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Role of biosensor for environmental monitoring

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Introduction

Biosensors play a crucial role in environmental monitoring by providing rapid, sensitive, and specific detection of pollutants and hazardous substances in air, water, and soil. These devices leverage biological recognition elements, such as enzymes, antibodies, or nucleic acids, to interact with target analytes, producing a measurable signal proportional to the concentration of the substance. By integrating biological components with physicochemical detectors, biosensors enable real-time analysis and continuous monitoring, offering an efficient and cost-effective alternative to traditional laboratory-based methods. Their application ranges from detecting heavy metals and pesticides to monitoring microbial contamination, thereby helping to protect ecosystems and human health by ensuring timely detection and mitigation of environmental hazards.

Biosensor

The International Union of Pure and Applied Chemistry (IUPAC) defines a biosensor as a self-contained integrated device that uses a biological recognition element that is kept in direct spatial contact with a transduction element to provide specific quantitative or semiquantitative analytical information.

An immobilized biological component (such as an enzyme, DNA, cell organelle, whole cell or tissue, etc.) interacting with an analyte in close proximity to a transducer equipped with a readout device to translate the complex biological interaction into a signal that can be easily read is called a biosensor. Therefore, biosensors take advantage of a biological component's inherent sensitivity and specificity.

Biosensors constitute three essential components:

Biological component: The biocomponent shapes the basis of analysis through interactions with the analyte in the sample. Thus, the choice of a biocomponent is essential to the development of a biosensor for a certain analyte. A biocomponent is a biological substance or a biological byproduct.

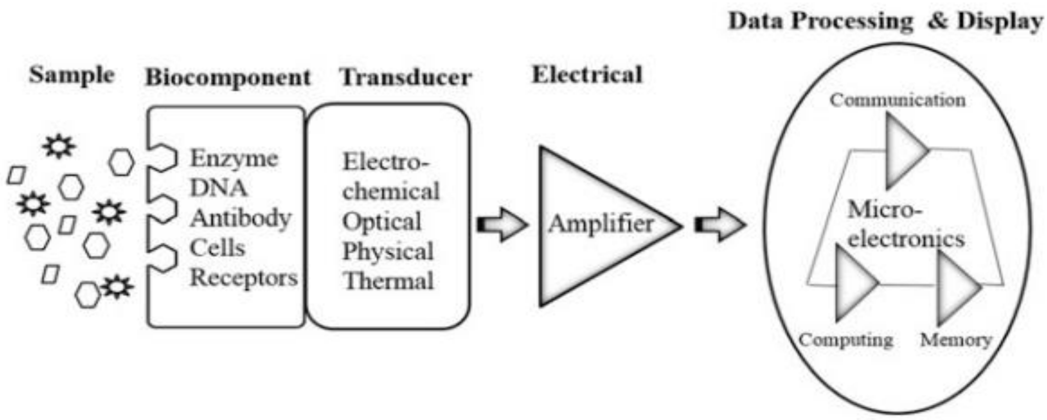

Fig. Basic working principle of biosensors

Transducer: Depending on the transducer, the biological signal generated by the interaction of the biocomponent with the analyte is transformed into an optical, electrochemical, or other physical-chemical signal. The choice of transducer is mostly influenced by the nature of the interaction and the biological signal generated, such as an alteration in pH following the interaction, a mass differential, the activation or inactivation of an enzyme, etc.

Readout device: Ultimately, the signal is processed and shown by the readout device together with any related microelectronics, such as a fiber-optic spectrofluorometer, plate reader, or electrochemical analyzer.

The key benefits of biosensors over the conventional techniques

- Rapid and continuous measurement
- High specificity and sensitivity
- Very less usage of reagents required for calibration
- Portability

Biosensors for Environmental monitoring

Numerous artificial chemicals and industrial byproducts have been introduced into the environment as a result of human technological advancement. Some of these compounds are well-known pollutants that have been shown to have an impact on environmental quality, such as pesticides, heavy metals, and PCBs (Rogers, 2006). A concern for the development of biosensor organisms has been the quick estimation of general quality parameters, such as the BOD, toxicity, and assessment of contamination by pathogenic organisms, in addition to the analysis of particular chemicals.

Biochemical Oxygen Demand (BOD)

Biochemical Oxygen Demand (BOD) is a measure of the amount of dissolved oxygen required by aerobic microorganisms to decompose the organic matter present in a water sample over a specified period, usually five days at 20°C. It is an important indicator of the organic pollution level in water bodies. With the help of biosensor, rapid determination of BOD has been achieved. Based on an amperometric oxygen electrode transducer modified with microorganisms that break down or metabolise organic pollutants, several BOD biosensors have been developed. *Torulopsis candida*, *Trichosporon cutaneum*, *Pseudomonas putida*, *Klebsiella oxytoca* AS1, *Bacillus subtilis*, *Arxula adeninivorans* LS3, *Serratia marcescens* LSY4, *Pseudomonas sp.*, *P. fluorescens*, *P. putida* SG10, *thermophilic bacteria*, *Hansenula anomala*, and yeast are among the microbial strains that have been utilised to create amperometric BOD biosensors.

Pesticides

A large number of pesticides fit into chemical families. The families of organochlorines, organophosphates, and carbamates are well-known insecticides. The way that organochlorine hydrocarbons, like DDT, work is by upsetting the sodium/potassium balance in the nerve fibre, which makes the nerve have to send signals all the time. While traditional methods like GC/MS and HPLC/MS can accurately quantify pesticide, they have several drawbacks, including being expensive and requiring a laboratory. To analyse pesticides more quickly, more affordably, and on-site, biosensors have been created. According to the hydrolytic activity of specific enzymes, such as glutathione S-transferase and OPH, biosensors can be generically categorised as catalytic biosensors or inhibition-based biosensors (Sassolas *et al.*, 2012). The most widely used bioassay principle for pesticide biosensors is enzyme inhibition.

Heavy Metals

Due to their high environmental persistence and inability to biodegrade, heavy metals pose a severe threat to the ecosystem and can find their way into food systems. Numerous biosensors for heavy metal detection have been created utilizing a range of biocomponents, including enzymes, whole cells, DNA, etc. Various enzymes, including acetylcholinesterase (AChE), urease, alkaline phosphatase, invertase, peroxidase, L-lactate dehydrogenase, tyrosinase, and nitrate reductase, have been employed in the detection of heavy metals (Turdean, 2011).

Recombinant DNA technology has been utilized to create heavy metal biosensors in addition to enzymes. To create different promoter reporter gene combinations, a range of specific and nonspecific heavy metal biosensors have been produced, as well as a variety of specific and nonspecific promoters reacting to different heavy metals. Heavy metals can interact with nucleic acids and have a strong affinity for DNA. Heavy metal biosensors have utilized DNA as a biocomponent due to this interaction characteristic. Both single-stranded (ssDNA) and double-stranded (dsDNA) DNA have been utilized in heavy metal research.

Enzymatic biosensor developed for different heavy metals

Enzyme	**Heavy metal ions detected**	**Respective detection limits**	**Detection method**
AChE	Hg^{2+}, Cd^{2+}, Zn^{2+}	0.1 nM, 0.5 mg/l, 2 mg/l	Amperometric
AChE	Cu^{2+}	50 µM	Amperometric
ALP	Co^{2+}, Ni^{2+}, Pb^{2+}	2 µg/l, 5 µg/l, 40 µ/l	Conductometric
GOx	Hg^{2+}, Cu^{2+}	2.5 µM, 2.5 µM	Amperometric
GOx	Hg^{2+}	1 ng/l	Amperometric

Toxicity

The degree to which a substance can harm an organism (such a plant, animal, or bacteria) or an organism's substructure (like a cell, tissue, or organ) is known as its toxicity. An automated biosensor for water toxicity was developed, which uses Thiobacillus ferrooxidans and an oxygen electrode to monitor cyanides in natural water sources. The foundation of the bioassay principle is the observation of a current rise brought on by the addition of toxicoids, which results in a decrease in oxygen consumption and an inhibition of bacterial respiration. Hara *et al.*, (2015) have created a toxicity biosensor that uses

A549 human lung epithelial cells, a mammalian cell used as the biological recognition agent.

Bioremediation

The method of bioremediation uses the ability of various bacteria to break down complex organic molecules into simpler inorganic elements. Many factors, including temperature, pH, available oxygen, metal ions, nutrients, and availability, affect the bioremediation process; keeping an eye on these factors will aid in process control. Biosensors have been created to keep an eye on the bioremediation process. Various molecular biosensors are used to track the bioremediation process. The majority of biosensors employed the technique of producing reporter genes, such as luciferase, under the guidance of a particular promoter that was sensitive to the analyte of interest. Other groups of environmental contaminants, such as polychlorinated biphenyls (PCBs), phenols, surfactants, polycyclic aromatic hydrocarbons (PAHs), inorganic phosphates, nitrates, etc., have also led to the development of biosensors for these pollutants.

Conclusion

In conclusion, biosensors represent a transformative advancement in environmental monitoring, offering precise, rapid, and real-time detection of contaminants and pollutants. Their ability to integrate biological recognition with advanced detection technologies allows for the continuous and on-site assessment of environmental quality, significantly improving our ability to protect ecosystems and public health. The deployment of biosensors can lead to more informed decision-making and prompt responses to environmental threats, ultimately fostering sustainable environmental management. As technology advances, the development of more robust, sensitive, and versatile biosensors will further enhance their utility and effectiveness in monitoring and preserving the natural environment.

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