An overview of the technologies for microplastics remediation

Professor Diane Purchase
Middlesex University
The IUPAC microplastic project

• The Environment, health and food safety impact of microplastics (https://iupac.org/project/2019-026-2-600)
• IUAPC Division VI (Chemistry and the Environment)
• Partners:
  • Div III – Organic and Biomolecular Chemistry
  • Div IV – Polymer
  • Div V – Analytical Chemistry
  • Div VII – Chemistry and Human Health
• Chair: Professor Weiping Wu
Microplastics - the challenge


Source: Will Parson/Chesapeake Bay Program
Microplastics and us

How We Eat, Drink and Breathe Microplastics

Average number of microplastic particles found per gram/liter/m³ of selected consumables

94.37 Bottled water
32.27 Beer
9.80 Air
4.24 Tap water
1.48 Seafood

0.44 Sugar
0.11 Salt
0.10 Honey

Estimated annual microplastic particles consumed per person
Between 74,000 and 114,000

* Including via inhalation. Estimates are "subject to large amounts of variation" and "likely underestimates."
Microplastics in the environment

<table>
<thead>
<tr>
<th>Shape</th>
<th>Size (µm)</th>
<th>Number of times recorded in research papers*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sphere</td>
<td>&lt;0.5</td>
<td>100</td>
</tr>
<tr>
<td>Fragment</td>
<td>0.5–1</td>
<td>30</td>
</tr>
<tr>
<td>Fibre</td>
<td>1–20</td>
<td>10</td>
</tr>
<tr>
<td>Film</td>
<td>20–50</td>
<td></td>
</tr>
<tr>
<td>Foam</td>
<td>50–100</td>
<td></td>
</tr>
<tr>
<td>Pellet</td>
<td>100–300</td>
<td></td>
</tr>
<tr>
<td>Ambiguous/unreported</td>
<td>300–1,000</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1,000–5,000</td>
<td></td>
</tr>
</tbody>
</table>

*Nature analysis of 156 detection and 159 exposure studies.

Source: Nature Analysis

Source: Janice Brahney, Utah State University
Microplastics remediation

Separation

Degradation

Roy et al. (2022)
Common Separation Techniques

- Sedimentation
- Flotation
- Coagulation/flocculation
- Filtration
- Electrostatic separation
Sedimentation to remove microplastics

- Settling of microplastics from water and other liquid media
- Factors affecting its efficiency:
  - Particle size and density
  - Fluid viscosity
  - Concentration of microplastics
  - Temperature
  - Agglomeration and flocculation
  - Shape and morphology
  - Presence of other substances


Bakhteeva I.A. et al., 2023. [https://doi.org/10.1007/s13762-023-04776-1](https://doi.org/10.1007/s13762-023-04776-1)
Using flotation to remove microplastics

• Separate microplastics from water or liquid environment based on their buoyancy and surface interactions

• Hydrophobic particles attached to air bubbles and causing them to rise to the surface

• The froth layer can be collected and removed

Coagulation and flocculation to remediate microplastic – chemically induced processes

• In wastewater treatment plants:
  • Flocculation
  • electrocoagulation
  • agglomeration

Strum MT et al., 2021. https://doi.org/10.3390/w13050675
Microplastic separation - adsorption

- Microplastic adsorbed onto an adsorbant
- E.g., microalgae and biochar

Microplastic separation – membrane technology

Microplastic separation from soil

Microplastic degradation – chemical processes

Advanced Oxidation Processes

Homogeneous Processes
- Using Energy
  - Ultraviolet Radiation
  - Ultrasound Energy
  - Electrical Energy
    - $O_3/UV$
    - $H_2O_2/UV$
    - $O_3/H_2O_2/UV$
    - Photo-Fenton
      - $Fe^{3+}/H_2O_2/UV$

- Without Using Energy
  - Electrochemical Oxidation
    - $O_3$ in Alkaline
    - $O_3/H_2O_2$
    - $H_2O_2/Catalyst$
  - Anodic Oxidation
  - Electro-Fenton

Heterogeneous Processes
- Catalytic Ozonation
- Photocatalytic Ozonation
- Heterogeneous Photocatalysis

Hamd W et al., 2022. doi: 10.3389/fmars.2022.885614
Microplastic degradation – thermal processes

• Gasification
• Hydrothermal coupled Fenton system
Microplastic degradation – biological processes

Advanced microplastic remediation using nanotechnology

- Adsorption
- Coagulation
- Filtration
- Catalytic degradation
- Real-time monitoring

Nanomaterials as adsorbants

- metal-organic frameworks e.g. zeolitic imidazolate framework (ZIF)
- Carbon-based nanomaterials
  - e.g., magnetic carbon nanotubes
  - e.g., chitin and graphene oxide sponges

Sun CZ et al., 2021 https://doi.org/10.1016/j.jhazmat.2021.126599
Nanomaterials as coagulants

• E.g. graphene oxide (GO)
• Graphene oxide sheets are synthesized through the oxidation of graphite, resulting in nanoscale graphene oxide flakes
• The graphene oxide sheets are functionalized with specific groups that enhance their interaction with microplastics, e.g., carboxyl or amino groups
• The formed flocs can either settle or be easily removed through filtration or other separation processes
Nanomaterial-based filtration system

- Nanofiber membranes
- Carbon Nanotube filters
- Nanoporous materials
- Nanocomposite filter
Catalytic degradation

• Advanced oxidation process - e.g., nano spiral, zero-valent iron nanoparticles
• Photocatalysis – e.g., TiO₂
• Nanocatalysis – e.g., Palladium (Pd) nanoparticles on Silica and zirconia

Real-time monitoring of microplastic remediation using nanotechnology

- Nanosensors
- Nanofluidic devices
- Remote sensing

Some limitations of microplastic remediation

• Limitations of separation technologies
  • Removal from the matrix but not treated
  • Coagulation and flocculation: and Cost of chemicals
  • Electrocoagulation: Electrodes longevity
  • Membrane filtration: Membrane fouling

• Limitations of degradation technologies
  • AOPs: decrease in the decomposition activity of microplastics after several cycling, especially in photocatalytic oxidation and electrochemical oxidation based on catalysts
  • Photochemical and photocatalytic degradation: Energetically expansive
  • Thermal treatment: energy intensive
  • Biodegradation: takes a long time
Final word
References


References

Thank you