The Canadian society for engineering in agricultural, food, and biological systems
CSAE
SCGR
La société canadienne de génie agroalimentaire et biologique

Paper No. 05-003

Biosensors – An Emerging Technology for the Agricultural and Food Industry

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Written for presentation at the
CSAE/SCGR 2005 Meeting
Winnipeg, Manitoba
June 26 - 29, 2005

Abstract.

A convenient, quick and cost-effective method to detect the presence of allergenic components and pathogens is one of the greatest challenges confronting the food processing industry. Biosensors are emerging as a highly promising tool for rapid diagnosis of pathogens and allergenic components in foods. Detection of contaminants, verification of product contents, product freshness and monitoring of raw materials conversion are the areas of potential biosensor applications. Biosensors can also be used to detect environmental pollutants, to determine the presence of pesticide residues in agricultural products and to monitor the plant and animal health. The aim of this study is to review the development, application and types, its current situation and future possibilities of biosensors in the food and agricultural industry.

Keywords. biosensors, food industry, agricultural industry, detection of pathogens

Introduction

Recent advances in electronic vision and computer technology have opened the research horizons for greater accuracy in process control, product sorting, and machine operation in the agricultural and food industry. The term biosensor has been variously applied to a number of devices either used to monitor living systems or incorporating biotic elements. Biosensor is a progressing interdisciplinary research between analytical chemistry, biology and microelectronics.

A biosensor is defined as a compact analytical device incorporating a biological or biologically-derived sensing element either integrated within or intimately associated with a physicochemical transducer. The aim of a biosensor is to produce either discrete or continuous electronic signals which are proportional to a single analyte or a related group of analytes (Turner et al., 1987).

The principle of detection is the specific binding of the analyte of interest to the complementary biorecognition element immobilized on a suitable support medium. The specific interaction results in a change in one or more physico-chemical properties (pH change, electron transfer, mass change, heat transfer, uptake or release of gases or specific ions) which are detected and may be measured by the transducer. The biological materials used in biosensor technology are the enzymes, antibodies and nucleic acids. Figure 1 shows principle of operation of a biosensor. Biosensors can be classified into four types based on the method of signal induction: optical, mass, electrochemical and thermal sensors. Ideal characteristics for a biosensor are higher accuracy, quick assay time, better sensitivity, higher specificity, robust and user friendliness.

In the food and the agricultural industries, the quality of a product is evaluated through periodic chemical and microbiological analyses which are expensive, slow, need well trained operators and in some cases, require steps of extraction or sample pretreatment, increasing the time of analysis. Biosensors can provide rapid, non-destructive and affordable methods for the quality monitoring of a product. Biosensors reduce assay time and cost or increase the product safety. Biosensors have been adapted to detect or measure analytes in on-line systems. Biosensors have the potential to create an analytical revolution to resolve the problems in the agricultural and the food industries.

For quality assessment, grading, and sorting of biological products, several types of electronic sensors are being developed for providing rapid and non-destructive determination of internal qualities. New markets for biosensors and other bioelectronic devices are developing. Biosensors offer enormous potential to detect a wide range of analytes in the food industry and environmental monitoring.

The aim of this article is to review the applications of biosensors in the agricultural and the food industries.

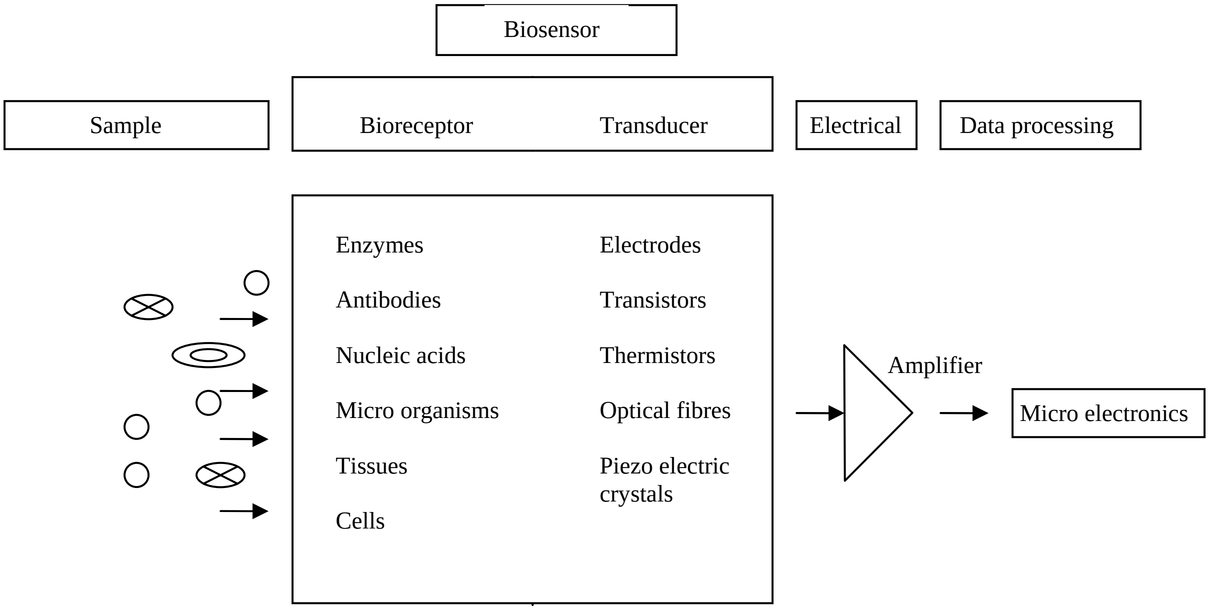

Figure 1. Principle of operation of a biosensor (Source: Velasco and Mottram, 2003).

Biosensors for the food industry

Consumers are placing significant importance on the quality of food products that they purchase. This has forced the agricultural and the food industries to place an increased emphasis on quality monitoring of products.

Food borne pathogens pose a risk to food safety and are a threat to the global food supply chain. The detection and identification of pathogens in raw food materials, food products, processing and assembly lines, hospitals and drinking water supplies continue to rely on time consuming conventional culturing techniques. Biosensors have the potential to revolutionize food and water supply monitoring by detecting the presence of residues, traces, chemicals, pathogens and toxins quickly.

Food and water supply monitoring

Radke and Alocilja (2005) developed a high density micro electrode array biosensor for detecting *E.coli* O157:H7 bacteria in food materials. They observed that the change in impedance of the biosensor is directly proportional to the number of bacteria immobilized on the biosensor surface. Figure 1 shows the impedance for different concentrations of E.Coli O157:H7 in pure culture. They detected up to 10 organisms of *E. coli* O157:H7 by testing the biosensor in different concentrations of bacteria in lettuce water sample. The advantage of this sensor is that it is field-deployable, easy to use, portable, and reagentless and provides results in minutes compared to hours or days for conventional methods.

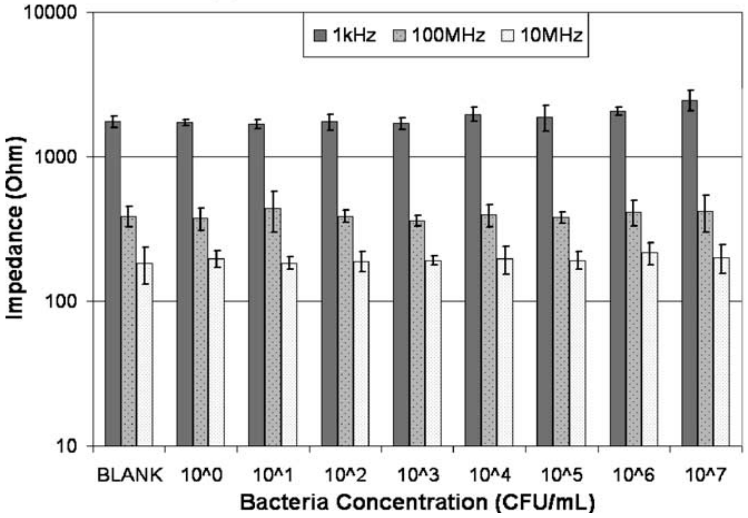

Figure 1. Impedance of *E.coli* O157:H7 bacteria concentrations in lettuce wash water at a frequencies of 1, 100 kHz and 1 MHz (Source: Radke and Alocilja, 2005).

Kim and Park (2003) developed a flow - type anti body sensor using quartz crystal microbalance chip as biological component and transducer to detect *E. coli* in drinking water, beef, pork and dumpling. The developed sensor was simple to use and economical in that it measures frequency changes due to mass deposits which are produced by antigen – antibody interaction. Figure 2 shows the relationship between E. coli concentration and frequency change.

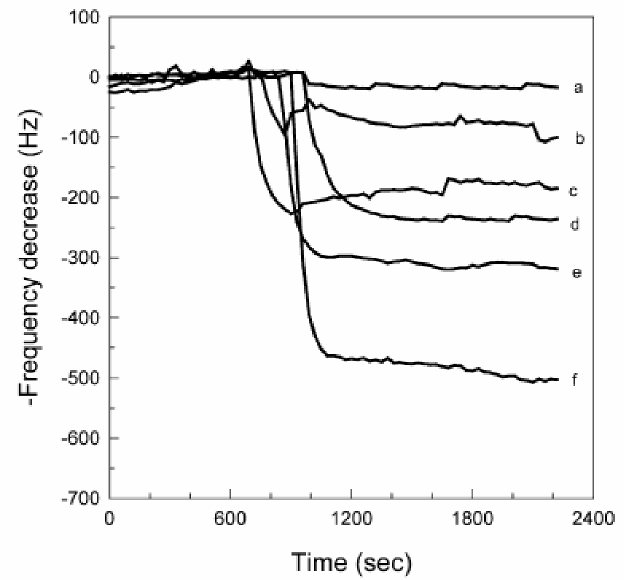

Figure 2. Concentration dependent responses of the flow-type antibody sensor. The added E.coli concentrations were (a) zero, (b) 2.3 X 10^6 , (c) 1.8 X 10^7, (d) 2.2X 10^7, (e) 3.1 X 10^7 and (f) 8.7 X 10^7 CFU/ml (Source: Kim and Park, 2003).

A lactose biosensor was designed and fabricated by Sharma et al. (2004) to estimate lactose in milk (Figure 3). The lactose biosensor was based on Langmuir – Blodgett films in which the electrodes produced amperometric response at different concentrations of lactose. The lactose biosensor was able to estimate the lactose concentration in few minutes compared to the tedious and time consuming methods such as spectrophotometry and polarimetry.

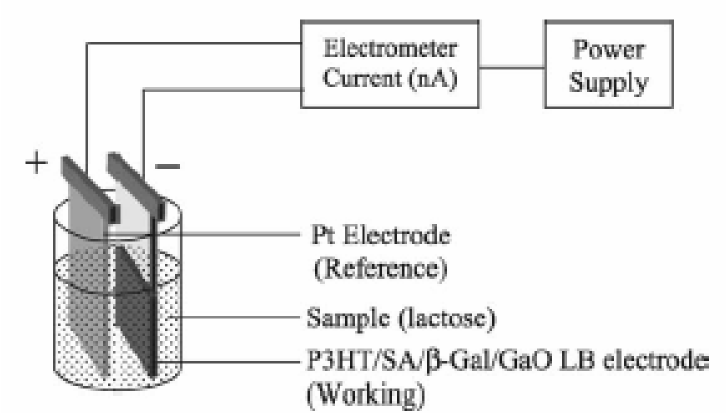

Figure 3. Schematic representation of lactose biosensor based on Langmuir Blodgett film as working electrode and platinum as reference electrode (Source: Sharma et al., 2004).

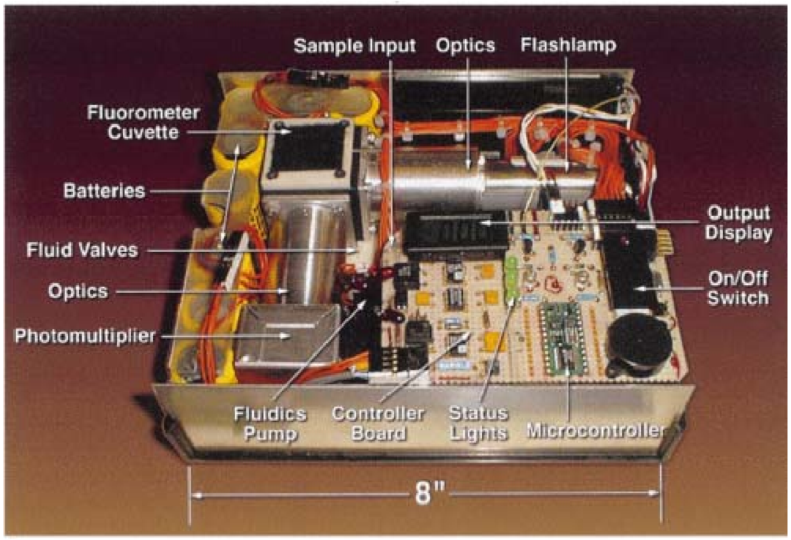

Figure 4. Pictorial representation of immuno chemical based fluorometric biosensor for detecting aflatoxins (Source: Carlson et al., 2000).

Carlson et al. (2000) developed a fluorometric biosensor to detect and quantify aflatoxins, a family of fungi produced carcinogens that are commonly found in a variety of agricultural products. The device developed by Carlson et al. (2000) operates on the principles of immuno-affinity for specificity and fluorescence for a quantitative assay (Figure 4).

The recognition and quantification of polycyclic aromatic hydrocarbons (PAH) from fish exposed to crude oil contaminated water is a valuable tool for the evaluation of warning signals indicating exposure. Polycyclic aromatic hydrocarbons are carcinogenic in nature. Lucarelli et al. (2003) developed an electrochemical DNA biosensor as a screening device for the rapid detection of accumulated PAH in fish bile. The DNA biosensor was realized by immobilizing the calf thymus double-stranded DNA onto disposable, screen-printed carbon electrodes. Such DNA biosensor is a competitive tool in terms of analysis cost and time, to rapidly evaluate biological and environmental samples.

Animal health monitoring

Digital Angel Corporation has developed a non-invasive, bio-thermo chip which has the ability to measure and monitor the temperature of an animal by passing a proprietary hand held scanner over the area where the microchip is implanted on the animal body. This biosensor redefines the way veterinarians and pet owners use temperature of the pet as a health indicator. The current method of rectal readings often stresses the animal, resulting in incorrect readings. The bio-thermo chip eliminates stress motivators, and provides an easy way to take frequent readings - for monitoring the effects of medication (Destron Technologies, 2005).

Biosensors for environmental monitoring

Stricter regulations and a greater public awareness of environmental issues bring requirements to monitor an ever-wide range of analytes in air, soil and water with greater accuracy. Increased public concerns over the safety of our environment also foster a need to monitor pathogens in field and stream. With greater pressure to recycle water, minimize the use of antibacterial agents and to maintain quality discharges, manufacturers in a wide variety of industries are seeking technologies to rapidly identify contamination problems at source. Meanwhile operators are looking to contain the costs of increasingly complex monitoring regimes. Biosensors capable of detecting an organism quickly will be important in the environmental monitoring of the pathogens.

The durability, sensitivity and low cost of signal transducers and the growing availability of enzymes, antibodies and genetically engineered micro organisms that interact with environmental pollutants have contributed to the recent interest in applying biosensors to environmental monitoring.

Land, water and air pollution monitoring

Biosensors for the detection of environmentally significant metal ions primarily use enzymes as recognition elements. Babkina and Ulakhovich (2004) developed an amperometric biosensor made of mercury film electrode and cellulose nitrate membrane containing single stranded DNA. They employed this biosensor for measuring ions of metals in water and air samples. The biosensor was able to determine the heavy metals based on the concentration of metal ions on the biosensor due to adsorption followed by the destruction of DNA – metal complex.

A bi-enzymatic optical and conductimetric biosensor based on phosphate alkaline and esterase activities on algae cells, was designed by Durrieu et al. (2004) to determine the chemicals in fresh water.

Researchers at Colorado State University has developed a fibre-optic biosensor for measuring multiple organic contaminants in groundwater (Fiber Optic Biosensors, 2001). The device uses a two layer detection element immobilized on the tip of an optical fiber. The presence of a contaminant leads to a pH change on the fiber tip, which is measured as a quantified change in fluorescence.

Pesticides detection in air has attracted the greatest interest for environmental biosensors. This is because pesticides typically function by means of interacting with a specific biochemical target either as a substrate or as inhibitors. Renault (2001) has developed a disposable biosensor based on inhibition of acyl cholinesterases by organophosphorous compounds for detection of pesticides in air.

Ong and Grimes (2001) fabricated a carbon dioxide sensor by depositing a thin layer of a composit of carbon nanotube and silicon dioxide upon a inductor capacitor resonant circuit. The permittivity of nano tubes changes linearly in response to carbon dioxide concentration. Figure 5 shows the application of sensor array to measurement of CO_2 atmospheres in a variable temperature and humidity environment.

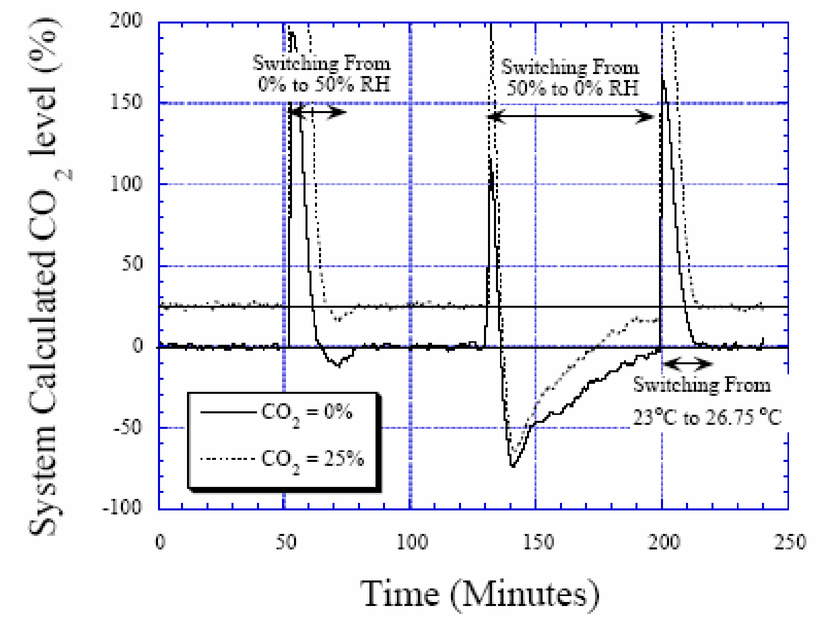

Figure 5. CO_2 concentration determined using Carbon Nanotube Sensors (Source: Ong, K.G and C.A. Grimes, 2001).

Biosensors composed of biological assays interfaced with various signal transducers can measure parameters such as microorganism toxicity, enzyme inhibition, biological oxygen demand, DNA damage, and identification and enumeration of microorganisms of environmental concern.

Conclusion

Due to their unique characteristics and flexibility, biosensors show great promise for food safety and environmental monitoring applications. Advances in areas such as toxicity, bioavailability and multi pollutant screening could widen the potential market and allow these techniques to be competitive.

Biosensors certainly enhance and sustain our quality of our life. There is a need for the commercialization of biosensors in the food and the agricultural industries. All food processing industries are potential customers for a quick, easy and reliable pathogen device. Biosensors with quicker detection time and reusable features will be much coveted by customers for real time diagnostics of pathogens and chemicals. As the world becomes more concerned with safe food and water supply, the demand for rapid detecting biosensors will only increase.

Acknowledgement

We thank the Canada Research Chair program for providing financial support for this study.

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