Carbon Nanotubes as a Novel Filter Media

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Outline

- **Background**
  - Carbon nanotubes
  - Novel antimicrobial properties of CNTs

- **Novel CNT Filters for Water Treatment**
  - Point-of-Use application
  - Novel application for organic removal

- **Conclusion**
Nanotechnology?

National Nanotechnology Initiative (NNI)

......Research and technology to control or develop at the atomic, molecular or macromolecular levels, in the length scale of 1 - 100 nanometer range.......
Nanotechnology?

RECHARD FEYNMANN (1959)

There is plenty of room at the bottom........
All things will not simply scale down in proportion.

Nanosized gold particle at different diameters
Carbon Nanotubes (CNTs)?

http://www.photon.t.u-tokyo.ac.jp/~maruyama/agallery/nanotubes/
Why Carbon Nanotubes?

**UNIQUE PROPERTIES:**
- Exceptional strengths
- High thermal stabilities
- Large surface areas
- Electrical properties (semi-conducting, metallic)

**IMPORTANT APPLICATIONS:**
- High-strength, light-weight fibers
- Nano-electronics and sensors
- Novel displays (FED)
- Fuel cells, energy storage applications
- Nanocomposite materials
Why Carbon Nanotubes?

We recently found novel antimicrobial properties of CNTs.
Antimicrobial property of CNTs

- SWNT aggregates
- Total cells (stained with both)
- Damaged cells (PI stained)
- Free swimming cells

- E. coli cells
- 0.9% (154 mM) NaCl solution
- pH = 5.6 ± 0.3
- Incubated at 37°C
Antimicrobial property of CNTs

1.1 Billion people lack access to improved water globally.

1.6 million children under age 5 die annually from waterborne illnesses.

(WHO & Unicef, 2006)
How do we increase the amount of water in developing countries?

- Build water and wastewater treatment plant to increase drinking water supplies
- Afford simple, on site technology to remove emerging contaminants from all types of water sources

![Diagram of water treatment process with Microfiltration (MF), Reverse Osmosis (RO), Disinfection, and Distribution stages]
Point-of-Use Treatment Needs List

- Low-cost of materials and production
- Low energy or gravity-driven operation
- Removal of bacteria
- Removal of viruses
- Portability
- Inhibition of biofilm formation
- Simple regeneration techniques for reuse
Concept of CNT Hybrid Filter
Concept of CNT Hybrid Filter

- Antimicrobial
- High permeability
- Very high surface area (adsorption, filtration)
- Can be regenerated at high temperatures/harsh conditions
- Compact and portable
Preparation of CNT Filter

Vacuum filtration of CNT dispersion in DMSO
Low Pressure Operation

![SEM image of SWNT layers](image)

**Diagram:**
- **Permeability** vs. **SWNT Loading** (mg/cm$^2$) and **SWNT Layer Thickness** ($\mu$m)
- **Permeability** ($10^3$ L/(m$^2$-hr-bar))
- ** Thickness**

**Graph Details:**
- **X-axis:** SWNT Loading (mg/cm$^2$)
- **Y-axis:** Permeability ($10^3$ L/(m$^2$-hr-bar))
- **Legend:**
  - □□□ Permeability
  - ••• Thickness

**Additional Information:**
- Thickness values: 0.0, 0.2, 0.4, 0.6, 0.8, 1.0 µm
- Permeability values: 260, 300, 280, 290, 270, 260 ($10^3$ L/(m$^2$-hr-bar))
Complete Retention and High Inactivation of Bacteria

- Base filter (PVDF)
- Hybrid (SWNT layer)

- *E. coli* K12
- $N_0 \approx 5 \times 10^5$ cells
- pH 5.7
- 0.9% NaCl
- 22 °C
- Flow rate, 125 LMH
Impacts on Microorganisms from Natural and Engineered Aquatic Systems

River Water

WWTP Effluent (1/5X)
CNT Filter for Viral Removal

- MS2 virus: ~ 30 nm
- $N_0 \approx 1.5 \times 10^6$ virus/mL
- pH 5.7
- 0.9 % NaCl
- 22 °C
- Flow rate, 125 LMH
Novel Application for Wastewater Treatment Contaminated by Organic Matters

Hybrid Filter with novel nanoparticles
‘Catch-and-Shoot’ of Organic Contaminants by CNT Filter

- High permeability with thousands of layers
- Very high surface area (adsorption, filtration)
- Physically and chemically stable
- Elevated chemical reaction rate
- Can be combined with A.O. process
Conclusion

- Novel CNT filter achieves complete retention of *E. coli*, and more than 80 % inactivation.
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Conclusion

- **Novel CNT filter achieves complete retention of** *E. coli*, **and more than 80 %** inactivation.

- **Novel CNT filter is capable of high viral removal** at gravity-driven pressures.

- **Novel CNT filter has potentials to** catch and shoot **of** organic contaminants
Thank you !
Impact of Natural Organic Matters

Inactivated Cells (%) vs. NOM Concentration (mg/L)

NOM=0mg/L

NOM=20mg/L

Kang et al., ES&T, 2009
Cytotoxicity of CNTs

Metabolic activity measured by CTC

Metabolic Activity (%)

Control  MWNT  SWNT

E. coli cells
0.9% (154 mM) NaCl solution
pH=5.6±0.3
Incubated at 37°C

Kang et al., Langmuir, 2008
Cytotoxicity of CNTs

- Morphological changes: SEM images of *E. coli*

MWNT  
SWNT

Leakage of Intracellular Materials

Kang et al., Langmuir, 2008