Your partner for
Commercialization of Nanofibers Products

May 2016
Agenda

- Nanofibers - A world in $10^{-9}$ m
- Nanospider™ technology
- About Elmarco
- Nanospider™ Products
- Key for successful scale up towards commercialization
- Growth of Nanofibers Market & Industries
- Nanofiber applications
Nanofibers - A world in $10^{-9}$ m

**Definition**

- **Nanofibers are a nanomaterial**
  - At least one dimension less than 100 nm
- **Industrial definition: diameters below 1,000 nm**
  - Made from polymers
  - Created and used as a layer or web

**Benefits**

- Very large specific surface area
- Extremely high porosity
- Small pore size – good breathability
- Wide range of polymers capable of spinning
- Possibility to incorporate different additives
Ways to make Nanofibers

<table>
<thead>
<tr>
<th>Process</th>
<th>Technological Advances</th>
<th>Can the process be scaled</th>
<th>Control on fiber dimensions</th>
<th>Material Flexibility</th>
<th>Fiber diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing</td>
<td>Laboratory</td>
<td>Limited</td>
<td>No</td>
<td>Limited</td>
<td>2-100 nm</td>
</tr>
<tr>
<td>Template Synthesis</td>
<td>Laboratory</td>
<td>No</td>
<td>Limited</td>
<td>Limited</td>
<td>100 nm</td>
</tr>
<tr>
<td>Self-Assembly</td>
<td>Laboratory</td>
<td>No</td>
<td>No</td>
<td>Limited</td>
<td>5-100 nm</td>
</tr>
<tr>
<td>Phase Separation</td>
<td>Laboratory</td>
<td>No</td>
<td>No</td>
<td>Limited</td>
<td>50-500 nm</td>
</tr>
<tr>
<td>Electrospinning</td>
<td>Industrial</td>
<td>Yes</td>
<td>Yes</td>
<td>Wide</td>
<td>50-500 nm</td>
</tr>
<tr>
<td>Melt Electrospinning</td>
<td>Laboratory</td>
<td>No</td>
<td>Yes</td>
<td>Wide</td>
<td>200-800 nm</td>
</tr>
<tr>
<td>CO2 Laser</td>
<td>Laboratory</td>
<td>No</td>
<td>Limited</td>
<td>Limited</td>
<td>100-500 nm</td>
</tr>
<tr>
<td>Force Spinning</td>
<td>Laboratory</td>
<td>No</td>
<td>Limited</td>
<td>Wide</td>
<td>200-500 nm</td>
</tr>
<tr>
<td>Sea &amp; Ireland</td>
<td>Industrial</td>
<td>Limited</td>
<td>Limited</td>
<td>Limited</td>
<td>200-500 nm</td>
</tr>
<tr>
<td>Melt Blown</td>
<td>Industrial</td>
<td>Yes</td>
<td>Yes</td>
<td>Wide</td>
<td>400-50,000 nm</td>
</tr>
</tbody>
</table>
Nanofibers – Scale

**Nano vs. Micro**

**Electrospinning**
Elmarco Nanospider™

**Fine Fiber Meltblown**

**Meltblown**

Fiber diameter:

- **50-500 nm**
- **100nm - 10 µm**
- **1 - 50 µm**
Nanofibers – Scale  

Nano vs. Micro

Major Nonwoven Production Process

- Spunbond
  - Fiber diameter: 5 - 100 µm

- Meltblown
  - 1 - 50 µm

- Electro Spinning
  - Elmarca Nanospider
  - 50 - 500 nm
1890: Lord Raleigh observed electrostatic atomization of conductive fluid under applied voltage

1897: Lord Raleigh, observed electrostatic atomization of conductive fluid under applied voltage

1914: John Zeleny studied the phenomena occurring in the electrospay process

1934: Anton Formhals assigned the first U.S. patent for the electrospinning process

1952: Radushkevich and Lukyanovich created hollow graphitic carbon fibers

1960: Oberlin, Endo and Koyama developed a CVD process for creating nanoscale carbon fibers

1976: Oberlin, Endo and Koyama developed a CVD process for creating nanoscale carbon fibers

1980s: Donaldson Co. introduced manufacturing of electrospun polymeric nanofibers at industrial level

1987: Hyperion Catalysis assigned first U.S. patent for hollow carbon fibers

1991: Sumio Iijima discovered multi-walled carbon nanotubes

1993: IBM Almaden Research Center and NEC discovered single-walled carbon nanotubes

1995 and beyond: Increasing R&D activities in the field of nanofibers and their fabrication processes

2004 Elmarco Nanospider NS Lab launched
Electro Spinning: A growing technology

Electro Spinning Related Publications by Country of Origin

- China: 40%
- United States: 32%
- South Korea: 16%
- Japan: 7%
- Singapore: 5%

International Patent Applications by Publication Year

- Number of publications
- Patent count: 0, 500, 1000, 1500, 2000, 2500, 3000

Electro Spinning Related Publications

Number of publications
Electrospinning (ES) – How to make nanofiber web? – Conventional approach

The process of electrospinning was patented by J.F Cooley in February 1902 (U.S. Patent 692,631) and by W.J. Morton in July 1902 (U.S. Patent 0,705,691)

Movie
Technical Challenges by Needle type technology for mass production

Conventional NEEDLE TYPE

Electrospinning is **NOT** Suitable for Industrial Scale Production

- CLOGGING AT NEEDLE (NOZZLE) TIP
- MECHANICAL COMPLEXITY OF DESIGN
Nanospider™ Electrospinning
The Elmarco Way

NanoSpider™ Technology does NOT use Needles
Nanospider™ - Needle-free technology

Benefits

- Electrode is uniformly coated in polymer
- Nature defines the distance between Taylor cones
- Mechanically simple
- Lower operating costs
- Lower equipment costs
- Higher fiber packing density
- Higher fiber uniformity
- Higher web uniformity
- Lower equipment costs
- Lower operating costs
Nanospider™ IN ACTION

Production Line Photos – Courtesy by ATIRA - Ahmedabad Textile Industry’s Research Association (India)
Nanospider™ - Technology Development
Generation 1.1 – non-Water Solvents

- **Principle:**
  - Describe in many patents
  - Example: PCT/CZ2007/000082

- **Shape of spinning electrode**
  - Wire place on rotation shape
Nanospider™ - Enhanced 2Gen technology

Benefits of 2Gen technology based on stationary wire electrode system:

- Nanofiber and nanofiber web uniformity
- Low polymer and solvent consumption
- Highly volatile solvents capability
- Designed for long time shifts
- Cost effective operation
Nanospider™ - Needle-free technology

- Needless: Nature defines the distance between Taylor cones
- Simplicity of design
- Robustness against clogging of a spinneret
- Increased productivity though the simultaneous operation of numerous jets.

Nanospider™ – Quality

- Uniformity in all directions
- Homogeneous size distribution
- Defect-free structure
- Reproducibility (repeated results at long-term)
- Industry-proven technology
Nanospider™ - Web Uniformity

Cross profile uniformity

![Graph showing linear speed vs. pressure drop with various linear speeds including 0.4 m/min, 0.6 m/min, 0.8 m/min, 1 m/min, 1.5 m/min, 2 m/min, 2.5 m/min, 3 m/min, and Filter paper. The graph indicates the standard deviation is 3 – 52 Pa.](image)
Nanospider™ - Fiber Uniformity

Table 1. shows SEM picture (magn. 5000 x) with PA6 nanofiber layer, frequency diagram of fiber diameter and basic statistical data.

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Count of fibers</td>
<td>80</td>
<td>Mean</td>
<td>71 nm</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>17 nm</td>
<td>Coefficient of variation</td>
<td>24%</td>
</tr>
</tbody>
</table>
Tuning at industrial scale - PA6

<table>
<thead>
<tr>
<th>Mean fiber diameter</th>
<th>147 nm</th>
<th>110 nm</th>
<th>50 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average pore size</td>
<td>500 nm</td>
<td>330 nm</td>
<td>165 nm</td>
</tr>
</tbody>
</table>
### Nanospider™ - Process Stability

The stability of the Nanospider electrospinning process over 24 hours is shown. The chart indicates a relatively stable process with a mean pressure drop of 169 Pa and a standard deviation of 6 Pa, resulting in a coefficient of variation of 4%. For the basis weight, the mean is 0.063 g/m² with a standard deviation of 0.003 g/m², leading to a coefficient of variation of 5%.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Coefficient of Variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure drop*</td>
<td>169 Pa</td>
<td>6 Pa</td>
<td>4%</td>
</tr>
<tr>
<td>Basis weight</td>
<td>0.063 g/m²</td>
<td>0.003 g/m²</td>
<td>5%</td>
</tr>
</tbody>
</table>
Nanospider™ - Material flexibility

<table>
<thead>
<tr>
<th>Organic</th>
<th>Inorganic</th>
<th>Biopolymers</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA6, PA 6/12</td>
<td>TiO₂, SiO₂, SnO₂, WO₃, Al₂O₃, Li₄Ti₅O₁₂</td>
<td>Gelatin, Chitosan, Collagen, Pullulan, PAA, PVA, PLA, PCL</td>
</tr>
<tr>
<td>Polyaramid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OR (Polyurethane)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PES (Polyethersulfone)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVA (Polyvinylalcohol)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PAN, PEO, PS, PVP, PVP-I</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PVDF, PVDF-CTFE</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Selected examples only, numerous other polymer systems have been deployed.
Nanofiber Production Technology – Industrial

Needle-free (Nanospider™)

Centrifugal

Multi-nozzle

Multi-needle
# Quality Comparison – PA6

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Nanospider™</th>
<th>Benchmark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fiber diameter</td>
<td>Mean fiber diameter: 100 nm</td>
<td>Mean fiber diameter: 160 nm</td>
</tr>
<tr>
<td></td>
<td>(controlling fiber diameter at industrial scale)</td>
<td>(no fiber diameter control)</td>
</tr>
<tr>
<td>Fiber diameter distribution</td>
<td>Narrow: StDev: 21</td>
<td>Wide: StDev: 73</td>
</tr>
<tr>
<td>Defects</td>
<td>Defect free</td>
<td>Beads, droplets, discontinuous and non-uniform fibers</td>
</tr>
<tr>
<td>Uniformity (Thickness, MD and CD)</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Pore size</td>
<td>Uniform pore structure with controllable pore size</td>
<td>Non-uniform pore structure – no pore size control</td>
</tr>
</tbody>
</table>
ABOUT ELMARCO

Elmarco is the industry's first supplier of industrial scale nanofiber production equipment.
Elmarco - Global support and service

Liberec, Czech Republic
- Global HQ, Sales, Service - Europe
- Corporate R&D
- Equipment production

Raleigh, NC, USA
- Sales, Service, Americas, Showroom

Tokyo, Japan
- Sales, Service, Asia-Pacific, Showroom

Elmarco - Global support and service
### Elmarco - Milestones

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td><strong>Elmarco’s Nanofiber division was formed in 2004</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>• First Nanospider™ lab prototype developed for water soluble polymers</td>
<td>• 2007: first industrial Nanospider™ line was installed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• First Nanospider™ equipment for solvent-based polymers developed</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td></td>
<td>• New World-class Technology Center in Liberec and supporting offices in the US and Japan was opened</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td>• 2007: first industrial Nanospider™ line was installed</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 2Gen Nanospider™ technology introduced</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• First installation of 2Gen NS Line 1600</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 2Gen lab tool introduced</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Air filtration reference product development</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 100 Nanospider™ machines sold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• First Nanospider™ line installed in cleanroom facility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• 150 Nanospider™ machines sold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• High perform. Nanospider™ technology for NF membranes</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>
Elmarco, an Innovator
- Top High-tech Company in Czech Republic

A visit of
Mr. Vaclav Klaus, President of Czech republic
to Elmarco HQ in Czech republic on Wednesday, April. 20, 2011
The total number of participants: 340

From which field?

- University, Research Institute: 20%
- Industry, commercial company: 80%
Elmarco, an Innovator - EXPO 2010, Shanghai

Elmarco NanoSpider Model In Czech Pavilion at EXPO 2010

Nanofiber Technical Seminar At Elmarco Day, Oct. 2010
Elmarco - Tokyo Showroom

Since February 2011

August 30 - September 1, 2010
North Carolina, USA
http://www.nano3millennium.com/
**Nanospider™ - Product portfolio**

<table>
<thead>
<tr>
<th>Lab Products</th>
<th>Production Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NS LAB</strong></td>
<td><strong>NS 1S500U</strong></td>
</tr>
<tr>
<td>0.3 m width</td>
<td>0.5 m width</td>
</tr>
<tr>
<td>Single electrode</td>
<td>Single electrode</td>
</tr>
<tr>
<td>Standalone spinning unit</td>
<td>Standalone spinning unit (line)</td>
</tr>
</tbody>
</table>

**Elmarco’s flagship product**

- Designed for the academic and basic research market
- Optimized for the rigors of industrial labs and corporate R&D
- Targeted towards reliable 24/7/365 production
Nanospider™ - NS 8S1600U

Technical data
• Stationary wire principle electrodes
• 8 spinning electrodes per unit
• 1,6 m spinning electrode width
• Scalability up to 4 units (32 spinning electrodes) in line

Benefits
• Optimized for non water soluble polymers
• High throughput per unit
• High nanofiber web and fiber uniformity
• Low volume polymer system with reduced solvent & polymer consumption
Nanospider™ - NS 8S1600U

Production volume scalability

- 1, 2, 3 or 4 spinning units in line
- 8, 16, 24 or 32 spinning electrodes in line
- Start with one unit and scale up by addition of spinning units
- Centralized process control
- Optional peripheral equipment
NS8S1600U Major Peripheral Equipment

Filling & Cleaning Station + Polymer Mix Station

Precise Air Conditioning Unit

Adhesion Module

Hot Air Dryer

Solvent (Waste Air) Treatment System

Scrubber Type

Catalytic Oxidization Type
Production Layout Example – NS8S1600U
Nanospider™ - NS 4S1000U

Technical data
• Stationary wire principle electrodes
• 4 spinning electrodes
• 1,0 m spinning electrode width (configurable between 0,3 – 1,0 m)

Benefits
• Optimized for non water soluble polymers
• High nanofiber web and fiber uniformity
• Cost effective equipment for early stage manufacturing
Nanospider™ - NS 1S500U

Technical data

- 500 mm spinning electrode width
- Run time per batch approx. 60 min, (depends on polymer / solvent solution)
- Integrated unwind / rewind with low substrate speed capabilities for thick membrane materials preparation
- Process data tracking for PC analysis

Benefits

- Full time shit operation enabled by peristaltic pump for continuous feeding of polymer solution
- Easy to switch between production and experimental work
- Enabled for higher gsm and composite samples preparation
- Easy set up and operation

Movie
Nanospider™ - NS LAB

Technical data

- Spinning electrode width: 300 mm
- Run time per batch: 30 - 80 min (depends on polymer / solvent solution)
- Volume of solution per batch: 40 ml
- Substrate speed: 0 - 5000 mm/min
- Spinning voltage: 0 - 80 kV
- Integrated substrate unwind / rewind

Benefits

- Designed for experimental work
- Compact and affordable research tool
- Easy to scale up to industrial technology
- Time saving experimental work
- Safety door locks and shut off switches
Nanospider™ - NS LAB

Basic research and development
• Robust platform for creating a uniform nanofiber membrane for materials science, technical textile and membrane experimental work
• Designed for experimentation and product development in academic, research and industrial spheres

Basic application exploration
• Ideal for exploratory research in membrane, air filtration, liquid filtration, medical, and many other areas
• Designed to enable basic materials science exploration such as process parameters and new material development
Nanospider™ - NS LAB

Stationary wire electrode system

- The same industrial-proven technology as found in industrial NS production lines
- High throughput
- High nanofiber diameter uniformity
- High nanofiber web homogeneity
- Easy to scale up to NS production lines

Easy to scale up
Nanospider™ - NS LAB 200, NS LAB 500

Technical data
• Interchangeable spinning electrode
• 500 or 200 mm spinning electrode width
• Run time per batch up to 20 min (depends on polymer / solvent solution)
• Scalable volume polymer system
• Built in roll-to-roll capabilities for substrates

Benefits
• Designed for experimental work
• Easy to scale up to industrial technology
• Capable of spinning variety of polymers
• Coat numerous substrates, including cellulose, synthetics and fiberglass
• Time saving experimental work

Discontinued
A company who has mass production electrospinning technology will be the winner !!!

Source: BBC Research
Nanofibers Applications
APPLICATIONS BY INDUSTRY

Environment
- Optical waveguides
- Fuel cells
- Drug delivery materials
- Hard disk drives
- Flat panel displays
- Solar cells
- Lithium Batteries
- Wound care materials
- Tissue engineering
- Barrier garments
- Respirators
- Batteries
- Noise absorption
- Filters
- Sound insulation
- Thermal insulation
- Air filtration
- Water filtration
- Photocatalysts
- Ion exchange systems
- Electrostatic discharge
- Solar panels
- Optoelectronic devices
- Piezoelectric devices

Electronics

Energy

Defense
- Bulletproof uniforms
- Warfare protection
- Anticounterfeiting devices

Health

Automotive

Building

Consumer
- Biodegradable packaging
- High-tech textiles
- Personal care
- Bulletproof uniforms
- Warfare protection
- Anticounterfeiting devices
Nanofiber applications – Ready for commercialization

**Air filtration**
- Industrial HVAC
- Engine air Intake
- Cleanroom (HEPA, ULPA)
- Gas turbines
- Dust collectors

**Acoustic materials**
- Transportation
- Room acoustics
- Home appliances
- Industrial equipment

**Healthcare**
- Wound care
- Tissue engineering
- Drug release
- Surgical drapes
- Face masks

**Liquid filtration**
- Drinking water preparation
- Fuel and oil filtration
- Processing filtration
- Waste water treatment
- Seawater treatment

**Lithium-ion batteries**
- Battery separators
- Battery electrodes

**Performance apparel**
- Outdoor sportswear
- Protective clothing
- Footwear
Applications by Elmarco Nanospider™
Production Line customers

- Air filtration
- Liquid filtration
- Technical textiles
- Battery separators
- Medical
- Research, others

Note: Figures valid as of May 2013
FILTRATION

Nanofibrous filter media has enabled new levels of filtration performance in several diverse applications within a broad range of environments, with improved filter life, increased contaminant holding capacity and enhanced filtration efficiency.
BENEFITS OF NANOFIBROUS FILTER MEDIA

- Relatively straightforward way to upgrade low cost, low performance media to high end media at a lower or competitive cost.

- Often best performance combination metrics available (i.e. high efficiency, low pressure drop, longer life).

- Flexible and universal media design platform with wide variety of materials.
HEPA – Grade

Nanofibers not relevant

Commercial Solution

Development

EN 779:2012

- Course Filters
- G1-G4
- Average arrestance (Am) of synthetic dust %

EN 1822:2009

- Aerosol Filters
- E10-E12
- Integral efficiency MPPS

- Medium Filters
- M5-M6
- Average efficiency (Em) for 0.4 μm particles %

- Fine Filters
- F7-F9
- Minimum efficiency (ME) for 0.4 μm particles %

- H13-H14
- U15-U17
- Integral and Local efficiency MPPS

Nanofibers not relevant
Nanofiber Depth Filter Media

Nanofibers for surface filtration

Nanofiber layer

Substrate

Airflow

Nanofibers for depth filtration

Stiffening layer

Nanofiber layer

Capacity layer

Airflow

A synthetic nanofiber filter media which meets high mechanical efficiency, low pressure drop and high dust loading capacity
Gradient Media Design

Traditional media provides a coarse pre-filter upstream to enhance dust holding capacity and a nanofiber layer with finer pore structure and smaller fiber diameter downstream for high particulate filtration efficiency.

- **Substrate Layer**
  - Protecting nanofibers
  - Improving rigidity [for pleating]
  - PET spunbond

- **Nanofiber Layer**
  - Fine filtration (small particulates)
  - High filtration efficiency
  - Low pressure drop

- **Capacity Layer**
  - Pre-filtration (large particulates)
  - High dust holding capacity
  - Prevents clogging of nanofibers [Extends filter life]
  - PP meltblown

Air flow
Features

- 8 spinning electrodes per unit
- 1.6 m spinning electrode width
- Scalability up to 4 units (32 spinning electrodes) in line
## Performance

<table>
<thead>
<tr>
<th></th>
<th>English</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>High efficiency mini-pleat V-bank filter</td>
<td></td>
</tr>
<tr>
<td><strong>Nominal dimensions (H x W x D)</strong></td>
<td>24 x 24 x 12 (inches)</td>
<td>610 x 610 x 305 (mm)</td>
</tr>
<tr>
<td><strong>Media area</strong></td>
<td>172 ft²</td>
<td>16 m²</td>
</tr>
<tr>
<td><strong>Nominal face velocity</strong></td>
<td>492 fpm</td>
<td>2.5 m/s</td>
</tr>
<tr>
<td><strong>Initial pressure drop</strong></td>
<td>0.33 in wg</td>
<td>82 Pa</td>
</tr>
<tr>
<td><strong>Efficiency Rating per ASHRAE 52.2: 2007</strong></td>
<td>MERV 15 @ 1968 cfm &gt;95%</td>
<td>F9 @ 0.944 m³/s &gt;95%</td>
</tr>
<tr>
<td><strong>Efficiency Rating per ASHRAE 52.2: 2007 Appendix J</strong></td>
<td>MERV 15A (F9) @ 1968 cfm &gt;95%</td>
<td></td>
</tr>
<tr>
<td><strong>Dust holding capacity</strong></td>
<td>300 g @ 1.5 in wg</td>
<td>300 g @ 375 Pa</td>
</tr>
</tbody>
</table>

### Typical Applications
- Commercial buildings
- Hospitals
- Educational facilities
- Manufacturing facilities
- Research facilities

### Min. Composite Efficiency (%) after KCL conditioning

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1 - A (0.3 - 1.0 μm)</td>
<td>89</td>
</tr>
<tr>
<td>E2 - A (1.0 - 3.0 μm)</td>
<td>98</td>
</tr>
<tr>
<td>E3 - A (3.0 - 10 μm)</td>
<td>100</td>
</tr>
</tbody>
</table>

In accordance with ASHRAE 52.2:2007 Appendix J, an independent lab testing has certified the reference filter at **MERV 15A**.
Performance benchmarking with industry leading products. Nanofiber coating provides higher dust holding capacity with better mechanical filtration efficiency and lower pressure drop.
Discharge Durable Nanofibers

Filter Efficiency vs. Particle Size at 492 FPM

- No efficiency drop after discharge procedure
- Proven durability of nanofibers
- High mechanical filter efficiency
- Industry leading low pressure drop

Filtration Efficiency vs. Particle Size at 5.3 cm/s

- Baseline media
- IPA liquid bath 1min/24h
Mechanically Durable Nanofibers

![Diagram of filter media with air flow and labeled layers: Substrate layer, Nanofiber layer, Capacity layer.]

No damage after pleating & assembling.
HEPA Media

- Glass fiber is the industry standard for HEPA filters. Inexpensive.
- Despite low initial pressure drop of e-PTFE filter the rate of increase in pressure drop with PAO loading is substantially higher than microfiber glass media filter.

Microglass fiber  

![Microglass fiber](image1)

ePTFE  

![ePTFE](image2)

eSpun PA6  

![eSpun PA6](image3)

Pharmaceutical Engineering, Jan/Feb 2013, vol 33, No1
HEPA Media Design

- Multilayered composite media design for HEPA filters

- Fully synthetic composite media with high quality nanofibers
- Not fragile, flexible and easy to handle [Robust materials that perform better than wetlaid glass in materials handling.]
- Lower pressure drop than traditional wetlaid glass media
HEPA FILTER MEDIA made by PA6 Nanofibers

Sample dispatch note

<table>
<thead>
<tr>
<th>SAMPLE DETAILS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Polymer</strong></td>
</tr>
<tr>
<td><strong>Substrate</strong></td>
</tr>
<tr>
<td><strong>Defects</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measuring parameters</th>
<th>Properties</th>
<th>Measure d value</th>
<th>Unit</th>
<th>coeff. of variation</th>
<th>Number of measurements</th>
<th>Timing of measurements</th>
<th>Value</th>
<th>Result</th>
<th>Method description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure drop</td>
<td>200</td>
<td>Pa</td>
<td>± 8</td>
<td>25</td>
<td>end of sample</td>
<td>200 OK</td>
<td></td>
<td></td>
<td>testing area 20cm²; airspeed 5.3cm/s - Textest 3300</td>
</tr>
<tr>
<td>Fiber diameter</td>
<td>195</td>
<td>nm</td>
<td>± 51</td>
<td>60</td>
<td>end of sample</td>
<td>OK</td>
<td></td>
<td></td>
<td>SEM picture analysis</td>
</tr>
<tr>
<td>Adhesion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OK</td>
<td>finger test, wetting test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Filtration efficiency</td>
<td>99.995</td>
<td>%</td>
<td>± 0.005</td>
<td>13</td>
<td>end of sample</td>
<td>99.97% OK</td>
<td>SEM picture analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample volume</td>
<td>12</td>
<td>m</td>
<td></td>
<td></td>
<td></td>
<td>OK</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SAMPLE IMAGE
Applications

HVAC
- Commercial buildings
- Hospitals
- Universities
- Schools
- Airports
- Manufacturing facilities
- Hotel
- Entertainment complexes
- Research facilities

Automotive
- Cabin air intake
- Engine intake

Air Purifier & Vacuum Cleaner
- HEPA
Nanofiber applications – **Liquid filtration**

**Key features of nanofibers:**
- High porosity
- Small pore size
- Interconnected pore structure
- Unique physical and mechanical performance
- Design flexibility for chemical / physical surface functionalization

**Inexpensive substrate + thin nanofiber coating = superior filtration performance at a lower cost**

Nanofibrous filtering media could be used for filtration of water, beverages, bio-pharma materials, blood, chemicals, oils, diesel, petrol, etc.
LIQUID FILTER MEDIA made by PA6 Nanofibers

Sample dispatch note

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Order No.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### SAMPLE DETAILS

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Substrat e</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA6</td>
<td>PA meltblown</td>
</tr>
</tbody>
</table>

### Measuring parameters

<table>
<thead>
<tr>
<th>Properties</th>
<th>Measured value</th>
<th>Unit</th>
<th>coeff. of variation</th>
<th>Number of measurements</th>
<th>Timing of measurements</th>
<th>Result</th>
<th>Method description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis weight</td>
<td>2.13</td>
<td>gsm</td>
<td>± 3.1%</td>
<td>6</td>
<td>start/end</td>
<td>OK</td>
<td>peeling and weighting material</td>
</tr>
<tr>
<td>Fiber diameter</td>
<td>100</td>
<td>nm</td>
<td>± 18.0%</td>
<td>4x;&gt;50</td>
<td>start/end</td>
<td>OK</td>
<td>SEM picture analysis</td>
</tr>
<tr>
<td>Bubble point</td>
<td>185.2</td>
<td>kPa</td>
<td>± 3.6%</td>
<td>9</td>
<td>start/end</td>
<td>OK</td>
<td>PMI Capilary flow porometer</td>
</tr>
</tbody>
</table>

### SAMPLE IMAGE

- Sample image 1
- Sample image 2
- Sample image 3
PERFORMANCE APPAREL
Electrospun nanofiber webs can be engineered with a desired porous structure and a range of polymers. Manufacturers are able to optimize the performance of the composite material by the unique combination of nanofiber web properties:

- High specific surface area
- Low basis weight
- Small fibre diameter
- Porous structure with high permeability
- Potential to incorporate active chemistry

Performance apparel fabrics are evaluated on the performance of the composite material. Attributes most frequently evaluated include:

- Water resistance
- Breathability
- Water vapor transmission
- Windproof
- Resistance to wear
Waterproof breathable nanofiber membrane

- Porous structure with high permeability
- Low basis weight
- Small fibre diameter
- High specific surface area
- Potential to incorporate active chemistry

Waterproof breathable fabric with nanofiber membrane

[Image of waterproof breathable fabric with nanofiber membrane]
Air permeability is relatively low due to the nodules which interrupt air flow.

Air permeability is excellent due to the high porosity and interconnected pore structure.
Performance Apparel: Nanofibers Composite Recipe

<table>
<thead>
<tr>
<th>Polymer</th>
<th>Nanospider™</th>
<th>Post-Processing</th>
<th>NF Composite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Use hydrophobic NF Layer</td>
<td>NS4S1000U and NS8S1600U</td>
<td>Use calendar to compress the NF layer</td>
<td>1. Outer layer provides tear and abrasion resistance</td>
</tr>
<tr>
<td>Potential use of additives</td>
<td>To produce 5 – 10 gsm layer of NF on baking paper for delamination</td>
<td>Other coatings to improve water barrier</td>
<td>2. NF Layer for water barrier</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3. Soft inner layer for comfort</td>
</tr>
</tbody>
</table>
Nanofiber applications – Battery separators

Nanofiber separators characteristics
• Chemical stability
• Thermal stability
• Thickness
• Porosity (greater than 40%)
• Dimensional stability
• Pore and pore size distribution
• Tensile strength

Battery with superior parameters
• Lower consumption of polymer material due to lower basis weight of the membrane
• Significant increase of battery power density
• Higher charge and discharge rate
• Increase in battery life
Nanofiber applications – Healthcare

Nanofiber benefits for WOUND CARE
- Promote healing
- Protection from infection
- Providing soft and moist environment
- Anti adhesive effect to the derma
- Ease pain

Nanofiber benefits for DRUG RELEASE
- Slower drug release over a longer period
- Reduction of the first pass effect
- Higher initial drug concentration
- Lower overall drug consumption

Nanofiber benefits for TISSUE ENGINEERING
- Cell growth
- Proliferation
- Differentiation
- Ability to mimic the extracellular matrices
Potential Applications of PLA Nanofibers

- Implant medical devices
- Scaffolds for tissue engineering
- Drug delivery devices
- Hygiene products
- Biosensor
- Membrane for filtration
- Catalysis
- Food packaging