

US EPA ARCHIVE DOCUMENT

Fate, Transport, Transformation, and Toxicity of Nanomaterials in Conventional Drinking Water Treatment Processes

Yongsheng Chen, Paul Westernhoff, John C. Crittenden,
and *David Capco

Department of Civil and Environmental Engineering

*Department of Biology
Arizona State University

Email: yschen@asu.edu

Manufacturing activities [1,2,3]

■ Market

- By 2005 and 2015, the global market for nanoparticles will be close to \$ 1 billion and \$1 trillion dollars respectively.

■ Engaged Companies

- More than 140 companies
 - 54 companies are making nanotube carbons;
 - at least 20 companies are producing hundreds of tons of fullerenes annually)

■ Synthesized Nanomaterials

- At least 44 elements in the Periodic Table are being synthesized in Nanoscaled organic and inorganic compounds
 - Nanotubes (carbon nanotubes and metal oxide nanotubes),
 - nanoclays (clay particles),
 - quantum dots

Applications

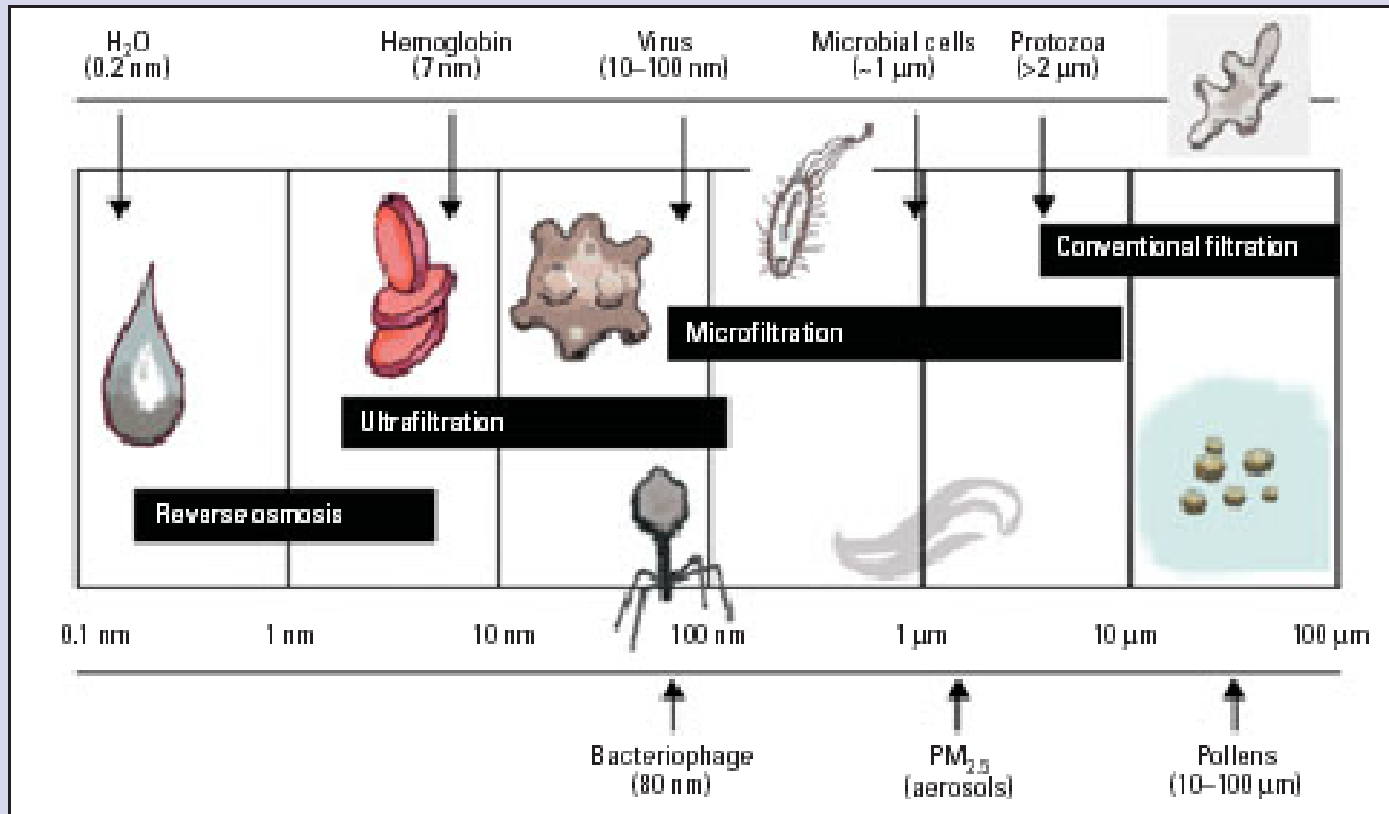
- Toothpaste
- Sunscreens (TiO_2 , ZnO nanoparticles)
- Nanofiber clothes;
- In situ remediation and treatments;
- Catalysts
- Sensors
- Drug delivery (using proteins to drugs to targeted area of the body)

Toxicity

- Potential passageways to human body [1,4, 5]
 - Lung
 - In vivo studies demonstrate that TiO₂ nanoparticles can produce inflammation in lungs of lab animals;
 - In vitro studies show that TiO₂ nanoparticles could produce free radicals that can cause cellular damage.
 - Digestive track
 - Nanoparticles are able to be uptaken by cells and to gain access to the blood stream, distributing to the organs in the body.
 - The most recent results show that nanoscale buckyballs cause brain tissue damage in largemouth bass and they are also toxic to the “water flea”
 - Skin
 - Nanoparticles can get deep into skin and be taken up into the lymphatic system.

Nanotechnology could pollute many media

Because nanoscale materials are in the same size range as hemoglobin and viruses and are even smaller than common irritants, such as particulate matter (<2.5 μm) and pollen, nanomaterials could pose serious health risks. Conventional air and water treatment techniques need to be evaluated for their efficacy to treat nanoscale pollutants.



Source: Ken Raniera, Lehigh University.

Figure 1. Developed by Ken Raniera [6]

Proposed Tasks

1. Characterize the fundamental properties of nanomaterials in aquatic environments;
2. Examine the interactions between nanomaterials and toxic pollutants and viruses;
3. Evaluate the removal efficiency of nanomaterials by sand filtration process;
4. Test the toxicity of nanomaterials in drinking water using cell culture model system of the epithelium.

TiO₂ Nanotubes Synthesized in our Group

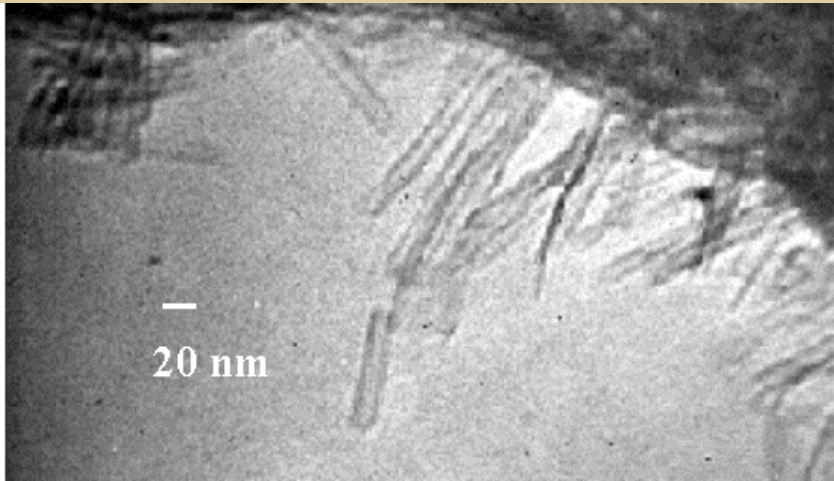


Figure 2. TEM micrograph of several TiO₂ nanotubes

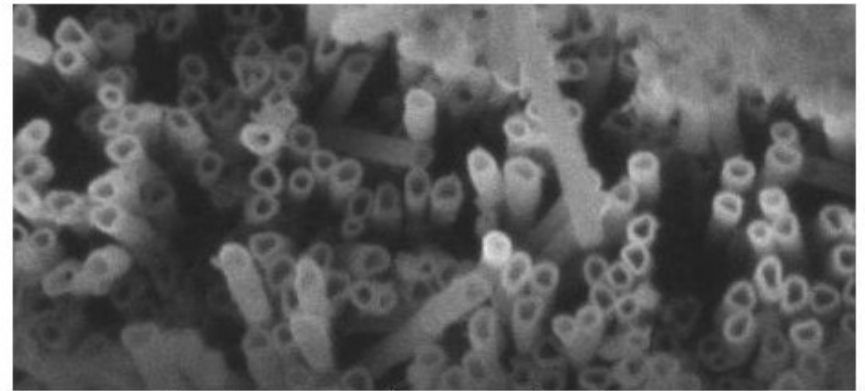


Figure 3. Image of several TiO₂ p-n junction nanotubes with an outer layer of TiO₂ (n-type semiconductor) and an inner of layer platinum. (Pore opening is ~150Å)

Table 1. Characteristics of the Selected Nanomaterials (*representative size of entire nanomaterial given for nanotube and nanosheet)

Material	Shape	Source of material	Average size (nm)^a	Specific area (m²/g)	Particle charge near neutral pH	Application
TiO₂	Particle	Degussa	50	50	Negative	Sunscreen, catalyst
TiO₂	Particle	BASF	500	NA	Negative	UV-protected fabrics
ZnO	Particle	Nanophase/ BASF	65	NA	NA	Sunscreen and cosmetic
Silica (SM-30)	Particle	Sigma	7	338	Negative	Catalyst support, separation materials and filtration media
Polymer fibers	Nanofiber	Nano-Tex,LLC	NA	NA	NA	wrinkle-resistant
Activated Carbon	Nanotube	Carbolex / Aldrich	30	189	Negative (hydrophobic)	Nanowire, nanosensor, and drug delivery
TiO₂	Nanotube	Synthesized by Investigators	40	300	Negative/positive	Catalyst, gas sensor, drug delivery
TiO₂	Nanosheet		60	NA	Negative/positive	Photocatalyst, self-clean material
ZnO	Nanosheet		80	NA	Negative/positive	Catalyst

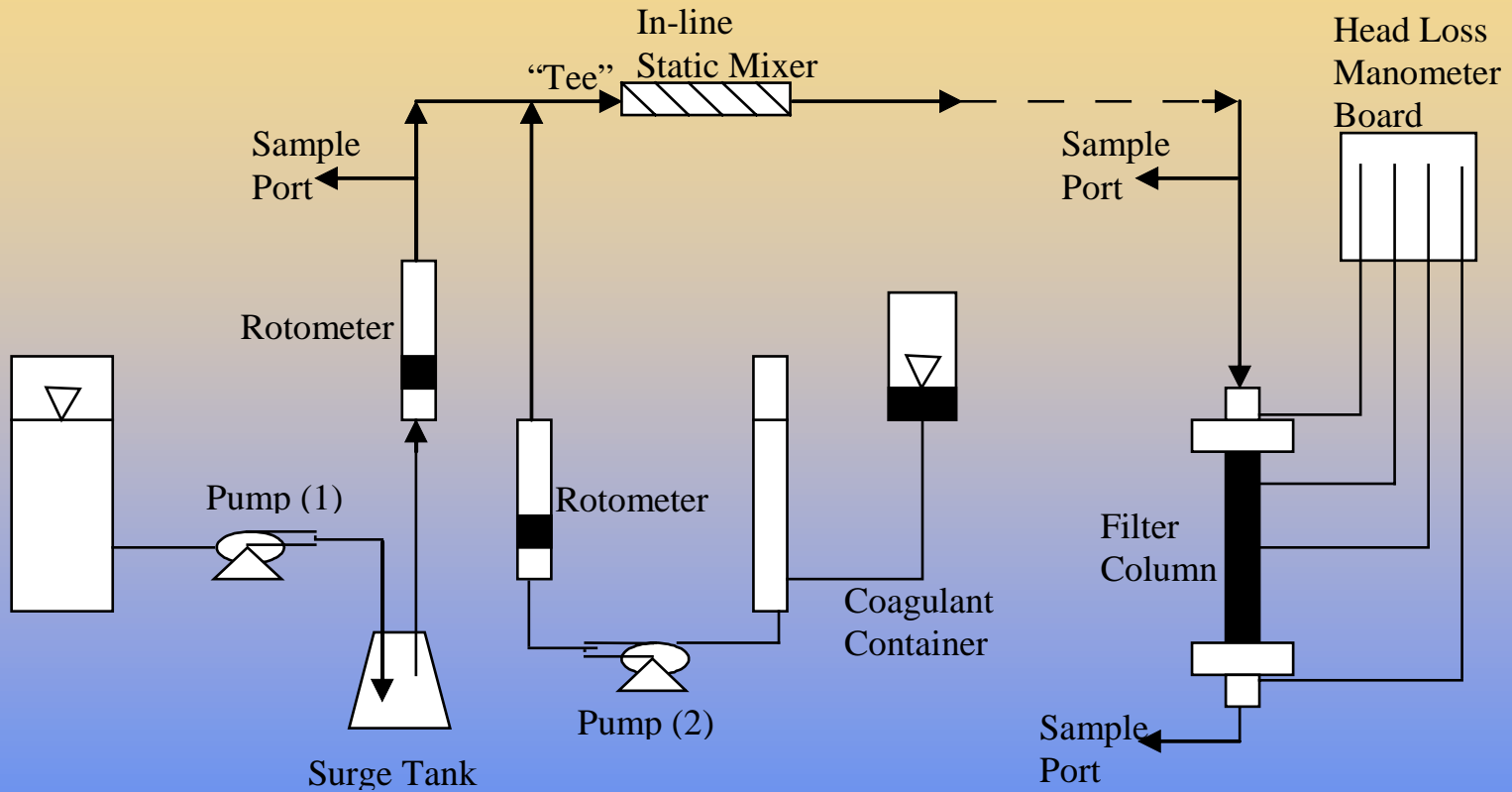
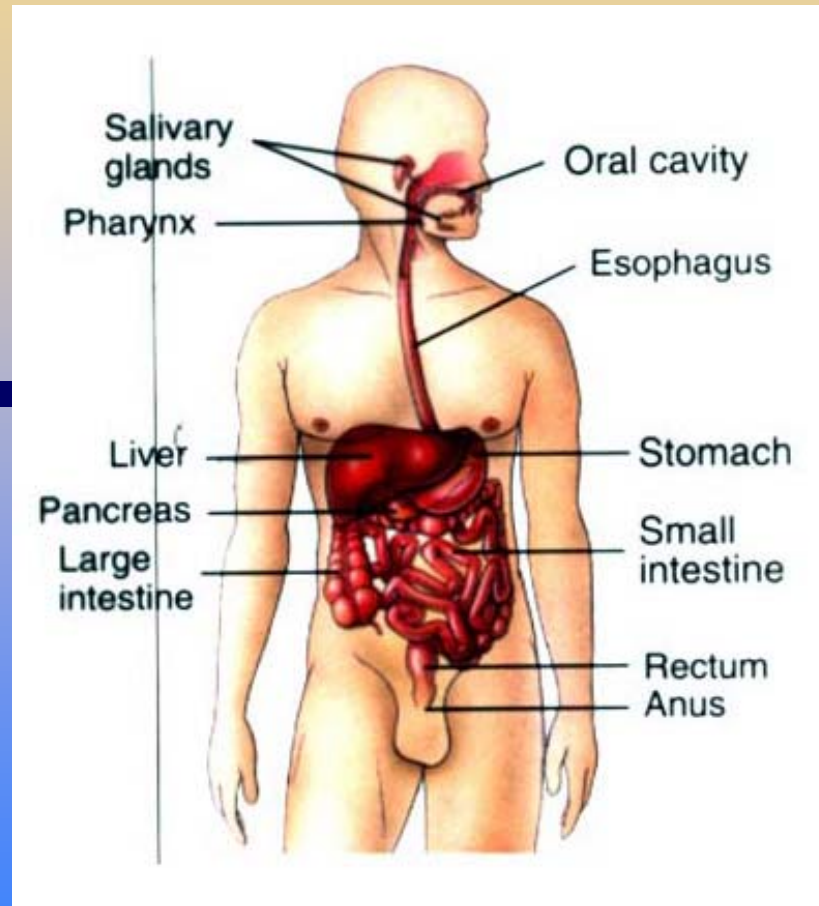


Figure 4. Filtration application schematic

Potential Sites of Nanoparticle Absorption



Cellular Models: Toxicity Assays

1) Trans-epithelial Resistance Assays.

2) Structural and Metabolic Assays

(including live/dead analysis, calcium levels analysis, junctional complex analysis, and oxidative stress analysis).

3) Trans-epithelial transport of nanomaterials to assess biological function of the epithelium.

Expected Results

- Provide fundamental information about the fate, transport and transformation of nanomaterials in the drinking water resources
- Provide the first evidence that such nanomaterials can or cannot be removed by conventional drinking water treatment processes.
- An improved toxicity assessment will be developed for the potential exposure risks of nanomaterials in drinking water.
- This research would ultimately provide essential information that would support policy and decision-making regarding handling, disposal, and management of nanomaterials in commerce, manufacturing and the environment.

References

- (1) ETC Group, Occasional Paper Series, 7, 1 (2003)
- (2) Business Wire, Inc., "Altair Nanotechnologies Awarded Patent for its Nano-sized Titanium Dioxide," Sept. 4, 2002
- (3) Bucher J., presentation at the symposium, "Nanotechnology and the Environment," American Chemical Society meeting in New Orleans, LA, March 23, 2003
- (4) Morgan, M. Granger, Baruch Fischhoff, Ann Bostrom, and Cynthia J. Atman. 2002. Risk Communication: A Mental Models Approach. Cambridge: Cambridge University Press.
- (5) Gumbleton M, Advanced Drug Delivery Reviews 49: 281 – 300 (2001)
- (6) Masciangioli T.; Wei-Xian Zhang, Environ. Sci. Technol. 102A (March 1, 2003)