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Chapter

Introductory Chapter: The Prospective of Biosensing in Environmental Monitoring

Kairi Kivirand and Toonika Rinken

1. Introduction

In recent years, an increasing number of actions for environmental monitoring have become more and more topical. Environmental monitoring is necessary to protect the environment from pollutants and minimize the impact of unfavorable components and processes. As the world's population continues to increase, so does the amount of pollutants that are released into the environment.

Environmental pollution is defined as "the contamination of the physical and biological components of the earth/atmosphere system to such an extent that normal environmental processes are adversely affected" [1]. The substances that cause pollution are categorized as pollutants, which are commonly classified according to their chemical structure (organic and inorganic compounds), their mode of action (endocrine effect or toxicity), their source (natural or manmade) or by their amount (micro and macro pollutants) [2]. A pollutant can be any chemical or geochemical substance, biological organism or physical substance, which has been released into the environment by man and has harmful, unpleasant or inconvenient effect [3]. Depending on the nature of a pollutant, pollution is classified as air, water, soil or land, noise, radioactive and thermal pollution [3].

The release of pollutants (e.g., heavy metals, pesticides, drugs and pharmaceuticals) to the environment is a worldwide problem and there is a growing need to combat with uncontrolled pollution. For example, the global environmental monitoring plan (GEMP) for persistent organic pollutants (POPs), prefiguring a major concern, has become an important component of the evaluation of effectiveness of Stockholm Convention [4]. It provides an organizational framework for the collection of comparable monitoring data on the presence of POPs in order to detect changes in their concentrations [5]. Most pollutants released to the environment are undetectable, until their effects make it impossible to ignore them and we have to deal already with the consequences. Therefore, it is necessary to detect pollution as soon as possible.

2. Traditional methods for environmental analysis

Different types of methods and techniques are used for environmental analysis. Traditional methods used for the detection of molecular pollutants are mostly based on chromatographic techniques (gas chromatography or ultra-high performance liquid chromatography coupled with mass spectrometry, thin-layer chromatography) and spectrophotometry. Chromatographic tools are sensitive and reliable

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but also time-consuming because they usually need sample pretreatment; the equipment is expensive and requires qualified personnel to perform the analysis. The biggest drawback of the abovementioned methods is the fact that due to long analytical procedures, their application for operative in situ measurements in cases when timely information is crucial is not possible. For example, pollutant concentrations in watercourses are dynamic and change in water flows. With weekly or even monthly sampling and analyzing, it is extremely unlikely that the maximum or the real concentration levels for a certain period can be determined. As a result, we see elevated levels of pesticides or nitrates in areas of intensive farming, even in groundwater, or increased lead levels in areas where it has been used in plumbing. In addition, thin-layer chromatography (TLC) has been often used for testing soils and groundwater for pollutants like pesticides, herbicides or fungicides. It is an effective and low-cost method and many samples can be analyzed simultaneously. However, TLC is applicable only for nonvolatile compounds; there are limitations in resolution capability and the absence of fully automated system [6].

The gold standard for the detection of microbiological pollutants is cultivation; however, DNA-based molecular diagnostics nowadays is becoming more and more popular. Microbiological cultivation is simple and inexpensive. However, there are some disadvantages: these methods rely on the growth of the target microorganisms in one or more nutrient media, the detection of growth is carried out by visual assessment and the confirmation of the presence of a particular pathogen usually involves a combination of biochemical and serological tests [7, 8]. In addition, the interpretation of the results can be subjective, and for some bacteria, the total test time can be as long as several days [8, 9]. For example, there is a drastic increase in pathogen concentrations, and the infection risks due to late results of potentially contaminated drinking water are very high [10]. With DNA-based molecular diagnostic methods like polymerase chain reaction (PCR), it is possible to identify specific bacterial strains, but this method still require several hours to obtain results and sometimes it fails to discriminate between related species and intragenomic heterogeneity [11].

3. Biosensing in environmental monitoring

Therefore, development of rapid real-time and reliable detection methods is essential. Biosensors are an alternative to traditional methods. Biosensors can act as pressure sensors, microphones, optical sensors, microfluidics, temperature and gas sensors [12]. In recent years, biosensors have also been developed to detect and recognize genetically modified microorganisms (GMOs) [13], which have generated heated debates, especially in the European countries (EU), about the safety of food and the potential impact to the environment [14]. Furthermore, biosensors can offer a strong potential for better understanding and investigating of the environment, including the fate and transport of contaminants. The number of opportunities to join science and new technology into biosensing systems is almost overwhelming. One of the first environmental biosensors was initially developed for nerve gas detection for the military in the late 1970s and modified for the detection of pesticides (organophosphorus and carbamate) in the environment and was based on the inhibition of the enzyme acetylcholinesterase [15]. Over the years, new biosensors have been developed for environmental monitoring. For example, biosensors for the detection of heavy metals like zinc, cobalt, cadmium, lead, etc. [16–22] have been developed. In addition, biosensors for the detection of phenolic compounds [23–26], pesticides [27–30], pathogens [9, 31–35] and drug residues [36, 37] have been developed.

Sensitivity, specificity, reliability, cost-efficiency and the possibility of on-line use are crucial factors for the design and construction of a biosensor for environmental monitoring. Functional bio-recognition elements are the key components, which define the affinity (low detection limit), specificity (low interference), dynamic range, response time and lifetime of the biosensing system.

Although most of the developed biosensor-based methods are not able to compete with traditional methods in terms of precision or reproducibility, they allow continuous on-site and real-time monitoring of a contaminated area and provide timely information about potential pollution.

Currently, only a few commercial biosensors are available for environmental monitoring [38]. Up to date, the biochemical oxygen demand (BOD) sensor, which was invented in Japan in the late 1970s, has commercially been the most successful biosensor for environmental applications.

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