Review Article

A Brief Review on Aptamer Based Biosensors for Detection of Environmental Pollution

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A B S T R A C T

Precise detection of the causal metabolite for disease, pollutant etc causing abnormality in human body and environment is the key to cure the defects caused by them. In this regard biosensors are the novel molecule used to detect a particular molecule with unbeatable precision. These biosensor have a large applications, be it in the field of agriculture, medicine, ecology etc. Detection of pollutant causing severe health hazards is one of the hot topics now a day. Recent advances in the biosensors development over the past few years have paved the way for future researchers to further modify these biosensing elements to enhance them to the extent that would be able to detect even a small amount of environment pollutant. Here in this review we are focusing toward the use of these biosensors in detecting the pollutant causing environmental pollution.

Introduction

Many of the diseases lead to alteration in the concentration of one or few metabolites in cell. Keeping this in mind there is a great need to develop systems which detect these small molecules in real time in order to optimize the dose of the medicine to cure it. Any molecule or device which can be used to sense the change in a particular substance in term of degree of signal produced via interaction with target is called as sensor. Biosensors, especially electrochemical in nature, appear to be promising technology in detecting environmental pollutants. Biosensor is an analytical device which is a hybrid of physical and chemical sensing technique, used for the detection of signal, which when combined with a biological component gives an output as a signal recorded by detector (Ali *et al.,* 2017). The sensitive biological element used in biosensor are derived from biological material like cells, tissues, organelles, enzymes, nucleic acids, micro-organisms, receptors etc. which interacts with the metabolite taken under study. These systems

when combined with other available physio-chemical sensing techniques can give an efficient, reliable, simple, cost-effective method for analyzing the contaminants present in the environment.

These types of sensors have been recognized by IUPAC a decade back only. These sensors have a receptor, which is used as bait for interpreting the biophysical or biochemical property of the medium. Moreover, the most intriguing character that sets this type of sensors apart from others is the presence of biological/organic recognition element which enables the detection of particular biological molecules in the medium (Wang *et al.,* 2006). Development of biosensors brought a new era of advancement in science.

It is a multidisciplinary technology, involving the collaboration of engineers, microbiologist, physicist, chemist, biologist, biotechnologist and so on (Hinze *et al.,* 1994). They have been widely used in different disciplines of science due to their outstanding success.

Medically, biosensors have been used for precise detection of tumors, pathogens, blood glucose level, other toxins etc. Some of the biosensors are designed to produce fluorescence on interaction with the target. Such biosensors have great importance for researchers to study and analyze the complex chemical processes going into the cells and could be used to target some specific locations in the cell and it can also be expressed in specific cells of an organism. The long term incorporation of any specific substance into the host cells could also be achieved through these biosensors (Palmer *et al.,* 2011).

Checking of food contaminant, gasses released from spoiled food, detection of food spoiling bacteria or fungus in fresh food etc can be done by the help of biosensor (Situ *et*

al., 2010). From environmental point of view, these biosensors could be used to detect pollution in air and presence of any pathogens, heavy metals etc (Tamayo *et al.,* 2001). In military defense systems, they can be used to detect the presence of any harmful biological materials that would otherwise remain undetectable and cause death. In this case mostly the biosensors can be employed to detect the bioterrorist attacks like the intentional use of the biological entities like *Bacillus anthracis*, Ebola, Hepatitis C viruses etc (Edelstein *et al.,* 2000).

Features of an ideal biosensor

The biocatalyst to be used for the analysis must be stable in normal storage conditions, highly specific in nature and should be stable over a large number of assays.

The interaction between biological component and analyzer should be independent of other physical parameters like pH, stirring and temperature, otherwise they would create problem in reaction leading to interruption in the results.

The response should be accurate, precise, reproducible and linear over the useful analytical range, without dilution or concentration. It should also be free from electrical noise.

The analyzer must be small and biocompatible in nature without toxic or antigenic effect, if the biosensor is to be used for critical monitoring in medicinal purposes.

The complete biosensor should be cheap, small, portable and capable of being used by semi-skilled operators.

There should be a market for the biosensor. There is clearly little purpose developing a biosensor if other factors (e.g. government

subsidies, the continued employment of skilled analysts, or poor customer perception) encourage the use of traditional methods and discourage the decentralization of laboratory testing.

Aptamer as a biosensor

The term aptamer is derived from Latin word *aptus* defined as 'fitting', and *meros* means 'particles' that are single-stranded DNA or RNA that fold into stable conformation identified by structural and pattern motif such as hairpins, loops, stems, triplexes or quadruplexes in three-dimensional space.

The advantageous properties of aptamer compared to antibodies are its stability, high resistance to enzymes, extreme of ionic strength, good tolerance of temperature or pH, high affinity and specificity to targets in the nano-molar to pico-molar range. Due to these properties aptamers are ideal for use in many novel types of *in vivo* and *in vitro* sensors. Whether you have an existing biosensor platform or are looking for a complete solution, base pair can provide customized development of aptamer biosensors.

The simplicity in modification process makes aptamer detectable and effective in many applications. Aptasensor are biosensors where aptamers are used in place of biological ligands to sense targeted compound. An aptasensor is a compact analytical device incorporating an aptamer (oligonulceotides) as the sensing element either integrated within or intimately associated with a physiochemical transducer surface.

As aptamers can react to targets sensitively and recognize their targets with a high specificity, aptasensor have a wide range of advantages over other existing sensors such as stability, design flexibility and cost-effectiveness, and these features favors their

use as a bio-recognition elements in biosensor development.

Environmental contaminants have direct effect on human health as well as other life diversity. Hence monitoring contaminants is one of the key issues towards understanding and managing health hazards to human and ecosystems caused by these contaminants. In this regards aptamer based electrochemical sensors have achieved intense significance because of their capability to resolve a potentially large number of problems and challenges in environmental contamination.

Nucleic acids both DNA and RNA are well known to carry and pass the genetic informations, however, they have found a key role in analytical monitoring during recent years. Due to the novelty of aptamer based sensors in environmental analytical science and there are great expectations for them as an alternative to conventional analytical tools. This review paper focuses on the recent advances in the development of aptamer based electrochemical sensors for environmental applications with special emphasis on emerging pollutants.

Aptamers are DNA or RNA (nucleic acid) that selectively binds with inorganic or organic substrate. Their affinity constant with their specific targets has been reported ranging from pico-molar to micro-molar which is in the comparable range of that of antigen-antibody interaction (Willner and Zayats 2007; Jenison *et al.,* 1994). Aptamers have been engineered via in-vitro selection method known as SELEX (Systematic Evolution of Ligands by exponential enrichment), first reported in 1990 (Hayat *et al.,* 2012b, 2013c; Paniel *et al.,* 2013). As compared to antibodies, aptamers have more advantages like their production in host animal don't need an immune response because they are produced automatically by

nucleic acid synthesis. Aptamers can be designed for small size targets (Mascini, *et al.,* 2012).

Classification of biosensors

On the basis of transduction principle used, biosensors can be distributed into the groups like optical, mass-dependent, electrochemical, sensitive to radiation and many more. Aptamers when combined with sensors gives aptasensors which come under electrochemical biosensor. Electrochemical aptasensors have been fabricated by incorporating aptamers into single walled carbon nanotubes (So *et al.,* 2005). Similarly, multiwalled carbon nanotubes have been used as modifier to immobilize amine linked aptamer on the screen printed carbon electrodes.

On the basis of bioelement used, biosensors can be categorized as nucleic acids, ligands, proteins, enzymes and saccharides etc.

On the basis of type of analyte detected, classes of toxins, drugs, enzymes, DNA or glucose based biosensors could be achieved.

Applications of biosensors

Till date, the growing field of biosensors has almost got quite strong hold in every walk of life. The most recent developments and improvements of this biosensing discipline have been studied in the basics fields of food, agriculture, medicine, and environmental studies.

Biological sensors that we know today in the biochemical field of science have some great potential for detecting and monitoring the interaction of biological molecules inside and outside the cells.

These sensors have provided easiness to the scientists of today in overcoming the undetectable levels of many harmful agents that would have otherwise remained undetected. Here, in the applications section of biosensors, some recent studies have been compiled to give an overall background of the most recent advantages that biosensors have provided in monitoring many harmful environmental agents that are responsible for the cause of some serious health hazards to humans and the ecosystem. In order to avoid hazards to human health and to the surroundings, a mechanism to understand, detect and remove the contaminants from the surroundings, like water, soil and air within adorable costs, quite quickly and with enhanced precision must beaver to be adopted today and this can be achieved using the biosensing techniques.

Biosensor based on enzymatic inhibition and based on high specificity to certain DNA, RNA or proteins that they can interact have been used for the removal of contaminants like, pesticides, other toxins and heavy metals from soil, air and water including many other versatile types of biosensors.

Sensors which are based on screen-printed electrodes (Tudorache *et al.,* 2007 and Hayat *et al.,* 2014) are widely being used by the biosensor industries to construct the biosensors for their increasing needs by food industries, environmental and medical departments. Major pollutants like heavy metals, polychlorinated biphenyls, pesticides, nitrogenous compounds and various pathogens including many viruses and bacteria can be successively detected and removed using biosensors.

Heavy metals pose maximum threat to health of humans and their hyper-accumulation leads to various inappropriate health conditions, as they cannot be easily biodegraded (Da Costa Silva *et al.,* 2004). Several types of biosensors have provided great success in detection and monitoring of the toxic levels of heavy metals

that would lead to injurious health conditions. Bacteria-based cell biosensor requires the use of genes that resist certain types of heavy metals like copper, mercury, tin cobalt etc. (Magrisso *et al.,* 2008). However, they can act when the heavy metals interact with their cytoplasm, dependence of these sensors is based on the conjugation of some luminescent proteins like luciferin, with those genes that resist heavy metals.

Enzyme-based biosensors have also provided promising results in that regard, like fibre-optic biosensors have been used for the detection of the toxic levels of various heavy metals like lead, cadmium, mercury, copper, nickel, cobalt etc. These biosensors work by inhibition of these heavy metal ions on various kinds of enzymes, these inhibitions are then monitored by using different types of biosensors with high specificity. Domínguez-Renedo O *et al.,* (2009) used amperometric biosensors for successful detection of inhibition of mercury ions (Hg+2) by urease enzyme action.

Also, inhibition of cobalt, nickel, mercury, gold and lead with same urease enzyme lead to the monitoring of the toxic levels using fibreoptic sensors.

Environmental pollution

Pollution is one of the severe problems which we are facing in day to day life. It may be due to smoke emitted by vehicles, industrial waste products released into water bodies, acid rain, fertilizers etc. Environmental contaminants monitoring is one of the emerging topic and key issues in understanding and managing hazards to human health and ecosystems. Looking into this context, aptamer based electrochemical sensors may have an intense significance because of their capability to detect a pollutant causing a large number of problems and challenges to human health and environment.

Application of biosensors in detecting environmental pollution

Detection of polychlorinated biphenyls (PCBs)

Polychlorinated biphenyls a group of non-biodegradable agents used as an ingredient of various types of herbicides and insecticides, although proved effective for pest control, but also lead towards its accumulation in the soil which are then taken up by the crops. Through these crops they enter into human body causing serious health problems, most of the times related to cancers. Biosensors have been most promising in the past years in precise detection of these organic compounds in foods and soils, using immunological biosensors that monitor antigen-antibody interaction using piezoelectric transducers (Ivask *et al.,* 2002).

Detection of biochemical oxygen demand

Microorganisms that live in sewers and waste waters usually break down organic compounds to produce toxic substances. Biochemical oxygen demand (BOD) is the amount of molecular oxygen (O_2) required by microorganisms to thrive in waste water and is mostly required during break down of organic compounds. This leads to the increased environmental pollution in water sources. A biosensor was developed by Nisshin Denki Electric Co. Ltd. in 1983 and was the first ever made commercial biosensor for BOD level monitoring.

Detection of pesticides

Organophosphates being commonly used as insecticides (pesticides) pose changes to the soil fertility, thus damaging many beneficial insects and microbes in soil and leads to the loss of biodiversity, for their detection, another type of nanotechnological sensors

have been used recently to measure toxic levels of these pesticides in soils and in water. Based on nanotechnology, enzymatic biosensors have been modified by allowing them to be immobilized. The common example is of acetylcholinesterase (enzyme) sensors which work by inhibiting acetylcholinesterase activity in order to detect organophosphates, where acetylcholinesterase activity is constantly monitored (Zhang *et al.,* 2014).

Detection of nitrogenous compounds

Commercial biosensors have also been introduced and used successfully to monitor dioxins, nitrates and dioxin-like compounds (Bahadır *et al.,* 2015).

Detection of microbes

Microbes based biosensors have also been developed and employed for detecting air borne contaminants and pathogens. Phage sensors can be used for detecting air borne pathogenic microbes.

Biosensor can be an effective tool for every situation where we have to detect a chemically and physically active substance. To develop a biosensor we need to find a very precise and specific reaction and find both bait and pray for it. The major hurdle in the biosensor development is the use of synthetic biological agents and cell surface receptors like antibodies, nucleic acids, and enzymes etc which can act as bait and pray. These synthetic receptors are not easily identified and are thus not allowed by the cell to cross the lipid bilayer. For biosensors to function properly they must get entry into the cells. Research work on biological agents could lead to the development of new biosensors that would have potential benefits to the wellbeing of humans. Once all developmental hurdles will be overcome, then it would be a

great success in the history of mankind, although it is being used, yet its success percentage still needs to be upgraded. With such good and precise detectability within less time, reduced costs and high specificity to certain microbes, proteins and other related biomolecules, biosensors have proved to be the best equipment for the detection of certain agents that would otherwise cause harm to human health. Moreover these sensing agents can also be employed for bioremediation of pollutants from the areas where most of the problems occur due to pollution leading to unhealthy conditions affecting ecosystem in a negative manner.

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