ISBN: 978-93-94570-41-2

3. An Introductory Approach to Biosensors: Types and their Applications

Dr. Manish Kumar, Dr. Preetismita Borah

CSIR-Central Scientific Instruments Organisation,
Chandigarh, India.

Abstract:

Recently biosensors have been attracted the researchers due to biomedical diagnosis, monitoring of treatment and disease progression, environmental observance, food quality testing, water analysis, drug discovery, forensics and biomedical research. Biosensors are stable, low cost, and more efficient devices for various applications. Biosensors have been applied as sophisticated tools for sensing and monitoring. Biosensors are very specific towards sensitivity, reproducibility and provide more precise readings. Biosensors are very easy to use for various applications. The purpose of using a biosensor is to use the signal of the biological component, combine it with the physiological chemical element and understand the signal. The working of a biosensor is based on the biochemical specificity of the biologically active material. Biosensors are combination of the biological sensitive component (like microorganisms, cell organelles, enzymes, and antibodies as well as animal and plant cells or tissues), the transducer material (applying in an electrical or physiochemical approach) and the signal reader. Here, we present an introductory approach to biosensors, working principle, their various types and applications in multiple areas.

Keywords:

Biosensor, transducer, biochemical, materials, and applications.

3.1 Introduction:

In the past, 1906 when M. Cremer invented that the acid concentration is proportional to the electric potential which arises between fluid parts situated other sides of a glass membrane [1]. Although, introduction of pH (concentration of hydrogen ion) reveled by Soren Peder Lauritz Sorensen in 1909 and pH measurements electrode was deduced in 1922 by W.S. Hughes [2].

From 1909 to 1922, Griffin and Nelson first explained the enzyme immobilization on aluminium hydroxide and charcoal [3, 4]. Leland C. Clark, Jr invented first biosensor in 1956 for oxygen detection. He is well-known as the ‘father of biosensors’ and his invention about the oxygen electrode is called ‘Clark electrode’ [5]. After that, Leland Clark demonstrated glucose detection through electrode of an amperometric enzyme in 1962. Meanwhile, first potentiometric biosensor was developed by Guilbault and Montalvo, Jr in 1969 for detecting urea [6]. In 1975 the first biosensor was commercialized by Yellow Spring Instruments (YSI).

There is generation of biosensors is tabulated from year of 1970 to 1992 in Table 1. Invention of the i-STAT sensor was great achievement in the biosensors world. Presently, this field is developed as a research for multidisciplinary area which combines all branches of science i.e. physics, chemistry and biology along with micro/nano-technology, electronics and medical area. The progress regarding biosensors has been indexed by 'Web of Science' through many thousand reports between 2005-2022.

Table 3.1: Important development of biosensors during 1970-1992

Year	Development	Reference
1970	Discovery of ion-sensitive field-effect transistor (ISFET) by Bergveld	[7]
1975	Fibre-optic biosensor for carbon dioxide and oxygen detection by Lubbers and Opitz	[8]
1975	First commercial biosensor for glucose detection by YSI	[9]
1975	First microbe-based immunosensor by Suzuki et al.	[10]
1982	Fibre-optic biosensor for glucose detection by Schultz	[11]
1983	Surface plasmon resonance (SPR) immunosensor by Liedberg	[12]
1984	First mediated amperometric biosensor: ferrocene used with glucose oxidase for glucose detection	[13]
1990	SPR-based biosensor by Pharmacia Biacore	[8]
1992	Handheld blood biosensor by i-STAT	[8]

Biosensor term is designated from "biological sensor". A biosensor is an analytical device, used for the detection of a chemical substance, which combines a biological component with a physicochemical detector [14].

3.2. Working of biosensor:

A biosensor is consisting of various essential components as given following details:

Analyte: A substance of interest which is detected. Such as, glucose is an 'analyte' in a bio-analytical device then it will detect glucose.

Bioreceptor: A molecule which identifies the analyte is called as a bioreceptor like enzymes, cells, aptamers, deoxyribonucleic acid (DNA) and antibodies. Signal generation process is in the form of light, heat, pH, charge or mass change, etc. which is due to interaction between bioreceptor and the analyte, known as bio-recognition.

Transducer: An element which converts one form of energy into another is deduced transducer. So, in the biosensor, transducer converts the bio-recognition process to a measurable signal. Mostly transducers produce two types' signals i.e. optical or electrical signals those are proportional to the amount of analyte–bioreceptor interactions.

Electronics: Electronically the transduced signal are processed and prepared to display. The signals are converted from analogue to the digital form then these signals are displayed as output in numeric, graphic, tabular or an image form.

Display: The display unit can be a computer display or a printer which shows measurements and graphs. The display unit generally made of using hardware and software.

Figure 3.1 represents the schematic working process of biosensor.

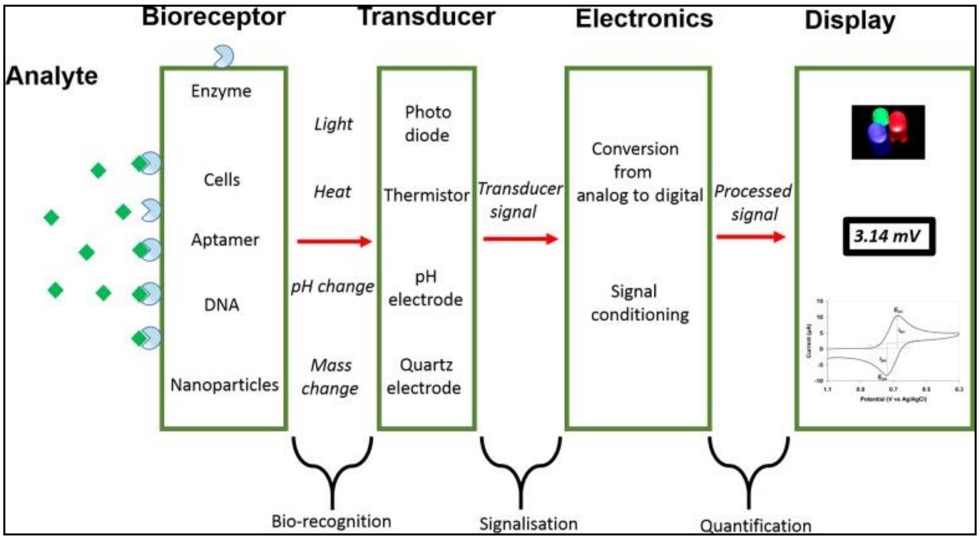

Figure 3.1: Schematic representation of a biosensor [15]

3.3. Types of Biosensors

The biosensors are found in various types which are based on the sensor device and bioreceptor. Some of them are discussed as follow:

3.3.1 Electrochemical Biosensor

This type of biosensor works to the reaction of enzymatic catalysis which provides electrons. These enzymes are called Redox enzymes. The electrochemical biosensor is three electrodes based such as a counter, reference, and working electrode. The current is measured at a fix potential. These biosensors detect many molecules in the body like glucose, cholesterol, uric acid, lactate, DNA, hemoglobin, blood ketones etc. [16].

Electrochemical biosensors are also classified into four types:

A. Amperometric Biosensors
B. Potentiometric Biosensors
C. Impedimetric Biosensors
D. Voltammetric Biosensors

3.3.2 Optical Biosensor:

These biosensors work on optical analysis. The transducing elements such as antibodies and enzymes and optical fiber are used in these sensors.

The optical fibers sense the elements applying various characteristic of light such as absorption, scattering and fluorescence [17].

3.3.3 Piezoelectric Biosensor:

These biosensors are based on mass and also expressed as Acoustic Biosensors because sound vibrations principle works there. When mechanical energy is converted to electric energy then this process is known as piezoelectricity. The piezoelectric effect analyzes changing in pressure, acceleration, temperature, force [18].

3.3.4 Microbial biosensor:

Microbial biosensor works when micro-organisms and a transducer are coupled for fast, perfect sensing of target analytes in various areas like medicine, environmental monitoring, defense, food processing and safety.

3.3.5 Enzyme biosensor:

This biosensor is applied to couple an enzyme with a transducer to produce a signal and this signal is amplified, stored, processed for the detection. These type of biosensors are fabricated using sensitive membrane - immobilized enzyme and electrode transducer system [19].

3.4. Applications of Biosensor:

Biosensors are used widely to increase the quality of life. These are being used for environmental monitoring, disease identification, food safety, defense, and drug discovery, Common healthcare checking, metabolites measurement, screening for sickness, insulin treatment, clinical psychotherapy, diagnosis of disease, in military, agricultural, veterinary applications, drug improvement, offense detection, processing and monitoring in industrial, ecological pollution control, study and interaction of biomolecules, detection of crime, pesticide detection, pharmaceuticals manufacturer and organs replacement etc. The detection of biomolecule is a signal about the disease or targeted drug such as electrochemical biosensor is applied to detect protein cancer biomarkers [20].

Biosensors monitor food traceability, quality, safety and nutritional value as per standard parameter to use ingredients [21]. Toxic elements can be traced from chemical and biological materials which can be used in defense. Biosensors can be used for the artificial implantation devices like pacemakers, prosthetic devices, and sewage epidemiology.

Figure 3.2 deduces applications of biosensor in various areas.

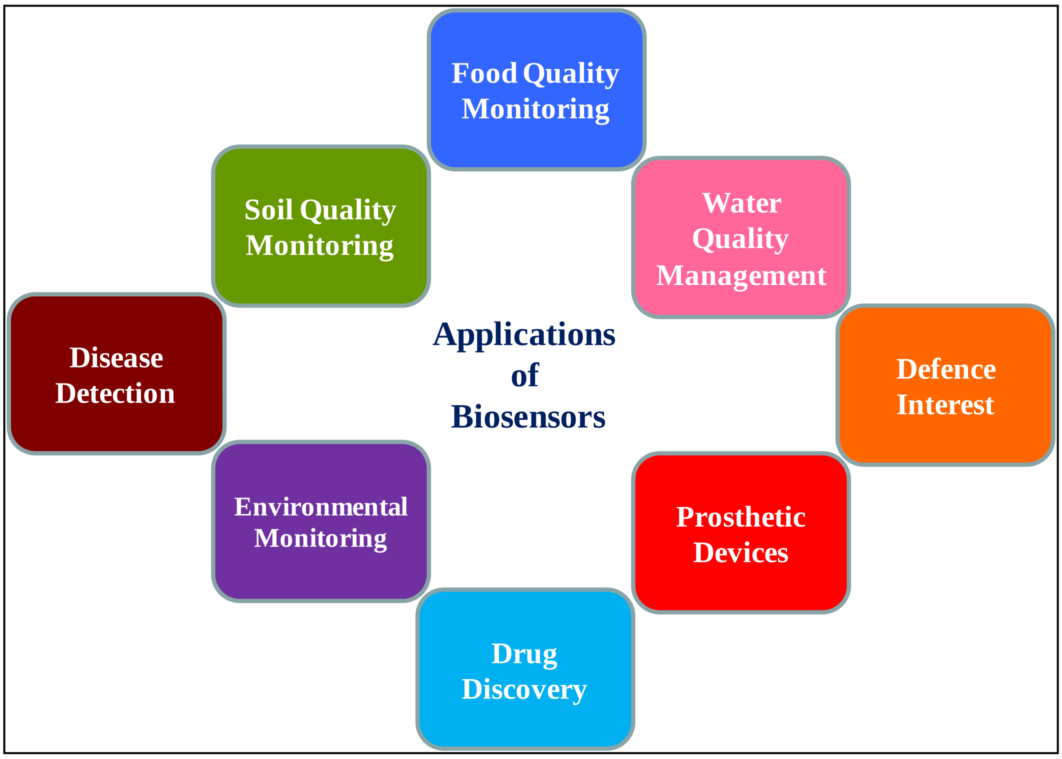

Figure 3.2: Schematic Representation of Biosensor Applications

3.5 Conclusion:

Biosensor is a system which sense, measures, and produce information about physiological change or existence of many chemical or biological elements in the ecological system. Biosensors combine the selectivity of biological system with the processing power of modern microelectronics to offer powerful new analytical tools with major applications in medicine, environmental diagnostic, food industries and agriculture. The advantages of biosensors are that these are small size, low cost, rapid results and easy to use.

3.6 References:

1. M. Cremer, Über die Ursache der elektromotorischen Eigenschaften der Gewebe, zugleich ein Beitrag zur Lehre von den polyphasischen Elektrolytketten. Z. Biol. 47 (1906) 562–608.
2. W.S. Hughes, The potential difference between glass and electrolytes in contact with the glass. J. Am. Chem. Soc. 44 (1922) 2860–2867.
3. E.G. Griffin, J.M. Nelson, The influence of certain substances on the activity of invertase. J. Am. Chem. Soc. 38 (1916) 722–730.
4. J.M. Nelson, E.G. Griffin, Adsorption of invertase. J. Am. Chem. Soc. 38 (1916) 1109–1115.
5. W.R. Heineman, W.B. Jensen, C. Leland, Jr. Clark, Biosens. Bioelectron. 21 (2006) 1403–1404.

6. G.G. Guilbault, J.G. Montalvo, Urea-specific enzyme electrode. J. Am. Chem. Soc. 91 (1969) 2164–2165.
7. P. Bergveld, Development of an ion-sensitive solid-state device for neurophysiological measurements. IEEE Trans. Biomed. Eng. 1(7) (1970) 70–71.
8. M.C. Vestergaard, K. Kerman, I.M. Hsing, E. Tamiya, Nanobiosensors and Nanobioanalyses. Tokyo, Springer; 2015.
9. E.H. Yoo, S.Y. Lee, Glucose biosensors: an overview of use in clinical practice. Sensors. 10 (2010) 4558–4576.
10. S. Suzuki, F. Takahashi, I. Satoh, N. Sonobe, Ethanol and lactic acid sensors using electrodes coated with dehydrogenase–collagen membranes. Bull. Chem. Soc. Jpn. 48 (1975) 3246–3249.
11. J.S. Schultz, Optical sensor of plasma constituents. 4,344,438 A. U.S. Pat. 1982.
12. B. Liedberg, C. Nylander, I. Lunström, Surface plasmon resonance for gas detection and biosensing. Sens. Actuators. 4 (1983) 299–304.
13. A.E. Cass, G. Davis, G.D. Francis, H.A.O. Hill, W.J. Aston, I.J. Higgins, Ferrocene-mediated enzyme electrode for amperometric determination of glucose. Anal. Chem. 56 (1984) 667–671.
14. C. Dincer, R. Bruch, E. Costa-Rama, M.T. Fernández-Abedul, A. Merkoçi, A. Manz, G.A. Urban, F. Güder, Disposable Sensors in Diagnostics, Food, and Environmental Monitoring. Adv. Mat. 31 (30) (15 May 2019) e1806739.
15. N. Bhalla, P. Jolly, N. Formisano, P. Estrela, Introduction to biosensors. Essays Biochem. 60(1) (2016) 1–8.
16. M. Choudhary, K. Arora, Electrochemical biosensors for early detection of Cancer. Biosensor based advanced cancer diagnostics, 2022.
17. R.K. Darsnaki, A. Azizzadeh, Review article Biosensors: functions & applications. Jr Bio. Today's World 2 (1) (2013) 53-61.
18. Encyclopedia of electronic components. Vollume 1, (Power sources & conversion: resistor,capacitors, inductors,switches, encoders, relays, transistors) 2012.
19. G. Rocchitta, A. Spanu, P.A. Serra, Enzyme biosensors for biomedical applications: Strategies for safeguarding analytical performances in biological fluids. 30 May 2016.
20. P. Jolly, N. Formisano, P. Estrela. DNA aptamer-based detection of prostate cancer. Chem. Pap. 69 (2015) 77–89.
21. B.V. Dorst, J. Mehta, K. Bekaert, E. Rouah-Martin, W. De Coen, P. Dubruel, Recent advances in recognition elements of food and environmental biosensors: a review. Biosens. Bioelectron. 26 (2010) 1178–1194.