Advance in Filter Integrity Testing for PTFE Media
HEPA Filter Media

Microglass

ePTFE – Nelior-PC (non-oil tolerant)
ePTFE next generation – Nelior (oil-tolerant)
Traditional Glass Media HEPA Filters

• Developed in the 1940’s
• Slurry of glass fibers in water with binder
  – Poured on a moving screen conveyor
  – Water vacuumed from below
  – Baked dry in oven
• Pleated into media packs
• Potted in urethane in filter frames
• Media is delicate and vulnerable at every stage
  – Manufacturing to filter installation and testing
  – Media is extremely fragile
Filter Media Composition

• Glass fibers
  – Combination of fine and course
  – Media is 92% open space
  – A 2’ x 4’ filter has 65,000 sq. ft of glass surface
    • About 1.5 acres of glass surface

• Binder
  – Holds fibers together

• Waterproofing
Why Use a 0.3 μm to Define a HEPA Filter?

• Once was considered the most difficult particle size to filter
  – Langmiur’s work during WWII
  – Mathematical calculation only
  – Later proved to be reasonably accurate
Glass Media Filtration Theory

**Inertial Impaction** - Particle inertia causes it to leave flow stream lines and impact on fiber.

**Interception** - Particles with less mass stay with the airstream and impinge upon the fiber as they go around it.

**Diffusion** - Brownian motion/diffusion due to molecular bombardment.
Relative Effect of Particle Collection Methods
# ASHRAE Grade Efficiency

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Product Name</th>
<th>Air Flow</th>
</tr>
</thead>
<tbody>
<tr>
<td>FARR COMPANY</td>
<td>ASHRAE GRADE FILTERS</td>
<td>250 FPM/1000 CFM</td>
</tr>
</tbody>
</table>

**Dimensions:** 24" X 24" X 12"

**Test Dust:** ATMOSPHERIC AIR

**Test Aerosol:** ATMOSPHERIC AIR

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Typical particle size efficiency of various ASHRAE grade filters

![Graph showing particle size efficiency](graph.png)

- **ASHRAE 90-99%**
- **ASHRAE 60-95%**
- **ASHRAE 60-65%**
- **ASHRAE 40-45%**

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**Particle Diameter, µm**

- 0.01
- 0.02
- 0.03
- 0.1
- 0.2
- 0.3
- 2
- 3

**Initial Efficiency, %**

- 100
- 90
- 80
- 70
- 60
- 50
- 40
- 30
- 20
- 10
- 0
HEPA Efficiency Chart

Ongoing scientific studies on nanoparticles
HEPA >99.97% efficient at 2 to 4 nanometers.
Preliminary results introduced in “Second International Symposium on Nanotechnology and Occupational Health” (Minneapolis Oct 2005)
Cross Section of Dirty Glass Medium

Air Flow
Blow up of Glass Filter Medium

Air Flow
Very close view
Second Generation HEPA Filters

ePTFE

Aka, Teflon, or Gore-Tex
Discovery of PTFE

Discovery

- Accidentally discovered by Dr. Roy Plunkett at DuPont, April 6, 1938
- Plunkett had been attempting to find a better coolant gas.
- He left a batch of tetrafluoroethylene gas in a pressure container overnight, and on returning the next day, there is a layer of white waxy solid.
- The name, polytetrafluoroethylene, was abbreviated to Teflon for simplicity and is a registered trademark of DuPont

Material Features

- Low coefficient of friction
- Outstanding temperature stability
- Outstanding electrical properties
- Outstanding chemical resistance
- Outstanding weathering and UV resistance (although PTFE can be degraded by gamma radiation dosages above 70 Mrad)
- Good toughness but generally low mechanical strength
- High specific gravity
- Translucent to opaque
- Higher cost
What is PTFE?

Chemically
- **Polytetrafluoroethylene**

What gives PTFE its unique properties?
- Fluorocarbon solid – strong bonding
- High molecular weight (at least 5,000,000) – long chain
- High Melting point (327°C) – long chain
- Hydrophobic – bonding structure
- Third lowest coefficient of friction (0.05 to 0.10) against any solid – Slipperiness
- Inert to many chemicals
Discovery of Expanded PTFE (ePTFE)

Another Accidental Discovery

- Bill Gore leaves his job at DuPont to pursue his belief in the untapped potential of PTFE and launched W. L. Gore & Assoc. in the basement of their home in Newark, Delaware (January, 1958)
- Expanded PTFE (ePTFE) accidently discovered by Bob Gore in October, 1969
- Frustrated with rods breaking when trying to slowly stretch hot PTFE rods, he quickly draws a hot PTFE rod
- Bob finds that he can stretch PTFE 1000-times its original length
- 1st ePTFE commercial product – Teflon Pipe Tape Sealant (1970)
- Gore’s industrial filter bag business begins, and Gore is the first to use expanded PTFE for filtration, pioneering membrane surface filtration to capture contaminants and other particles (1973)
- ePTFE Gore-Tex in apparel was introduced (1976)
- First HEPA filter in 1994
Process Filtration for BioTech and Pharmaceutical Applications

1. Contamination Risk Reduction
   - Durability and Stability
   - Enhanced Air Quality ("efficiency where it matters")

2. Energy Efficiency
Glass and ePTFE HEPA Filter Media

Both images are magnified equally
**PTFE vs. Glass Media Fibers**

- Micro-glass broken fibers at pleat tip
- Nelior media intact at pleat tip

**Fiber Size:** 450-500 nanometer (.45-.50 microns)
**Pore Size:** 1.5-2.0 micrometer
**Thickness:** 450-500 micrometer
**H13 MPPS Eff:** >99.95%

**Fiber Size:** 50-150 nanometer (.05-.15 microns)
**Pore Size:** 1.2-1.5 micrometer
**Thickness:** 80-120 micrometer
**H13 MPPS eff:** >99.95%
ePTFE Media Value Features

High overall particulate collection efficiency:

But the better MPPS efficiency is only half the story...

In the critical particle range of 0.07 μm up to 0.5 μm, ePTFE has a superior particulate collection efficiency.

The total number of viable airborne particles/m³ entering critical pharmaceutical areas can therewith be significantly reduced by a factor of up to 2.

This high efficiency performance of ePTFE also ensures that the risk of small microorganisms (e.g., viruses) entering classified environments is minimized as these require the larger sized particles as vehicle.

ePTFE Filtration Technology outperforms traditional HEPA in filtration efficiency for the critical particle size range

- MPPS = Most Penetrating Particle Size
- Comparative MPPS graphs are based on efficiency tests with class H14 flat media sheets @ airflow of 2.6 cm/s
Low Operating Resistance

SEM photographs at 10,000x magnification:

<table>
<thead>
<tr>
<th></th>
<th>Wet laid media</th>
<th>ePTFE media</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average pore size</td>
<td>3.0 µm</td>
<td>0.7 µm</td>
</tr>
<tr>
<td>Fiber diameter</td>
<td>0.5 - 1.0 µm</td>
<td>0.02 - 0.2 µm</td>
</tr>
<tr>
<td>Air movement effect</td>
<td>Non slip-flow</td>
<td>Slip-flow</td>
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Slip-flow air movement:
1. ePTFE media consist of fine nanometer-scale fibers
2. Scale of the fibers is small enough so that the distance between air molecules is significant in relation to fiber size
3. Air molecules hardly collide with the fiber surface and retain their velocities: low pressure drop
4. Because of the slip-flow phenomenon, viable particles can travel much closer to the fiber surface so that they can get caught easier: high efficiency

A = 50% lower pressure drop. B = 33% lower pressure drop, higher efficiency class
Comparative MPPS graphs are based on efficiency tests with flat media sheets @ airflow of 5.3 cm/s
ePTFE Media and Theory

- Predominant filtration by interception

- Low resistance to airflow due to “slip flow” principle: Nano fibers bend air less thus lower resistance
1. Air molecules collide with the fiber surface

2. Boundary layer formed at fiber surface: **Viscous flow**

3. Viscous flow is causing significant pressure drop

4. Viable particles are more difficult to catch

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1. Nano fiber is so small that most air molecules do not collide with the fiber

2. Air molecules can easily pass the fiber: **Slip-flow**.

3. Slip-flow is causing very low pressure drop.

4. Viable particles can travel much closer to the fiber surface getting captured.

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Laminar Velocity Profiles in a Duct

Note the boundary layer
Photometer – DOP / PAO Method

• Industry standard since 1960’s
  – Mil Standard 282, 1956 required 80 – 100 µg DOP / L
  – NSF Std 49, 1983 required > 10 µg DOP/ L

• Poly alpha olefin (PAO) replaced DOP in 1990’s

• FDA regulated facilities to test filters at least every 6 to 12 months

• Aerosol challenge of 10 - 20 µg PAO/ l of air
  – 15 µg PAO/l = 20 grams PAO / 800 cfm filter / hour
Impact of Oils on Early Generation ePTFE Media
Impact of PAO on HEPA Media

Differential Pressure vs. PAO Loading

- ePTFE
- PAO Sensitive
- Glass Media

Resistance, “wc”

Calculated Mass PAO (grams)
Modern Equipment to Test Modern Filters

• Advantages over traditional DPC testing
  – User friendly
  – Warns of insufficient challenge
  – Warns of non uniform mixing
  – Only audible beeps when Np is reached
  – Reads out directly in leak as a percent of challenge
  – Provides
Leak Detection (1 cfm or 28.3L/m)

If using a 1 cfm instrument, the following formula applies

**Leak detection when scanning**

\[ N_P = \frac{C_u \times P_L \times D_p}{60 \times S_r} \]

- \( N_P \): Number of counts that represent a potential leak during scanning
- \( C_u \): Upstream challenge concentration (particles/ft\(^3\))
- \( P_L \): Local penetration % expressed as a decimal (example 0.01% = 0.0001)
- \( D_p \): Probe dimension in the direction of scan (inches)
- \( S_r \): Scan rate (inches/sec)
- 60: Conversion: 60 seconds/min
Leak Sizing (1 cfm or 28.3L/m)

If using a 1 cfm instrument, things become much more simple

**Leak sizing with a stationary probe**

\[ P_L = \frac{C_d}{C_u} \]

- \( P_L \): Local penetration (leak) % expressed as a decimal (example 0.01% = 0.0001)
- \( C_u \): Upstream challenge concentration (particles/ft\(^3\))
- \( C_d \): Downstream challenge concentration (particles/ft\(^3\))
ScanAir Pro

Smart Upstream Sampling and Downstream Filter Scanning
SAP Handheld Interface

- Upstream
- Downstream
- Visual Sample Indicator
- Start Sample
- Settings
- Alarm Setting
- Stop Sample

Reading from left to right:

- Upstream
- Downstream
- Visual Sample Indicator
- Start Sample
- Settings
- Alarm Setting
- Stop Sample

Reading from top to bottom:

- Visual Sample Indicator
- Start Sample
- Settings
- Alarm Setting
- Stop Sample

Reading from bottom to top:

- Stop Sample
- Alarm Setting
- Settings
- Start Sample
- Visual Sample Indicator

Reading from middle to top:

- Visual Sample Indicator
- Start Sample
- Settings
- Alarm Setting
- Stop Sample
An aerosol diluter is built into the system in order to determine upstream concentrations.

Software alerts a user if there is insufficient and/or non uniform upstream concentrations.
System Configuration

- **% Significant Leak**
- **Units**
- **Upstream Challenge**

**Alarm**
- 0.010%

**Scan Rate**
- 2 "/s

**Units**
- ft³

**Mode**
- Scan

**Upstream Challenge**
- 20000000 / ft³

**Np**
- 6

**Scan Rate**
- inches/sec, cm/sec

**Sample Mode**
- Size/Scan

**Calculated Np**
Leak Sizing

Solair 3100
S/N: 123456789
Cal Date: 2014/07/07

Start Time:
2013/01/01 23:50:50

Company:

Filter:

Reagent:

Operator:

Leak Alarm: 0.01%
Upstream Challenge: 6,000,000/ft³

Leak Size: 0.050%
Leak Size: 0.020%
Leak Size: 0.025%

End Time:
2013/01/01 23:59:59

Result:

Signature:
Next Generation of ePTFE Oil Tolerant Filters

Exciting Advances in HEPA filters
Impact of PAO on HEPA Media

Differential Pressure vs. PAO Loading

- ePTFE
  - PAO Sensitive
- ePTFE – PAO Tolerant
- Glass Media

Resistance, "wc"

Calculated Mass PAO (grams)
Filter Life Comparison PTFE vs. Glass Filter
Filter Life Comparison PTFE vs. Glass Fiber

- Conventional PTFE (with pre/middle range filter)
- Commercial fiberglass (with pre filter)
- New fluororesin (with pre filter)
- New fluororesin (with pre/middle range filter)

Test period (day)
Pressure drop (Pa)
Impact of PAO on HEPA Media

Differential Pressure vs. PAO Loading

- ePTFE – PAO Resistant
- Glass Media
- ePTFE – PAO Sensitive

Calculated Mass PAO (grams)

Resistance, “wc”

0 0.20 0.40 0.60 0.80 1.00 1.20
0 50 100 150 200 250 300 350 400
**What is Nelior and NeliorPC?**

ePTFE media that should be tested with a Particle Counter

<table>
<thead>
<tr>
<th>Nelior PC</th>
<th>Nelior</th>
<th>Commercial Microfiberglass</th>
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<tbody>
<tr>
<td><img src="image1" alt="SEM Image (x5000)" /></td>
<td><img src="image2" alt="SEM Image (x5000)" /></td>
<td><img src="image3" alt="SEM Image (x5000)" /></td>
</tr>
<tr>
<td>Membrane or Microglass <strong>Surface</strong></td>
<td>Membrane</td>
<td><strong>GF</strong></td>
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<tr>
<td>View</td>
<td>SEM Image</td>
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<td>Membrane or Microglass <strong>Edge</strong></td>
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- **M** Membrane
- **NW** Nonwoven
- **GF** Glass Fiber
The reasons why Nelior has...

- high efficiency
- many fibrils
- low pressure drop
- thin fibrils
- excellent durability
- nonwoven layer gives protects membrane

Nonwoven Layer (for support)

Expanding PTFE Membrane (~100μm depth)

PTFE Nodes (for structure)

PTFE Fibrils (for filtration)

Human Hair (~60μm diameter)

Ref: 100μm in SEM Scale

~1.5x Human Hair Diameter
Comparison of PAO Challenge Concentration Ranges

Aerosol Concentration µg/l

Particle Counter

- Microglass
- ePTFE (oil-tolerant)

~0.03 – 0.3 µg/l

Photometer

- ePTFE (oil-sensitive)
- Microglass
- ePTFE (oil-tolerant)

~10-40 µg/l
Summary

• Glass media has been around for 75 years
  – Fragile but oil tolerant
  – Good dust holding capacity

• Early ePTFE media since 1994
  – Very durable
  – Not tolerant of oil challenge aerosols
  – Limited dust holding capacity
  – Less than 50% of the resistance of glass
Summary

• Latest generation of ePTFE
  – Very durable
  – Over twice the oil holding capacity of glass media
  – Dust holding capacity exceeds glass
  – Approximately 50% lower resistance than glass
Questions?