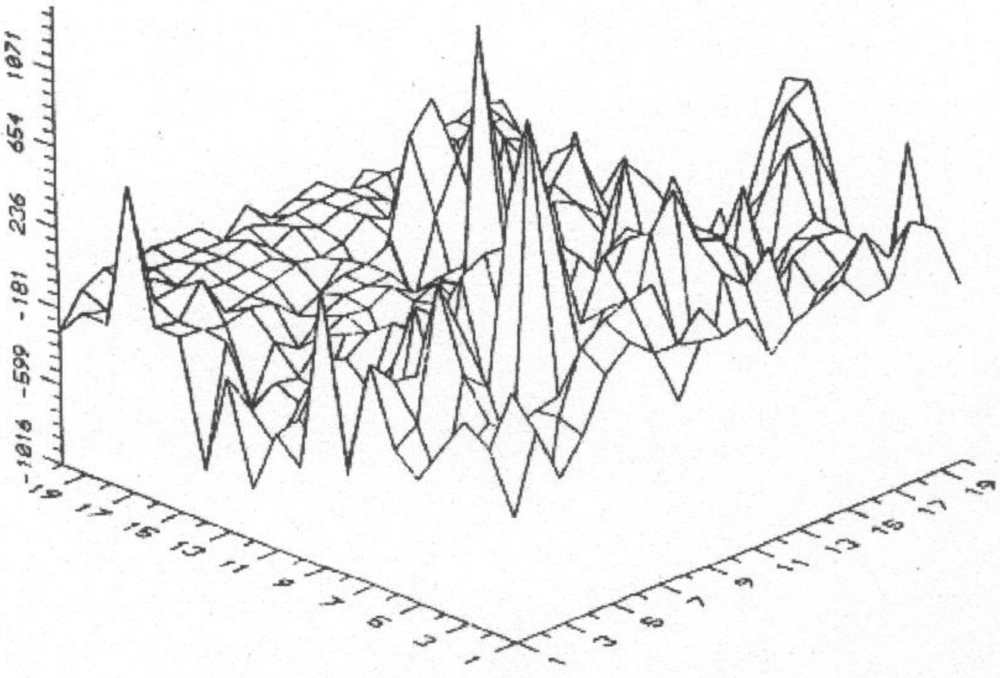
Fibers are slightly negatively charged from triboelectrification during polymer processing



Surface Charge Potential of hot-charged web

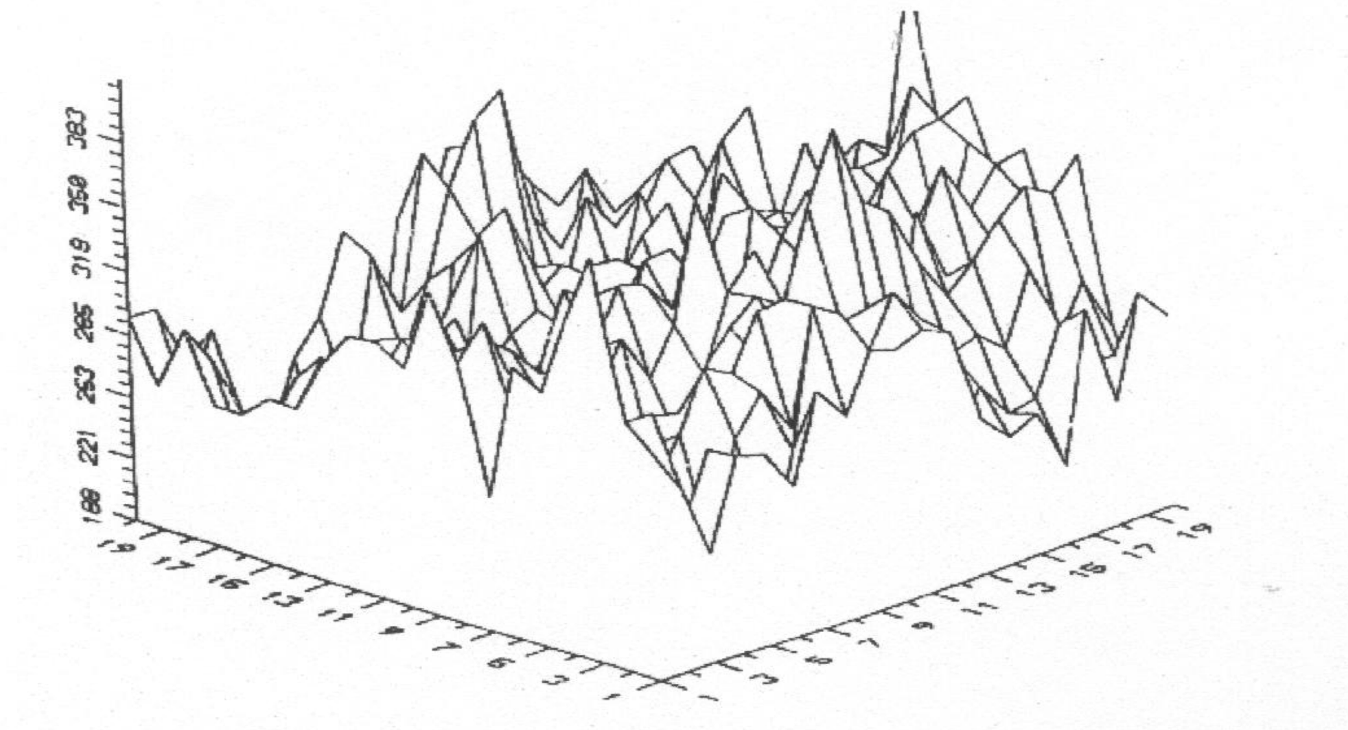
(face side, fluffy side)

Charges are randomly distributed



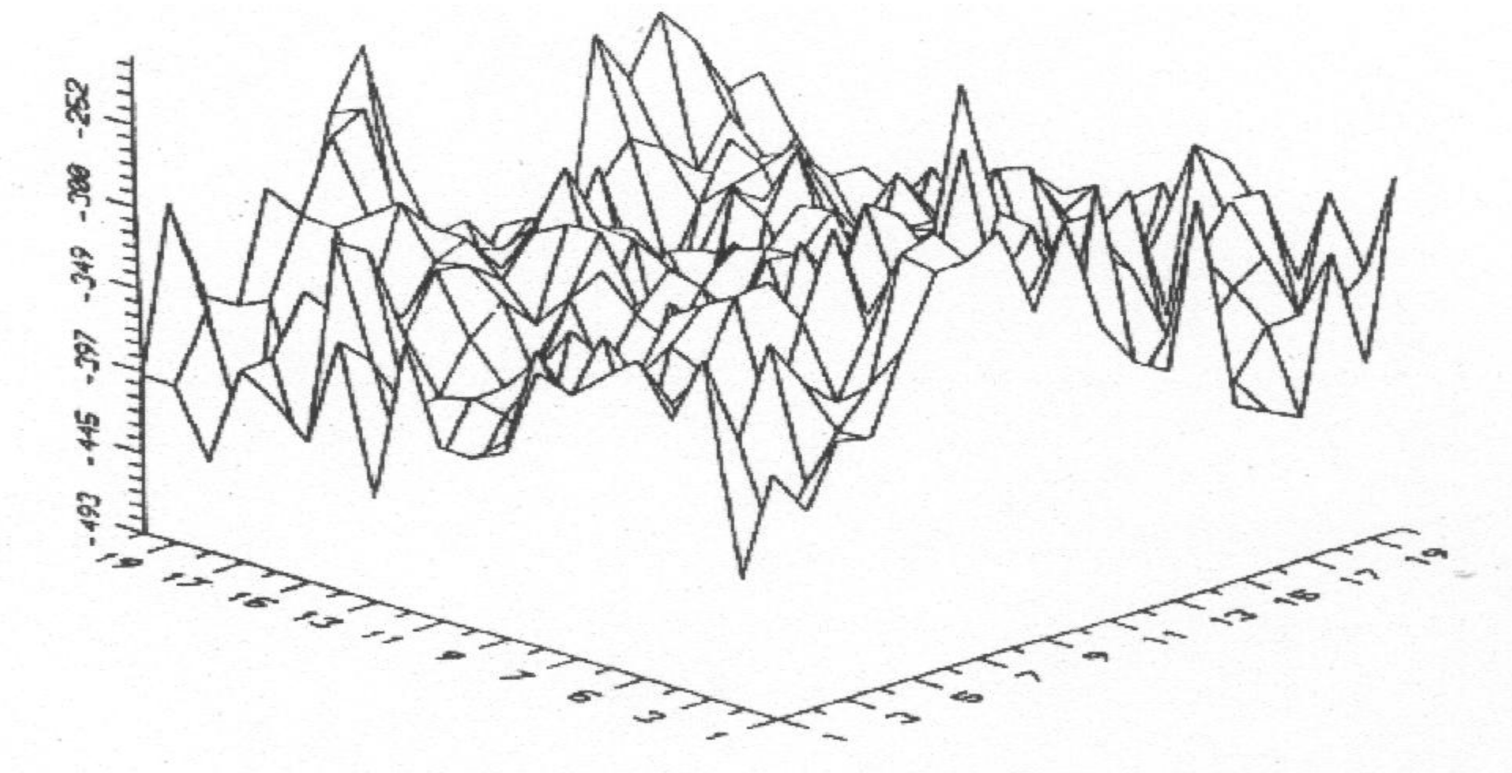
Surface Charge Potential on Face Side

Single polar, uniformly-distributed positive charges



Surface Charge Potential on Screen Side

Single polar, uniformly-distributed negative charges



Conversion of Charge Potential (V) to Charge Density

$$\sigma = \frac{V\varepsilon_0\varepsilon_r}{t}$$

V - measured charge potential from Slide 14

ε_0 – permitivity in vacuum (8.854187817...×10^{-12} F/m)

ε_r - relative permitivity (dielectric constant)

t - thickness of the media

σ = 2X10^{-9} C/cm2

Corona charging

Tribocharging

Two or more dissimilar electronegativity of fibers

Hydrocharging (friction between fibers and liquid)

Inspired by the nature - Thunderstorm

Hydrocharging

MB properties and performance w/charging

Basis Weight	**30 gsm**
Thickness	**.3 mm**
Pressure Drop	**3 mm H2O or 30 Pa**
Filtration Velocity	**5.3 cm/s**
Effective Fiber Diameter	**5 microns**
SEM-Equivalent Fiber Diameter	**1.9 microns**
Porosity	**89%**
Pore Size	**20 microns**
Air Permeability (ft3/ft2/min)	**44.5**
NaCl Filtration Efficiency w/o charging	**39.70%**
Filter Quality per mmH2O	**0.1686**
NaCl Filtration Efficiency Corona charging	**99.364%**
NaCl Filtration Efficiency Hydro charging	**99.996%**
Reference	
NaCl FE hydro (B.W. 25 gsm)	**99.978%**
Pressure Drop (B.W. 25 gsm)	**2.5 mmH2O or 25 Pa**

Brilliant

More can be done in terms of respirator structure

$$\Delta P \propto v$$
$$v = Q/A$$
$$\Delta P \propto \mathrm{Q}$$

Respirator with exhalation valve not allowed for virus respirators


Made in Taiwan

Survivability of COVID-19 on the surface of Materials (70F, 50% RH)

NEJM: March 14, 2020

Copper surface for 4 hours

Cardboard for 24 hours

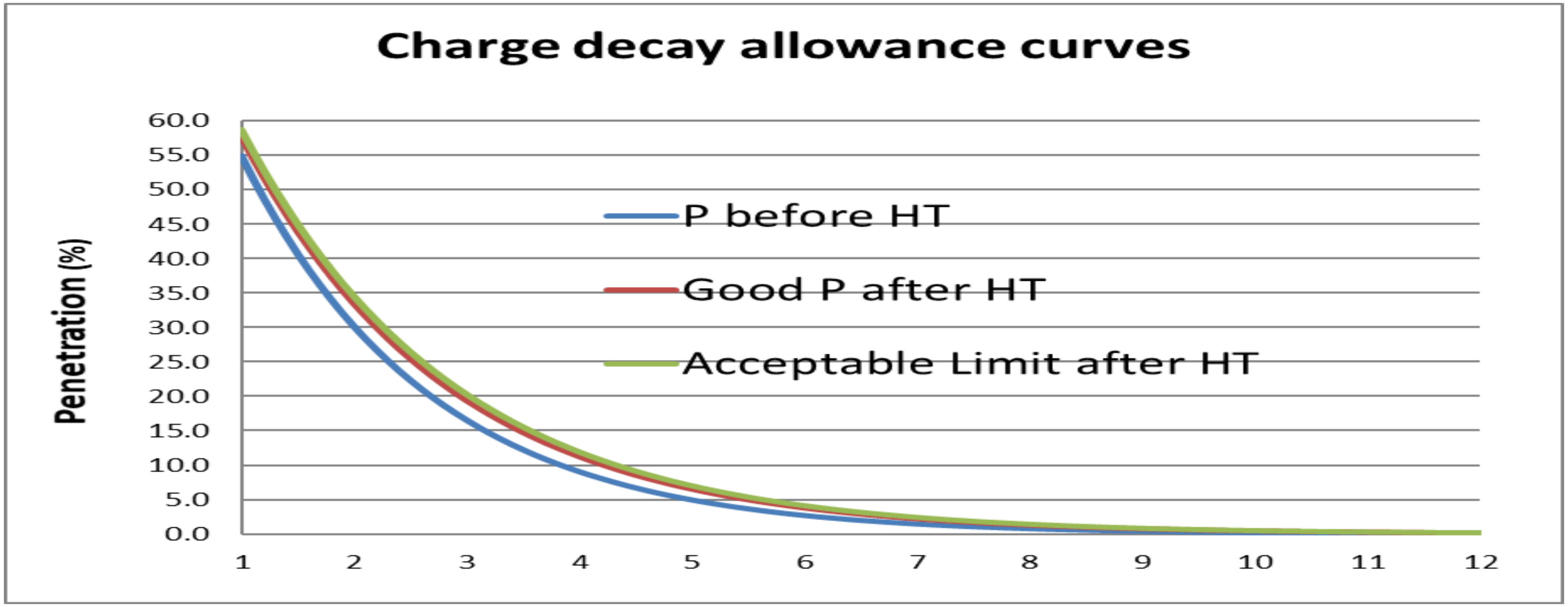
Stainless steel for 2 days

Plastic surface for 3 days

Natural Sterilization (7 days)

Natural Sterilization (7 days)

Quiescent charge decay rate



An example of N95

Initial: 98.5%

After Heat Treatment: **97.82%**

Shelf life of respirators and masks

2 yrs (masks) – 5 yrs (respirators), 9 years seen in a commercial respirator

Say 10 yrs of shelf life

Manufacturing of **one billion** pieces for stockpile w/population of 300 M –

Ship and refill 200 million pieces each year in the sequence of manufacturing date

Meaning, 1 billion pcs in the warehouse all the time, the shipped 200 million pcs have at least **5 years** of shelf-life time.

The Nobelly Prize

The Nobel Prize - mRNA
Katalin Kariko

Hydrohead

Tsai Hydrohead Equation

$$\bar{D} = \frac{d_f}{g(\alpha)}$$

$$P = \frac{4\gamma}{D}$$

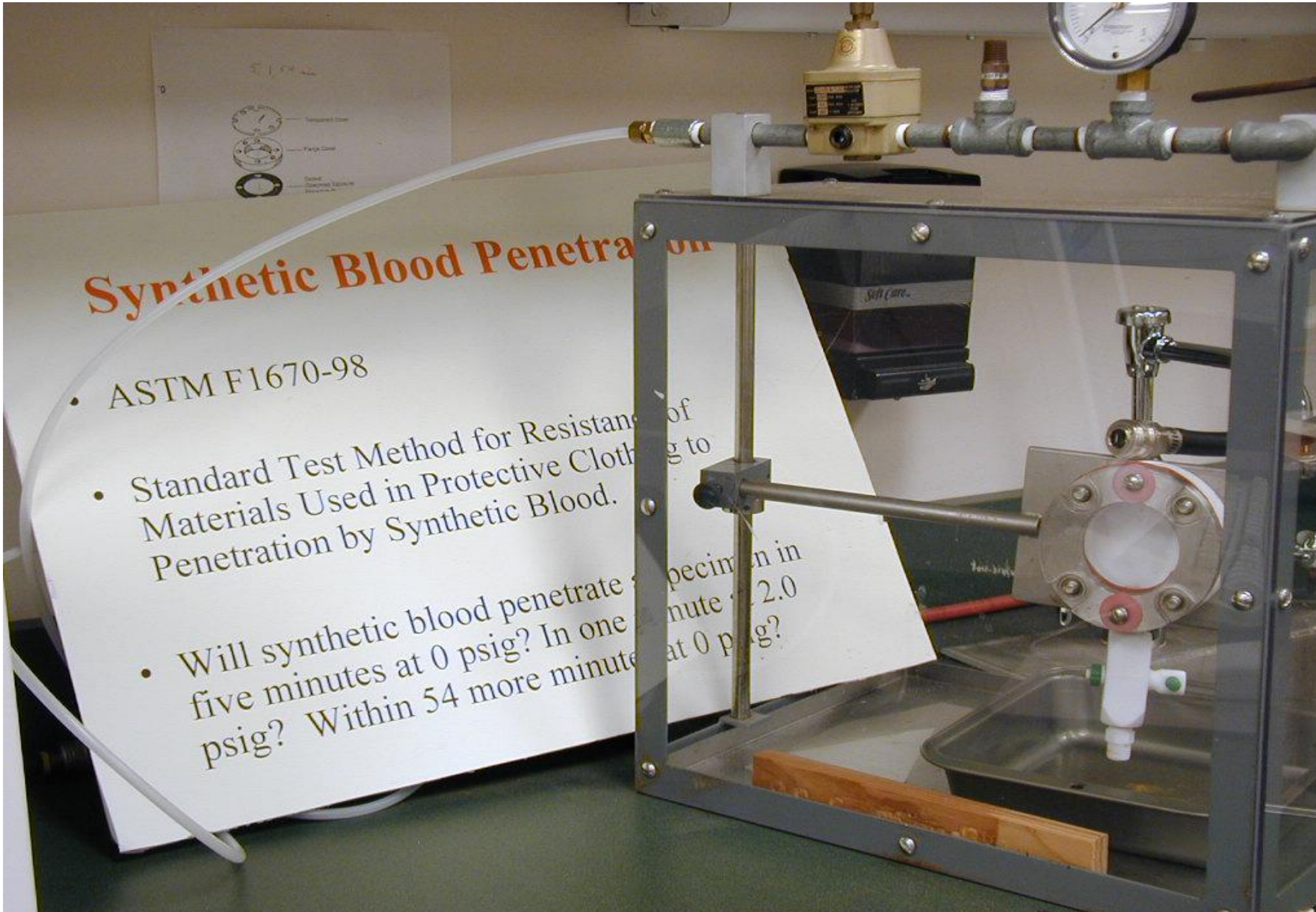
$$P = \frac{4\gamma}{d_f} g(\alpha)$$

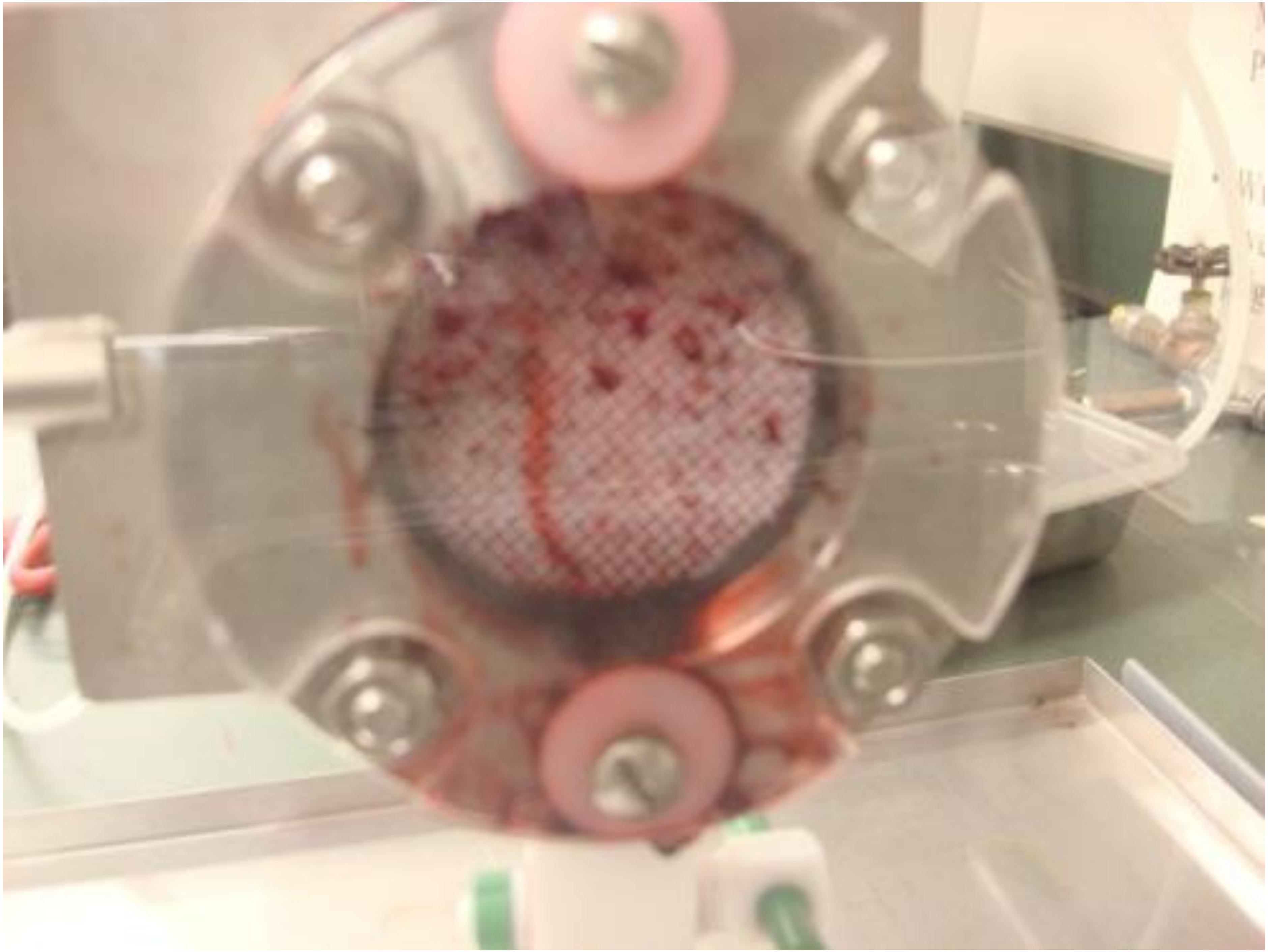
$$g(\alpha) = 1/\left(\frac{1}{2(1-\alpha)^2 \alpha^{1.5} (1+56\alpha^3)}\right)^{0.5}$$

Theoretical and experimentatl hydrohead values

Sample	Fiber Dia.	Mean Pore	Max. Pore	Hydro (cm)	
	(mm)	(mm)	(mm)	Theo	Exp
MB1	**0.98**	**12.7**	**25.4**	**113**	**110**
MB2	**1.2**	**15.6**	**31.2**	**92**	**90**
SMMMS	**2.1**	**27.7**	**55.4**		**52**
Image	**0.45**	**5.9**	**11.8**	**245**	

2 PSI = 142.6 cmH2O


Blood Penetra
ASTM F1670-98
Standard Test Method for Resistan of
Materials Used in Protective Cloth g to
Penetration by Synthetic Blood.
Will synthetic blood penetrate
five minutes at 0 psig? In one
psig? Within 54 more minut



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Thank you for coming!