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Biosensors, Types and Applications—A Review

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Abstract

Biosensor has rapidly become essential analytical tools, since they offer higher performance in terms of sensitivity and selectively than any other currently available diagnostic device. The development of biosensor technology represents a crucial task for environmental pollution management. There is a considerable need to project and realize biosensors with the best features for commercialization, such as selectivity, sensitivity, stability, reproducibility and low cost. With appropriate progress testing and commercialization, biosensors will have an important impact on environmental monitoring, reducing costs and increasing the efficiency of certain applications. The same multiple approach might be used for development of biosensor platforms suitable for use in fields as diverse as environmental and agrifood to industry, research security and defense, medical and clinical. This review paper focused on the various types of biosensors and its applications.

Keywords: *biosensor, types of biosensors, applications*

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INTRODUCTION

A biosensor is an analytical device for the detection of an analyte that combines a biological component with a physicochemical detector component[1]. Biosensors are also known as immunosensors, optrodes, chemical canaries, resonant mirrors, glucometers, biochips, biocomputers, and so on. A commonly cited definition is "a biosensor is a chemical sensing device in which a biologically derived recognition entity is coupled to a transducer, to allow the quantitative development of some complex biochemical parameter"; and also "a biosensor is an analytical device incorporating a deliberate and intimate combination of a specific biological element (that creates a recognition event) and a physical element (that transduces the recognition event)". The name "biosensor" signifies that the device is a combination of two parts: (i) a bio-element, and (ii) a sensor-element[1].

A specific "bio" element (say, enzyme) recognizes a specific analyte and the "sensor" element transduces the change in the biomolecule into an electrical signal. The bio-element is very specific to the analyte to which it is sensitive. It does not recognize other analytes. Depending on the transducing mechanism used, the biosensors can be of many types such as, (i) Resonant biosensors, (ii) Optical-detection biosensors, (iii) Thermal-detection biosensors, (iv) Ion-sensitive field effect transistor (ISFET) biosensors, and (v) Electrochemical biosensors. Details of all these different types of biosensors will be discussed in this article. The electrochemical biosensors based on the parameter measured can be further classified as: (i) conductimetric, (ii) amperometric, and (iii) potentiometric. Biosensors can have a variety of biomedical, industry, and military applications. The major application so far is in blood glucose sensing because of its abundant market potential. However, biosensors have tremendous potential for commercialization in other fields of application as well. In spite of this potential, however, commercial adoption has been slow because of several technological difficulties. For example, due to the presence of biomolecules along with semiconductor materials, biosensor contamination is a major issue.

The bio-element may be an enzyme, antibody, living cells, tissue, etc.; and the sensing-element may be electric current, electric potential, and so on. Different combinations of bio-elements and sensor-elements constitute several types of biosensors to suit a vast pool of applications[2].

TYPES OF BIOSENSORS

Resonant Biosensors

In this type of biosensor, an acoustic wave transducer is coupled with an antibody (bio-element). When the analyte molecule (or antigen) gets attached to the membrane, the mass of the membrane changes. The resulting change in the mass subsequently changes the resonant frequency of the transducer. This frequency change is then measured.

Optical-Detection Biosensors

The output transduced signal that is measured for this type of biosensor is light. The biosensor can be made based on optical diffraction or electrochem iluminescence. In optical diffraction-based devices, a silicon wafer is coated with a protein via covalent bonds. The wafer is exposed to UV light through a photo-mask and the antibodies become inactive in the exposed regions. When the diced wafer chips are incubated in an analyte, antigen-antibody bindings are formed in the active regions, thus creating a diffraction grating. This grating produces a diffraction signal when illuminated with a light source such as laser. The resulting signal can be measured or further amplified before measuring for improved sensitivity.

Thermal-Detection Biosensors

This type of biosensor is exploiting one of the fundamental properties of biological reactions, namely absorption or production of heat, which in turn changes the temperature of the medium in which the reaction takes place. They are constructed by combining immobilized enzyme molecules with temperature sensors. When the analyte comes in contact with the enzyme, the heat reaction of the enzyme is measured and is calibrated against the analyte concentration. The total heat produced or absorbed is proportional to the molar enthalpy and the total number of molecules in the reaction. The measurement of temperature is typically accomplished via a thermistor, and such devices are known as enzyme thermistors. Their high sensitivity to thermal changes makes thermistors ideal for such applications. Unlike other transducers, thermal biosensors do not need frequent recalibration and are insensitive to the optical and electrochemical properties of the sample. Common applications of this type of biosensor include the detection of pesticides and pathogenic bacteria.

Ion-Sensitive Biosensor

These are semiconductor field effect transistors (FETs) having an ion-sensitive surface. The surface electrical potential changes when the ions and the semiconductor interact. This change in the potential can be subsequently measured. The Ion-Sensitive Field Effect Transistor (ISFET) can be constructed by covering the sensor electrode with a polymer layer. This polymer layer is selectively permeable to analyte ions. The ions diffuse through the polymer layer and in turn cause a change in the FET surface potential. This type of biosensor is also called as an Enzyme Field Effect Transistor (ENFET) and is primarily used for pH detection[3–4].

Electrochemical Biosensors

Electrochemical biosensors are mainly used for the detection of hybridized DNA, DNA-binding drugs, glucose concentration, etc. The underlying principle for this class of biosensors is that many chemical reactions produce or consume ions or electrons which in turn cause some change in the electrical properties of the solution which can be sensed out and used as measuring parameter. Electrochemical biosensors can be classified based on the measuring electrical parameters as: (1) conductimetric, (2) amperometric, and (3) potentiometric[4].

Conductimetric

The measured parameter is the electrical conductance / resistance of the solution. When electrochemical reactions produce ions or electrons, the overall conductivity or resistivity of the solution changes. This change is measured and calibrated to a proper scale. Conductance measurements have relatively low sensitivity. The electric field is generated using a sinusoidal voltage (AC) which helps in minimizing undesirable effects such as Faradaic processes, double layer charging and concentration polarization.

Amperometric

This high sensitivity biosensor can detect electroactive species present in biological test samples. Since the biological test samples may not be intrinsically electroactive, enzymes are needed to catalyze the production of radioactive species. In this case, the measured parameter is current.

Potentiometric

In this type of sensor, the measured parameter is oxidation or reduction potential of an electrochemical reaction. The working principle relies on the fact that when a ramp voltage is applied to an electrode in solution, a current flow occurs because of electrochemical reactions. The voltage at which these reactions occur indicates a particular reaction and particular species[5].

GLUCOSE BIOSENSORS

The most commercially successful biosensors are amperometric glucose biosensors. These biosensors have been made available in the market in various shapes and forms such as glucose pens, glucose displays, etc.

Glucose reacts with glucose oxidase (GOD) to form gluconic acid while producing two electrons and two protons, thus reducing GOD. The reduced GOD, surrounding oxygen, electrons and protons (produced above) react to form hydrogen peroxide and oxidized GOD (the original form). This GOD can again react with more glucose. The higher the glucose content, more oxygen is consumed. On the other hand, lower glucose content results in more hydrogen peroxide. Hence, either the consumption of oxygen or the production of hydrogen peroxide can be detected by the help of platinum electrodes and this can serve as a measure for glucose concentration.

Disposable amperometric biosensors for the detection of glucose are also available. The typical configuration is a button-shaped biosensor consisting of the following layers: metallic substrate, graphite layer, isolating layer, mediator modified membrane, immobilized enzyme membrane (GOD), and a cellulose acetate membrane. This biosensor uses graphite electrodes instead of platinum electrodes (as originally used by Clark). The isolating layer is placed on the graphite electrodes which can filter out certain interfering substances (ascorbic acid, uric acid) while allowing the passage of hydrogen peroxide and oxygen. The mediator modified membrane helps in keeping the GOD membrane attached to the graphite electrode when the electrochemical reaction takes place at a specific applied potential. The cellulose acetate outer layer placed over the GOD membrane also provides a barrier for interfering substances. The amperometric reading of the biosensor (current versus glucose concentration) shows that the relationship is linear up to a specific glucose concentration. In other words current increases linearly with glucose concentration, hence it can be used for detection.

The current and future applications of glucose biosensors are very broad due to their immediate use in diabetic self-monitoring of capillary blood glucose. These types of monitoring devices comprise one of the largest markets for biosensors today and their existence has dramatically improved the quality of life of diabetics[6].

MICROBIAL BIOSENSORS

Microbial sensors are based on microorganisms in intimate contact with a transducer, which converts the biochemical signal into a quantifiable electrical response signal. The aim of this combination is the sensitive determination of a large spectrum of substances in various fields, especially biotechnology and pollution control. The first reported biosensors based on microorganisms related the respiration rate of the immobilized microbes to the concentration of the substrate to be detected. Such biosensors were used for biological oxygen demand (BOD) monitoring. Several such BOD sensors have now been commercialized and new industrial standard methods based on these devices are being developed. BOD sensors offer a great advantage over the five-day-BOD laboratory test. Such biosensors have been also reported for toxicity monitoring. The main advantages of microbial sensors are that they are inexpensive and easy to construct. Microbial biosensors based on bioluminescent microbes such as *Vibrio fishceri* have also been reported. Canada is a world leader in this highly commercializable technology. However, the most recent focus on microbial biosensors is based on the use of recombinant microorganisms that recognize and report the presence of specific environmental pollutants[2].

Significance of Microbial Sensors

Environmental issues are most concerned nowadays. Concern over the pollution risk to drinking water from industry and agriculture, and the need for continuous online monitoring is growing. There is increasing use of living organisms as the sensitive agent to detect the presence of pollutants, and whole-cell biosensors are seen to have particular advantages in such environmental monitoring. The development of a mediated amperometric biosensor, incorporating the cyanobacterium *Synechococcus sp.* as the biocatalyst, for online herbicide monitoring is developed. The biosensor is able to detect a wide range of herbicides with sites of action on the photosynthetic electron transport chain. Thus microbial biosensors can help in mitigating problems related to our basic needs, i.e., food and water, hence overcoming many health and environment problems. Microbial sensors have the advantages of tolerance to measuring conditions-a long lifetime, and cost performance[7].

Advantage of Using Microbial Cells

The use of microbial cells in place of isolated enzymes offers several advantages over enzyme electrodes, such as, elimination of the tedious enzyme extraction and purification steps; avoidance of the need for a cofactor, and increased stability. The microbial sensors show an increased stability because the enzyme environment is optimized by evolution and well suited for recovery. These sensors are essentially living and may be fed and kept alive for a long period. Furthermore, the whole cell may perform multistep transformations that could be difficult, if not impossible, to achieve with single enzymes. However, microbial sensors suffer from the multi-receptor behavior of intact cells, resulting in a rather poor selectivity.

Principles of Different Microbial Biosensors

Based on Oxygen Electrodes

These are based on the ability to measure the respiratory activity of microorganisms and its alteration as a result of the presence of a tested substance. This allows a relatively simple transduction of the substrate response of microorganisms by an oxygen electrode. The microbial sensors herein reported measure the change in respiratory activity of microorganisms that are monitored directly by an electrochemical device. This sensor type is called as a respiratory electrode. The main parts of such a biosensor are the microorganisms as the recognition system and an oxygen electrode as the physical transducer. The parts are separated by a gas permeable membrane. The cells are immobilized using an outer semipermeable membrane covering the sensor.

Based on Respiratory Inhibition

Yeast can be used as a microorganism for such sensors, and thus cyanide can be measured by respiratory inhibition using an oxygen electrode. Cyanide is extremely toxic because it inhibits the respiration of life forms. The respiratory chain in the inner mitochondrial membrane in yeast contains the enzyme complexes through which electrons pass from NADH to O_2. Compounds such as potassium cyanide and sodium cyanide bind to *heme a* in cytochrome a and cytochrome a_3 in the cytochrome oxidase complex. The resultant inactivation of *heme a* causes a decrease in the respiration. The cyanide-induced decrease in respiratory activity causes a decrease in oxygen consumption. The cyanide concentration can be measured from the change in the oxygen consumption of the immobilized microorganisms with an oxygen electrode.

Based on Potentiometric Detection

These devices generate the potential developed across an ion-selective membrane separating two solutions, proportional to the logarithm of the analyte concentration, according to the Nernst equation. For example, immobilized *Streptococcus faecium* containing three sequential enzymes required for the hydrolysis of arginine has been used for arginine detection with a pNH_3 electrode. Karube *et al.* described a microbial biosensor for glutamic acid using immobilized *E. coli* with a glutamate decarboxylase activity in conjunction with a carbon dioxide gas sensitive electrode. A biosensor based on bacteria *Proteus morganii* has been developed for cysteine detection[5]. *P. morganii*, which contains a cysteine desulfhydrase catalyzing the conversion of cysteine to pyruvate, yields NH_3 and H_2S. In this biosensor, both pNH_3 and pH_2S electrodes could be used as a physical transducer.

Microbial Biosensors

A microbial biosensor based on optical detection employs whole-cell microorganisms to catalyze, sense, and transmit optical signals. These signals may correspond to light emission, reflection, fluorescence, or absorption. Primarily, the bioluminescence genes in the marine bacteria *Vibrio fishceri* are used in the construction of *LUX gene* reporters. The essential components in designing an optical biosensor include a photon-detection unit (e.g., photomultiplier), an optimal light-transmission device (e.g., liquid light guide or fiber-optic cables) and a converter unit to transform the light signals into electrical readings[6].

APPLICATIONS

One of the major driving forces for the development of biosensors is biomedical diagnosis. The most popular example is glucose oxidase-based sensor used by individuals suffering from diabetes to monitor glucose levels in blood. Biosensors have also found potential applications in the agricultural and food industries. However, very few biosensors have been commercialized.

Agricultural Industry

Enzyme biosensors based on the inhibition of cholinesterases have been used to detect traces of organophosphates and carbamates from pesticides. Selective and sensitive microbial sensors for the measurement of ammonia and methane have been studied[7]. However, the only commercially available biosensors for wastewater quality control are BOD analyzers based on micro-organisms like the bacteria *Rhodococcus erythropolis* immobilized on collagen or polyacrylamide. Standard BOD measurements in which the effluent is pretreated and exposed to bacteria and protozoa require incubation at 20 °C for 5 day. In contrast, BOD biosensors have throughputs of 2–20 samples per hour and can measure 0 mg L21 to 500 mg L21 BOD. When coupled with automatic sampling they can be implemented online[7].

Food Industry

Biosensors for the measurement of carbohydrates, alcohols, and acids are commercially available. These instruments are mostly used in quality assurance laboratories or at best, online coupled to the processing line through a flow injection analysis system. Their implementation inline is limited by the need of sterility, frequent calibration, analyte dilution, etc. Potential applications of enzyme-based biosensors to food quality control include measurement of amino acids, amines, amides, heterocyclic compounds, carbohydrates, carboxylic acids, gases, cofactors, inorganic ions, alcohols, and phenols[8]. Biosensors can be used in industries such as wine, beer, yogurt, and soft drinks producers. Immunosensors have important potential in ensuring food safety by detecting pathogenic organisms in fresh meat, poultry, or fish[8].

CONCLUSIONS

Biosensor technology is an emerging technology having vast scope of application in almost every field. Most biosensors systems have been tested only on non-real samples such as in distilled water or buffer solutions; a few biosensors applied to real samples have appeared in the recent years. Some representative examples of their application to the determination of different classes of key pollutants and environmental quality parameters, such as BOD, toxicity or endocrine effects, in a variety of matrices are listed. The application of biosensors to real samples must be a necessary step before their commercialization, which is, in general, the aim of the device development. Most commercial biosensors developed are needed to focus in clinical applications, such as for glucose and lactate. Prospective biosensor market for food, pharmaceutical, agriculture, military, veterinary and environment are still to be explored.

REFERENCES

1. Rogers KR. Biosensors for environmental applications. *Biosens Bioelectron.* 1995; 10: 533–41p.
2. Rodriguez-Mozaz S, Marco MP, Lopez de Alda MJ, *et al*. Biosensors for environmental applications: future development trends. *Pure Appl Chem*. 2004; 76(4): 723–52p.
3. Choi MMF. Progress in enzyme-based biosensors using optical transducers. *Microchimica Acta*. 2004; 148: 107–32p.

4. Loung JHT, Male KB, Glennon JD. Biosensor technology: technology push versus market pull. *Biotechnol Adv*. 2008; 26: 492–500p.
5. Choi MMF. Progress in enzyme-based biosensors using optical transducers. *Microchimica Acta*. 2004; 148: 107–32p.
6. Marquette CA, Blum LJ. State of the Art and Recent Advances in Immunoanalytical Systems. *Biosensors and Bioelectronics*. 2006; 21: 1424–33p.
7. Wittman C, Riedel K, Schmid RD. Microbial and Enzyme Sensors for Environmental Monitoring. In: Kress-Rogers E (Ed.). *Handbook of Biosensors and Electronic Noses. Medicine, Food and the Environment*. New York: CRC Press; 1997. 305–6p.
8. Deshpande SS, Rocco RM. Biosensors and Their Potential Use in Food Quality Control. *Food Technol*. 1994; 48(6): 146–50p.