Developments of Nanomaterials and Nanotechnology Applied to Water Treatment

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Introduction
Nanotechnology has been demonstrating a remarkable growth over the last years and has great potential to improve water treatment processes and overcome the limitations of conventional technologies. The research aims at presenting a critical review of the developments that can be applied to water treatment, focusing on the unique properties of nanomaterials which enable them to remove inorganic, organic and microbial pollutants by adsorption or catalysis.

Nanosorbents
In nano-scale, absorbents have significantly larger surface areas than bulk particles, which results in high adsorption capacity.

**Iron Oxide**
- Removal of heavy metals
- Modifications can further enhance the properties of the material

**Magnesium Oxide Nanoparticles**
- Powerful biosorbents
- (Surface area: 600 m² g⁻¹)

**Mercaptosuccinic acid (MSA) coating of silver nanoparticles**
- Mercury uptake, with a adsorption capacity of 8000 mg g⁻¹

**Akageneite (K – FeCO3)**
- Size up to 6μm, surface area of 330 m² g⁻¹
- High adsorption capacity for Cr(VI), Cd(II), Au(V), Zn(II)
- Regeneration potential

**Zeolites**
- Can remove multiple heavy metals by adsorption and ion exchange.
- Recommended for passive remediation applications, as the amount of waste generated could be high.
- Functionalization can improve their abilities in water; for example chlorosilane reagents can change their hydrophilic/hydrophobic properties.

**Carbonaceous nanomaterials**
- CNTs with a diameter of few nm can have surface areas as high as 559 m² g⁻¹. Oxidation treatment can increase the surface area even more.
- Very effective for organic contaminants, such as TCP.
- Active removal of NOM.
- Activated carbon fibers (ACFs) can remove simultaneously multiple toxic organic chemicals.
- Issues to be addressed: high cost and poor recovery

**Metallic**
- **Titanium Dioxide (TiO2)**
- Can oxidise effectively organic pollutants (phenols) and persistent pathogens (viruses, hepatotoxins), rapidly, without the addition of chemicals.

**Nanocatalysts**

**Metal Oxides**
- TiO₂ can oxidise effectively organic pollutants (phenols) and persistent pathogens (viruses, hepatotoxins), rapidly, without the addition of chemicals.
- Activation of the nanoparticles in the visible light region by doping with silver, iron and carbon can reduce or eliminate the UV requirements.
- Advanced preparation methods, such as the sol-gel method, can improve the materials’ properties.
- A promising modification is the use of composite material, such as CNT/TiO₂.
- **Zinc oxide** can successfully degrade organics.

**Fullerenes**
- C₆₀ derivatives have demonstrated remarkable performance in removing organic and microbial contaminants.
- C₆₀ has been found more effective than TiO₂, for MS-2 bacteriophage destruction, while visible light inactivation of viruses and bacteria has also been reported.
- The next step is to assess the cytotoxicity and the impacts of ROS in depth, and improve the recovery and re-use systems.

**Nanocatalysts for water remediation**
- ZVI nanoparticles stabilised with CMC (carboxymethyl cellulose) present improved performance in (CVI) reduction.
- Palladium, alone, or preferably as part of bimetallic nanoparticles (Pd/Au, Pd/Mg), is powerful in reducing organic contaminants.
- Amongst the most promising applications is the use of nanocatalysts for DNAPL remediation of contaminated aquifers.

Case Study: Titania Photocatalysis
TiO₂ systems can reduce satisfactory AOX, TOC and toxicity levels from industrial paper processing effluents.
For the commercialisation of the application, the sustainability of the system should be encouraged by:
- exploiting solar illumination (rather than UV irradiation)
- modifying the nanocatalysts with novel synthesis methods to enhance their properties
- immobilising the particles onto films, or other structures, and
- reducing oxygen requirements, possibly with the aid of electrodes. [2]

Case Study: Electrically Switched Ion Exchange Technology for wastewater treatment
Successful removal of cesium, chromate and perchlorate ions from wastewater.
Combination of ion exchange and electrochemistry, with the aid of nanocomposites formed by a conducting polymer/CNT.

Arsenic™ for Arsenic and Uranium removal

**Hybrid ion exchange (HIX), where the resin is impregnated with hydrous iron oxide nanoparticles.**

**Advantages**
1. Simple design and operation.
2. Does not alter the water quality characteristics.
3. Meets successfully the drinking standards for arsenic and uranium.
4. Does not require a backwash procedure.

**Table 1: Design parameters of HIX [4]**

<table>
<thead>
<tr>
<th>Design parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of vessels</td>
<td>2</td>
</tr>
<tr>
<td>Size of vessels</td>
<td>D: 1.07m</td>
</tr>
<tr>
<td></td>
<td>H: 1.52m</td>
</tr>
<tr>
<td>Loading capacity</td>
<td>0.00353 m³ s⁻¹</td>
</tr>
<tr>
<td>Theoretical Hydraulic Loading Rate</td>
<td>305 m³ m⁻² d⁻¹</td>
</tr>
<tr>
<td>Volume of media</td>
<td>0.76m³</td>
</tr>
<tr>
<td>Theoretical ERCT</td>
<td>5.3 min</td>
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<tr>
<td>Actual ERCT</td>
<td>8.8 min (average)</td>
</tr>
<tr>
<td>Actual working capacity</td>
<td>33,100 BV</td>
</tr>
</tbody>
</table>

**Conclusions**
- The most common application for nanosorbents is the removal of inorganic and organic pollutants.
- Nanocatalysts are usually applied to degrade organic substances and purify water from microbial contaminants.
- Ion exchange technologies can be optimised by the incorporation of nanomaterials or nanocomposites.
- Nanotechnology promotes sustainable, high-performance solutions, which can be applied to both developing and western countries.
- There is a need to understand and assess the possible impacts of nanomaterials to the environment and human health and develop appropriate legislation and policies.

References

**Figure 2:** Bench-scale EBIX system [1]

**Figure 3:** Process flow diagram and sampling locations for Upper Bodfish site [4]

**Figure 1:** The mechanism of photocatalysis [1]