Tackling the ancient problem of biofouling using modern sensing technology

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Introduction

The detection and management of biofouling poses a significant global industrial problem whereby the economic and occupational cost of hull inspections are a necessity carried out by dry-docking, divers and remote operated vehicles (Abbott et al., 2000). These methods rely on visual, photographic or sonar images of biofouling from the outside of a stationary vessel (Townsin, 2003).

Increased biofouling results in increased fuel consumption leading to the release of hundreds of millions of tonnes of carbon dioxide (Hellio and Yebra, 2009). Fig. 1) IMO set a target to half carbon dioxide emissions from shipping by 2050 (IMO, 2018) making biofouling management a priority.

One of the most common problem species is the blue mussel Mytilus edulis (Dürr and Watson, 2010). The aim of the study was to determine the efficacy of 3 different materials (PTFE, PVC, Nylon) 6 to their differing relative permittivity (Table 1, see discussion) in detecting M. edulis plaque using a 9pr Au PVDF planar sensor (Mason et al., 2013).

Method

Materials (50x50x1mm panels) were exposed to M. edulis under controlled conditions (28psu artificial seawater; B, C, Fig 2a). The control was not exposed to M. edulis. After 24 hours, M. edulis was removed (Fig. 2b), a well was stuck around the deposited plaques (Fig. 2a, 2d).

Samples were placed on the electromagnetic sensor with 400µl 28psu artificial seawater. Samples were measured with a Rhone and Schwarz Vector Network Analyser (VNA) (Fig. 2e, output: reflection coefficient (R) relative to frequency spectrum 10MHz – 15GHz. For each of the 3 materials, 3 repeats (60,000 data points) were run for each test and control (PTFE n=43; PVC n=61; Nylon 6 n=48).

PTFE showed the least efficacy, PVC and Nylon 6 showed high efficacy for M. edulis plaque detection.

Results

The mean reflection coefficient for the test and control on Fig. 3 demonstrate the best frequencies to be used for plaque detection via comparison to their respective standard error at 5.5GHz to 8.5GHz

A requirement for detection is the control reflection coefficient (R) is more is negative than the treatment reflection coefficient as affected by the relative permittivity (εr), plus the largest difference between reflection coefficient for treatment and control (Fig. 4 a-c).

Efficacy of the 3 materials for M. edulis plaque detection (Fig. 5):

- PTFE at 7.19GHz Tmax = 0.238, p = 0.812
- PVC at 8.16GHz U1 = 1,350, p = 0.009
- Nylon 6 at 5.84GHz U1 = 592, p ≤ 0.001

Fig. 4 The best frequency for each material was deduced as (a) 7.35GHz for PTFE, (b) 8.16GHz for PVC and (c) 3.84GHz for Nylon 6 and is shown by the yellow line.

Discussion and Conclusion

The electromagnetic waves of the sensor interact with the materials, artificial seawater and plaque for the test (Fig. 6). Each of these substrata have a relative permittivity (Table 1) that will impact the wave in accordance with Maxwell’s equations and therefore the reflection coefficient R = \( \frac{1 - \epsilon_r}{1 + \epsilon_r} \).

A higher relative permittivity reduces the speed of the wave and the wavelength

\[
\frac{c}{\sqrt{\epsilon_r}} = \frac{1}{\sqrt{1 + \epsilon_r}} = \frac{1}{\sqrt{1 + \epsilon_r}} = \frac{1}{\sqrt{1 + \epsilon_r}} \text{[m/s]}
\]

- The lower relative permittivity of PTFE and frequency spectrum could not identify a difference in the electromagnetic field at different points due to the longer wavelengths in this set-up.
- The higher relative permittivity of PVC and Nylon 6 (Table 1) affected the low energy electromagnetic waves to behave as if the signal had a shorter wavelength and so detected the presence of M. edulis plaque on their surface.
- The data demonstrated the higher relative permittivity of Nylon 6 functions as a surface to allow for the detection of M. edulis plaque at 5.84GHz.

In conclusion, M. edulis plaque were detected on the materials and the efficacy of detection was highest in PVC and Nylon 6. In further studies potentially Nylon 6 is the material to further develop the sensor.

Table 1 shows the relevant uses and relative permittivity of the tested materials.

Table 2 shows the relevant uses and relative permittivity of the tested materials.

Interaction with Material, seawater and plaque

Fig. 5 Reflection coefficient 511 dB (mean ± SE) at frequency 6.66GHz was selected to compare the 3 materials as they showed similar characteristics at this frequency.

Fig. 6 The red circle indicates the area where the electromagnetic waves interacts with the surface

Fig. 3 The mean reflection coefficient at frequency range 10MHz to 15GHz for the control and treatment (a) PTFE, (b) PVC and (c) Nylon 6. Standard error for the control and test is plotted to narrow down likely frequencies for detection shown in the yellow circle.

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References


Acknowledgements

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Fig. 1 Total carbon dioxide emissions (million metric tons) 19 (March), 9

Fig. 2 Shows the stages of the experimental sample setup of the test for PVC (a-d) and a sample on the sensor connected to the VNA (e).

Table 1

<table>
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<tr>
<th>Material</th>
<th>Commonly known as</th>
<th>Relative permittivity</th>
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<tbody>
<tr>
<td>PTFE</td>
<td>Teflon™</td>
<td>2.0–2.1</td>
</tr>
<tr>
<td>PVC</td>
<td>Scientific study to research mussel settlement</td>
<td>2.7–3.1</td>
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<tr>
<td>Nylon 6</td>
<td>Threads, ropes, filaments, nets, tie cords</td>
<td>3.6</td>
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Table 2

<table>
<thead>
<tr>
<th>Material</th>
<th>Relative permittivity</th>
<th>Uses</th>
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<tbody>
<tr>
<td>PTFE</td>
<td></td>
<td>Cookware, cookware, medical disposables</td>
</tr>
<tr>
<td>PVC</td>
<td></td>
<td>Synthetic blood vessels, medical disposables</td>
</tr>
<tr>
<td>Nylon</td>
<td></td>
<td>Industrial materials, automotive parts</td>
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Box 396, F:6.915, p=0.001

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