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Nanobiosensors in monitoring biodegradation of micropollutants

Celeste M. Felion (University of Glasgow, c.felion.1@research.gla.ac.uk)

Biodegradation is a promising, low-cost treatment for removing organic micropollutants from wastewater. However, biodegradation processes are largely viewed as a "black box", whereby the underlying mechanisms of removal are not fully understood. The ability to quantify chemical pollutants accurately and selectively at low concentrations in complex biological matrices is essential for biodegradation. However, analytical techniques used in biodegradation research utilise expensive instrumentation with high consumable and running costs. Nanomaterials-based biosensors are an emerging technology that have the potential to become a rapid, low-cost alternative to conventional trace analysis methods.

Micropollutants are environmental contaminants present at very low (sub parts-per-billion) concentrations which have the potential to cause adverse effects (*1*). Many organic micropollutants are everyday chemicals, which have been discharged into the environment for decades by municipal and agricultural wastewater treatment systems. These micropollutants include pharmaceuticals and personal care products, hormones, pesticides, disinfectants, and other household chemicals. Biodegradation, or the use of microorganisms to transform chemical contaminants to less harmful products, is one of the most cost-effective approaches towards removing micropollutants (*2*). Biodegradation occurs in a variety of water treatment processes, including activated sludge, membrane and moving bed bioreactors, and sand filtration (*2*). However, engineering biological waste treatment systems for enhanced micropollutant removal has significant challenges. Some of these challenges include identifying microorganisms with the metabolic capacity to degrade pollutants, and optimising treatment facility operating conditions (*2*,*3*).

Trace analysis in biodegradation

Analytical chemistry plays an important role in measuring micropollutant removal rates and efficiency. The standard workflow for measuring organic micropollutants from environmental matrices consists of sample extraction and pre-concentration followed by instrumental analysis (*4*). Solid phase extraction and other sorptive extraction techniques are most commonly used, as these can process larger sample volumes with less solvent consumption than liquid-liquid extraction. Traditionally, hyphenated techniques utilising liquid or gas chromatography (LC or GC) have been employed to quantify organic micropollutants (*4*). When combined with mass spectrometry (MS), organic micropollutants can be analysed at nanogram per litre (ng/L) concentrations.

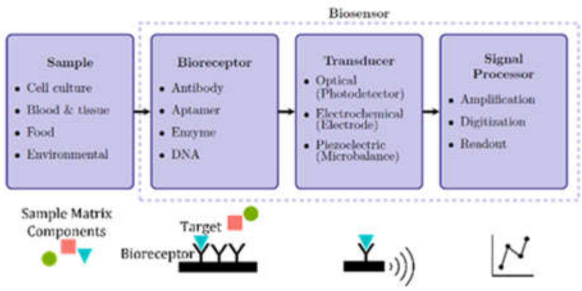

Figure 1. *Schematic showing the components of a biosensor.*

Nanomaterials-based biosensors

Biosensors are devices used to measure chemical or biological targets via a biological recognition element (**Figure 1**) (*5*). The biological recognition element is a biomolecule which is capable of binding to the target with a high degree of affinity and specificity, such as an antibody, a nucleic acid aptamer, an enzyme, or complementary DNA. In a biosensor, a target-bioreceptor binding event yields a physical or chemical change, which is detected by a transducer, such as a photodetector, electrode, and piezoelectric balance. The transducer then converts the physical or chemical response into an electronic signal, which is processed, converted into a digital form, and printed as an output.

Nanomaterials – or structures which are less than 100 nm in at least one dimension – have been used extensively in biosensors (*5,6*). Nanomaterials may be composed of organic or inorganic materials and can be synthesised in different geometries, such as nanoparticles, nanowires, nanosheets, and more complex structures. In addition to the high surface area-to-volume ratio which provides efficient bioreceptor immobilisation, nanomaterials possess unique physicochemical properties which are sensitive to changes in their environment, such as the interaction of the bioreceptor with the target. Thus, the nanomaterials in nanobiosensors are used to produce or enhance a measurable signal following target detection.

Nanobiosensors for micropollutants

Environmental monitoring is a rapidly emerging application for nanobiosensors (*5,6*). Nanobiosensors hold key advantages over conventional trace analysis of micropollutants, including minimal or no sample preparation, and the potential to be scaled down for portability and in-field monitoring (*7*). Nanobiosensors have been designed for numerous environmental contaminants, including seven substances listed under the European Union's Watch List (**Table 1**) (*8*). Electrochemical and optical sensors are the most common transducing mechanisms for organic micropollutants.

Table 1. *Examples of nanobiosensors for micropollutants listed under the EU Watch List (8).*

Substances	Nanobiosensor Type
17-Alpha-ethinylestradiol	Electrochemical immunosensor, silica nanoparticles (*9*)
17-Beta-estradiol, Estrone	Colorimetric aptasensor, gold nanoparticles (*10*)
Macrolide Antibiotics	Colorimetric immunosensor, gold nanoparticles (*11*)
Methiocarb	Colorimetric immunosensor, carbon nanoparticles (*12*)
Neonicotinoids	Fluorometric aptasensor, gold nanoparticles (*13*)
Amoxicillin	Electrochemical aptasensor, TiO_2-g-C_3N_4@gold nanoparticle composites (*14*)
Ciprofloxacin	Electrochemical aptasensor, carbon nanotubes (*15*)

Considerations for applications in monitoring biodegradation

Although numerous nanobiosensors have been designed for measuring micropollutants in various samples, these techniques have not yet been widely adopted. Biodegradation of micropollutants, particularly lab-based studies, has the potential to be a springboard application for demonstrating the utility of nanobiosensors in environmental research. The selective bioreceptor allows for micropollutant detection in a complex biological matrix, while the controlled nature of the inoculum and medium allows for reproducibility across laboratories in ways that field sampling is limited. In addition, this application could benefit from simpler and more cost-effective analytical methods for micropollutant quantification where multi-target analysis is unnecessary.

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