Technical Seminar about Nano Fiber Technology

by aeolus filter corp

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Nanotechnology –

A novel and promising approach to nonwoven fabrics

NAFA Technical Seminar 2007
Introduction

Particle Deposition Mechanisms

Established Manufacturing Techniques for Nanofibers

Development of a new Production Process

Comparison of Manufacturing Techniques

Conclusion
**Introduction - What is Nanotechnology?**

Nanotechnology is the creation of functional materials, devices, and systems through control of matter on the nanometer (1 to 100+ nm) length scale and the exploitation of novel properties and phenomena developed at that scale.
Potential Applications for Polymer Nanofibers

**Tissue engineering scaffold**
- Adjustable biodegradation rate
- Better cell attachment
- Controllable cell directional growth

**Wound dressing**
- Prevents scar
- Bacterial shielding

**Medical prosthesis**
- Lower stress concentration
- Higher fracture strength

**Filter media**
- Higher filter efficiency

**Protective clothing**
- Breathable fabric that blocks chemicals

**Cosmetics**
- High utilization
- Higher transfer rate

**Material reinforcement**
- Higher fracture toughness
- Higher delamination resistance

**Drug delivery**
- Increased dissolution rate
- Drug-nanofiber interlace

**Heamostatic devices**
- Higher efficiency in fluid adsorption

**Optical applications**
- Liquid crystal optical shutters

**Electrical conductors**
- Ultra small devices

**Sensor devices**
- Higher sensitivity
- For cells, arteries and veins

**Polymer Nanofibers**

**Potential Applications for Polymer Nanofibers**

- Tissue engineering scaffold
- Wound dressing
- Medical prosthesis
- Filter media
- Protective clothing
- Cosmetics
- Material reinforcement
- Drug delivery
- Heamostatic devices
- Optical applications
- Electrical conductors
- Sensor devices
Growth Rates for Nonwovens for Filtration

![Graph showing growth rates for nonwovens for filtration from 1995-2002, 2000-2005, and 2005-2010. The graph compares the compound growth rate of nonwoven total and nonwoven for filtration.]

Source: Nonwoven End Use Products; World Market Forecast to 2010 David Rigby Associates Limited, January 2003
Some Facts:

- Indoor air contaminants: Volatile organic compounds, allergens, microorganisms ...
  - **Health and productivity related threats**
- 90% of particles are < 1 μm
- Particles adsorb chemicals, including carcinogens and mutagens

Particles contain many irritants, toxic chemicals and nitrogen oxides
- **Negative environmental impact**

Constant enhancement of filtration media is of great importance
Overview

- Introduction
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Particle Deposition Mechanisms - Overview

- Screening
- Inertial impaction
- Interception
- Diffusion
Particle Deposition Mechanisms - Slip Flow Effect I

For nanofibers another effect has to be taken into account:

**Slip flow effect**

- **Non-slip flow**: Air velocity is zero at the fiber surface.
- **Slip flow**: Air velocity is not zero at the fiber surface.
Particle Deposition Mechanisms - Slip Flow Effect II

Knudsen number:

\[ Kn = \frac{\lambda}{r_f} \]

With:
- \( \lambda = \) gas mean free path (for air: \( \lambda = 0.006 \mu m \))
- \( r_f = \) radius of the fiber

- \( Kn < 0.1 \) non-slip flow
- \( Kn > 0.1 \) slip flow starts
- \( Kn \approx 0.25 \) definit slip flow!

For fibers with diameters smaller than 0.5 \( \mu m \) the slip flow effect has to be taken into consideration!
Particle Deposition Mechanisms - Slip Flow Effect III

**Impacts of the slip flow effect**

- **Decreasing pressure drop**

\[ \Delta p = \frac{\eta U_0 f(\alpha)}{d_f^2} \]

where

- **Increasing collection efficiency**

\[ f(\alpha) = 64\alpha^{1.5}(1 + 56\alpha^3) \]

for \( 0.006 < \alpha < 0.3 \)

With:
- \( \eta \) = viscosity
- \( d_f \) = diameter of the fiber
- \( t \) = thickness of filter
- \( U_0 \) = face velocity of filter
- \( \alpha \) = Volume fraction of fibers in a filter

\[ \alpha = \frac{fiber \ volume}{total \ volume} = 1 - \text{porosity} \]

For example, a filter having a \( d_f \) of 0.1 μm and \( \alpha \) of 0.05 has a \( \Delta p \) that is 70% of that predicted.
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Manufacturing Techniques

- Electrospinning
- Meltblown Process
- Island-In-The-Sea
Manufacturing Techniques - Electrospinning

Advantages

- Fiber diameters as low as 50 nm
- Various polymers applicable
- Homogeneous fiber diameters

Disadvantages

- Low production rate
- Use of environmentally critical solvents
- Two-step-process
- Fibers only in layers
Manufacturing Techniques – Island-in-the-Sea

- Spinning of bicomponent fibers
- Island-in-the-sea structure
- Different geometries
- Dissolving sea-polymer

**Advantages**
- Standard spinning processes for bico-fibers
- Narrow diameter range

**Disadvantages**
- Nano-range not easy achievable
- Solvent use
- Two-step-process

Source: Kuraray
Manufacturing Techniques – Meltblown

Advantages

- High productivity
- Solvent free
- Single step process

Disadvantages

- Recently increasing R&D activities
- New improvements for finer fiber diameters

- normal operation: fiber diameters of only 1-2 microns
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  (Filter Material with Integrated Nanofibers)
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New Production Process - Characteristics

- **Integration** of polymer nanofibers into nonwoven material
- **Inline** Process
- **Solvent free** fabrication of fibers with different diameters
- **Task specific** fiber diameters for filtration
- **Gradient control** of nanofiber distribution

Enhanced filtration performance
One-layer pleatable filter material
Unmixed Material
**Integrated Nanofibers - Performance**

**Why do we need integrated nanofibers?**

- Nanofibers increase filtration efficiency
- Integrated nanofibers increase **deep bed filtration**
- Result: Longer lifetime

![Diagram showing air flow through filter media with increasing nanofiber density.](image)
Introduction

Particle Deposition Mechanisms

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Development of a new Production Process

Comparison of Manufacturing Techniques
( Electrospinning vs. Modified Meltblown Process)

Conclusion
Nanocoated Filter Media via Electrospinning

Nanofibers like a grid on top of structure of single fibers and bundles of standard medium

No Nanofibers in the middle of standard medium

Fiber diameters:

Standard medium: approx. 21 μm
Nanofibers: approx. 250 nm
Nanocoated Filter Media via Electrospinning II

After treatment with NaCl

- NaCl-particles mainly on Nanofibers
- Only few particles on "common" thick fibers
Enhancement of collection efficiency of more than 10%!

Normalized Collection Efficiency

Normalized Pressure Drop [Pa]
Nanocoated Filter Media via Electrospinning IV

Characteristics

- Nanofiber size: mainly 100 – 300 nm
- Microfiber size: 1 – 20 microns
- Costs
- Solvent Disposal
- Surface filtration
- Coverage of big holes not sufficient
Modified Meltblown Process
Nanofibers Generated by the Modified Meltblown Process

- Nanofibers are integrated into 3-dimensional structure
- Integration of Nanofibers into the Meltblown-process

Fiber diameters:
- Standard medium: approx. 20 μm
- Nanofibers: approx. 250 nm
Nanofibers Generated by the Modified Meltblown Process II

Particle concentrated on Nanofibers in the Middle of the Media

After treatment with NaCl

Only few particles are captured by “common” thick fibers
Enhancement of collection efficiency with consistent pressure drop
Nanofibers Generated by the Modified Meltblown Process IV

Characteristics

- Nanofiber size: mainly 100 – 300 nm
- Microfiber size: 1 – 20 microns
- Quality assurance by microscopy and filtration performance tests
- High process stability and safety
- High productivity of nanofibers (solvent free)
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How can we achieve optimal filtration performance?

\[ \Delta p = \frac{\eta t U_0 f(\alpha)}{d_f^2} \ldots \]

- Understanding scientific correlations
- Competitive process development
- Enhanced product characteristics
Thank you for your kind attention!

Feel free to ask questions
Literature


