DEVELOPMENT OF MICROPLASTIC REMEDIATION TECHNIQUES FROM MARINE SEDIMENTS

Presented by Ir. Michiel Van Melkebeke$^{1,2}$
Co-authored by: Prof. Dr. Ir. Steven De Meester$^1$ and Prof. Dr. Colin Janssen$^2$

Friday 17th of June 2022
16:30 – 16:45
Room 2 Session XXII
PLASTIC POLLUTION

Balance of plastic production and fate (m = million tonnes)
8300m produced → 4900m discarded + 800m incinerated + 2600m still in use (100m of recycled plastic)

*Data for 2015

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WHERE DO THEY COME FROM? WHERE DO THEY GO?

LAND BASED - INLAND - 0.50 Mtpa
LAND BASED - COASTAL - 9 Million tonnes per annum
AT SEA - 1.75 Mtpa
FISHING LITTER - 1.15
SHIPPING LITTER - 0.60
TOTAL PLASTIC ENTERING THE MARINE ENVIRONMENT - 12.2 Million tonnes per annum
BEACHES - 2,000 kg/ km² (5% of total)
OCEAN SURFACE - 18 kg/ km² (1% of total)
SEA FLOOR - 70 kg/ km² (94% of total)

Source: Eunomia Research & Consulting Ltd. (2016) Plastics in the Marine Environment
RESEARCH OBJECTIVE

Development of a separation technique that is able to isolate microplastics from marine sediments (during dredging operations)

1. Qualitative and quantitative feed characterisation

2. Fundamental analysis of the characteristics, sinking behaviour and surface properties of typical microplastics

3. Evaluation of proven separation techniques
## WHAT IS THE TARGET FEED?

Maintenance dredging: Scenario 1  
Beach nourishments: Scenario 2

<table>
<thead>
<tr>
<th>Feed constituent</th>
<th>Size range</th>
<th>Average density [kg/m³]</th>
<th>Contact angle* [°]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sediment</td>
<td>&lt; 63 µm</td>
<td>63 µm – 2 mm</td>
<td>2650</td>
</tr>
<tr>
<td>Low-density MPs</td>
<td>1 µm – 5 mm</td>
<td>1 µm – 5 mm</td>
<td>925</td>
</tr>
<tr>
<td>High-density MPs</td>
<td>1 µm – 5 mm</td>
<td>1 µm – 5 mm</td>
<td>1400</td>
</tr>
</tbody>
</table>

*contact angle > 90° = hydrophobic, contact angle < 90° = hydrophilic

Explore techniques that separate particles based on density and/or polarity
SINKING BEHAVIOUR OF MICROPLASTICS

Municipal plastic waste ➔ 7 plastic products ➔ Shredding ➔ Sieving + Selection

Analysis ➔ Sinking velocity measurements ➔ Determination of best drag model

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## DRAG MODELS

<table>
<thead>
<tr>
<th>Author(s) drag law</th>
<th>Shape descriptors</th>
<th>Average error [%]</th>
<th>RMSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dietrich (1982)</td>
<td>CSF, P</td>
<td>19.43</td>
<td>28.46</td>
</tr>
<tr>
<td>Haider &amp; Levenspiel (1989)</td>
<td>$\Phi$</td>
<td>60.53</td>
<td>67.41</td>
</tr>
<tr>
<td>Swamee &amp; Ojha (1991)</td>
<td>$\beta = f(\text{CSF})$</td>
<td>34.08</td>
<td>46.28</td>
</tr>
<tr>
<td>Ganser (1993)</td>
<td>$K1 = f(\Phi), K2 = f(\Phi)$</td>
<td>20.11</td>
<td>25.75</td>
</tr>
<tr>
<td>Dellino et al. (2005)</td>
<td>$\Psi = f(\Phi, \chi)$</td>
<td>23.88</td>
<td>30.61</td>
</tr>
<tr>
<td>Pfeiffer et al. (2005)</td>
<td>$\varphi$</td>
<td>48.46</td>
<td>59.78</td>
</tr>
<tr>
<td>Camenen (2007)</td>
<td>CSF, P</td>
<td>29.09</td>
<td>33.04</td>
</tr>
<tr>
<td>Dioguardi &amp; Mele (2015)</td>
<td>$\Psi = f(\Phi, \chi)$</td>
<td>46.90</td>
<td>50.93</td>
</tr>
<tr>
<td>Dioguardi et al. (2018)</td>
<td>$\Psi = f(\Phi, \chi)$</td>
<td>13.20</td>
<td>19.09</td>
</tr>
</tbody>
</table>

The drag coefficient $C_D$ is given by:

$$C_D = \frac{24}{Re_p} \left( \frac{1 - \Psi}{Re_p} + 1 \right)^{0.25} + \frac{24}{Re_p} \left( 0.1806 Re_p^{0.6459} \right) \Psi^{-Re_p^{0.08}} + \frac{0.4251}{1 + \frac{6880.95}{Re_p} \Psi^{5.05}}$$
WHAT ABOUT BIOFOULING?
WHAT IS THE TARGET FEED?

<table>
<thead>
<tr>
<th>Feed constituent</th>
<th>Size range</th>
<th>Average density [kg/m³]</th>
<th>Contact angle* [°]</th>
<th>Average sphericity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Scenario 1</td>
<td>Scenario 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment</td>
<td>&lt; 63 μm</td>
<td>63 μm – 2 mm</td>
<td>2650</td>
<td>&lt; 90</td>
</tr>
<tr>
<td>Low-density MPs</td>
<td>1 μm – 5 mm</td>
<td></td>
<td>925</td>
<td>&gt; 90</td>
</tr>
<tr>
<td>High-density MPs</td>
<td>1 μm – 5 mm</td>
<td></td>
<td>1400</td>
<td>&gt; 90</td>
</tr>
<tr>
<td>Bio-fouled MPs</td>
<td>1 μm – 5 mm</td>
<td></td>
<td>± 1100</td>
<td>&lt; 40</td>
</tr>
</tbody>
</table>

*water contact angle > 90° = hydrophobic, water contact angle < 90° = hydrophilic

Selection of most promising techniques: centrifugal sedimentation and froth flotation
DOES CENTRIFUGAL SEDIMENTATION WORK?

\[ u_t = \frac{d_p^2 |\rho_p - \rho_f| g}{18 \mu} \]

\[ u_c = \frac{d_p^2 |\rho_p - \rho_f| \Omega^2 r}{18 \mu} \]
Centrifuge grade efficiency as a function of particle diameter

- **Sediment particles**
- **Microplastics:**
  - 1400 kg/m³
  - 1100 kg/m³

Effluent discharge
WHAT ABOUT FROTH FLOTATION?

Promising…

- Based on difference in polarity
- Microplastics separated in a concentrated stream

...but practical issues in traditional setups

- How to deal with sediment (clogging)?
- How to create optimal air bubble flows?
- How to increase system flexibility?

## PROMISING RESULTS

### Microplastic recovery rate / Sediment entrainment

<table>
<thead>
<tr>
<th>High-concentration feed (1000:1)</th>
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<tbody>
<tr>
<td>Low-density microplastics</td>
</tr>
<tr>
<td>High-density microplastics</td>
</tr>
<tr>
<td>Sediment</td>
</tr>
<tr>
<td>- Scenario 1</td>
</tr>
<tr>
<td>- Scenario 2</td>
</tr>
</tbody>
</table>

### Average-concentration feed (100:1)

| Low-density microplastics                        | 100% |
| High-density microplastics                        | ± 85% |
| Sediment                                         |      |
| - Scenario 1                                     | ± 5.0 m% |
| - Scenario 2                                     | ± 0.1 m% |
WHAT IS NEXT?

Development of a separation technique that is able to isolate microplastics from marine sediments (during dredging operations)

1. Upscale of pilot installation

2. Integration on dredging vessel

3. Economic analysis
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