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Application of Electrochemical Sensing Technology in Environmental Monitoring and Its Development Prospects

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Abstract

In the current environmental protection scenario, environmental monitoring is particularly crucial. As an emerging monitoring method, electrochemical sensing technology is gradually gaining prominence due to its unique advantages. This technology not only has high sensitivity and can detect trace substances in the environment quickly, but it also comes at a relatively low cost, making it easier to promote and use in various grassroots units. In the realm of air monitoring, electrochemical sensing technology can track the concentration of pollutants in the air in real-time, including sulfur dioxide, nitrogen oxides, and other harmful gases. The presence of these gases will not only affect air quality but may also pose a threat to human health. Through electrochemical sensing technology, we can monitor the concentration of pollutants in the air promptly and implement necessary measures to control them. In the realm of water quality monitoring, electrochemical sensing technology also plays a crucial role. Heavy metals, organic matter, and other pollutants in water can be detected through electrochemical sensing technology. Compared with traditional water quality monitoring methods, electrochemical sensing technology offers a faster response speed and higher sensitivity, enabling better reflection of real-time changes in water quality.

Keywords

Electrochemical sensing technology, environmental monitoring, application, development prospects

1. Introduction

With the rapid development of computer technology and microelectronics technology, as well as the widespread application of many new processes and technologies, electrochemical sensors are very important for electrochemical sensing technology. They are generated through the interaction between the sensor and the target analyte. Specific signals are then converted into identifiable electrochemical signals proportional to the concentration of the target analyte according to certain rules, thereby achieving qualitative or quantitative analysis of the target analyte, with high sensitivity, and good selectivity. The advantages of low cost, simple operation, and ability to conduct online monitoring and even in vivo analysis in complex systems have become a research field in electroanalytical chemistry. There are many classification methods for electrochemical sensors. According to their different output signals, they can be divided into potential sensors, current sensors and conductivity sensors. Electrochemical sensors are a type of chemical sensor and a special type of sensor in modern chemical analysis and measurement. Electrochemical sensing technology will continue to develop in the direction of intelligence and integration, and will also be widely used in environmental monitoring, providing fast and simple analysis methods. This article mainly conducts a detailed analysis from three aspects: the basic working principle of electrochemical sensing technology, an overview of environmental monitoring, the current status of electrochemical sensing technology in environmental monitoring, and its specific application in environmental monitoring [1].

2. Working principle of electrochemical sensor

An electrochemical sensor is a measurement method that achieves qualitative or quantitative analysis by measuring the electrical or electrochemical properties of target analytes. Compared with traditional methods, electrochemical sensors have the advantages of simple operation, low price, fast analysis speed, and suitability for on-site detection. They have gradually become a hot spot of research at home and abroad, and have broad application prospects in many fields such as ecological environment testing, medicine, and food testing.

3. Application of electrochemical sensors in environmental monitoring

3.1 Water quality monitoring in the ocean

3.1.1 Monitoring of nutrient salts

Seawater contains many types of nutrients, such as nitrates, nitrites, ammonium salts, active phosphates, silicates, etc. If the concentration of nutrients in seawater is too high, it will lead to eutrophication of seawater and the ocean. Algae reproduce rapidly, consuming a large amount of dissolved oxygen in seawater, causing many marine fish to be unable to survive, and even red tides will occur, which will seriously damage the marine ecological environment. In order to effectively protect the marine ecological environment, it is necessary to monitor seawater nutrient salts work [2]. Nitrate is an important nutrient salt in seawater and is of great significance to marine primary productivity and seawater artificial aquaculture. The potentiometric microfluidic sensor based on functional nanomaterials uses nitrate-doped polypyrrole nanowires synthesized by electrochemical polymerization, which greatly improves the selectivity and sensitivity of the sensor and has been successfully applied to the detection of nitrate in seawater.

3.1.2 Monitoring of organic pollutants

With the rapid development of offshore oil development and industrial production, marine environmental pollution problems are becoming more and more serious. The most typical organic pollutants among marine environmental pollutants include polycyclic aromatic hydrocarbons, polychlorinated biphenyls, dioxins, organic pesticides, etc. [3]. In terms of monitoring organic pollutants, electrochemical sensing technology, with its significant advantages, can monitor the actual situation of organic pollutants in seawater in a short time. Organic pollutants in seawater usually undergo a variety of reactions, and the use of oxidation-reduction reactions can produce some substances with strong electrochemical activity. In the detection of PCBs in marine sediments, an electrochemical immunosensor based on screen-printed electrodes uses immunomagnetic beads to achieve high-efficiency and high-selectivity separation of PCBs in samples. Most organic pollutants have relatively stable electrochemical properties and cannot directly produce electrochemical responses on the surface of functionalized electrodes. However, most organic compounds can produce electrochemically active substances through derivatization processes such as electrochemical oxidation, reduction, or online digestion. Combined with the high sensitivity and fast electrochemical response characteristics of electrochemical sensors, the development of online rapid detection of electrochemical Sensors has broad application space.

3.1.3 Detection of pathogenic bacteria and biotoxins

Pathogenic bacteria in seawater include those originating from land, such as Escherichia coli, Shigella, Listeria monocytogenes, and Salmonella, and others originating from natural seawater, such as Vibrio parahaemolyticus, Vibrio cholerae, and Vibrio vulnificus. The pollution of pathogenic bacteria in seawater will not only bring huge harm and losses to the aquaculture industry, but also threaten people's health and safety. Immunobiosensors have the characteristics of rapidity, portability, strong specificity, simple production, sensitive recognition, and therefore have become a research hotspot in the field of pathogenic bacteria detection. Sharma et al. developed an electrochemical enzyme-linked immunosensor to detect Vibrio cholerae in seawater [4].

3.2 Monitoring of harmful gases

3.2.1 Detection of formaldehyde

The electrochemical formaldehyde sensor ME3M-CH2O selected in this article has a resolution of up to 0.02 ppm. When the sensor is exposed to formaldehyde gas, the formaldehyde gas sensor uses a screen-printed carbon electrode as the substrate. The working electrode responds to formaldehyde gas and its surface uses. The improved polyacrylic acid ion sensing layer generates a very small current proportional to the concentration of formaldehyde gas. The polyacrylic acid ions are used to collect formaldehyde. At the same time, it is also a polymeric electrode. According to the structure of the formaldehyde sensor, the working electrode and the counter electrode are immersed in the When in the electrolyte, the concentration of CH2O can be determined by testing the size of the current. Each ppm of formaldehyde gas outputs a current of 1.1±0.5uA. After current and voltage conversion, the analog voltage value that the AD converter can receive is obtained. The applied voltage will cause polarization between the two electrodes [5]. The constant-potential electrochemical formaldehyde sensor has three electrodes.

3.2.2 Detection of CO

There are two main types of CO sensors: variable resistance type and electrochemical type. The CO sensor uses ME2-CO from Zhengzhou Weisheng Electronic Technology Co., Ltd. The variable resistance CO sensor uses a high and low-temperature cycle method, with a large range of 1000ppm. The high temperature cleans stray gases adsorbed at low temperatures because of the gas-sensitive materials used. The conductivity in clean air is low. The change in conductivity is mapped to the carbon monoxide gas concentration through the circuit, and then the corresponding electrical signal is output. When the indoor gas exceeds 300ppm, it indicates a flammable gas leakage and alarms in real time. Carbon monoxide is detected at low temperatures. As the concentration of carbon monoxide gas in the air increases, the conductivity of the carbon monoxide sensor increases [6].

3.2.3 Ozone electrochemical gas sensor

The measurement of ozone is a key part of air quality and many atmospheric chemistry experiments. The traditional ozone monitoring mechanism is based on UV absorption, which is relatively expensive and has a certain high energy loss, limiting fixed locations. The electrochemical sensor only requires 5V DC power, and the total power consumption is less than 5W. With a total weight of no more than 1 kilogram, this electrochemical sensor generates a voltage signal proportional to the concentration of ozone in the range of 5-10 ppm. The performance of both ozone sensors is very linear. The calibration and sensitivity of the sensor, which are affected by the relative humidity and flow rate of the gas sample, are performed separately. The linear calibration curve shows that the sensor performs exactly the same, even at different humidity and flow rates, during zeroing to compensate for the sensor's baseline drift. Rapid humidity changes (~20%/min) will produce significant and immediate changes in the sensor signal, with the sensor taking approximately 40 minutes to return to its original value. In contrast, slow humidity changes have a weak effect on sensor response. In order to test the performance of the miniaturized ozone meter, the ozone meter was used in the laboratory to detect ozone loss. Through seawater absorption and air quality testing for 18 days, the study showed that the absorption of ozone by seawater is linear with the linoleic acid in the microlayer of the seawater surface. The data detected from the ozone sensor over 18 days are in good agreement with the data obtained using the ultraviolet absorption method [7].

3.3 Monitoring of soil

3.3.1 Determination of soil pH

pH value is an important indicator reflecting the acidity and alkalinity of soil and has an important impact on the physical and chemical properties, nutrient status, heavy metal activity, and other aspects of soil. The electrochemical method for measuring soil pH is based on the principle of ion-selective electrodes and is achieved by measuring the concentration of hydrogen ions or hydroxide ions in the solution. During the experiment, soil samples and water were mixed in a certain proportion, and the pH value of the soil solution was measured through glass electrodes and reference electrodes. This method has the advantages of rapidness, accuracy, and easy operation, and is suitable for the determination of large batches of samples.

3.3.2 Soil nutrient analysis

Soil nutrients are elements necessary for plant growth, including nitrogen, phosphorus, potassium, etc.

Electrochemical methods for determining soil nutrients are mainly based on ion-selective electrodes and polarographic analysis. By measuring the concentration of specific ions in a solution, the nutrient content in a soil sample can be determined. For example, a nitrate ion-selective electrode can be used to measure the nitrogen content in the soil, a phosphate ion-selective electrode can be used to measure the phosphorus content in the soil, and a potassium ion-selective electrode can be used to measure the potassium content in the soil.

3.3.3 Research on the decomposition process of organic matter

The decomposition of organic matter in soil is an important part of the ecosystem cycle and has an important impact on soil quality, plant growth and pollutant degradation. The principle of the electrochemical method to study the decomposition process of soil organic matter is to study the decomposition process of organic matter by measuring the redox reaction of organic matter on the electrode. For example, organic acids can be oxidized on the anode to produce carbon dioxide and water, while releasing electric current. By measuring changes in electric current, the decomposition process and kinetics of organic acids can be studied.

4. Advantages and Disadvantages of Electrochemical Sensors

4.1 Advantages of electrochemical sensors

Can detect a specific gas: The degree of selectivity depends on the type of sensor, the target gas, and the concentration of the target gas; Linear output: low power consumption and good resolution; Good repeatability and accuracy: once calibrated to a known concentration, the sensor will provide repeatable, accurate readings of the target gas; not contaminated by other gases: the presence of other ambient gases will not shorten sensor life; more economical than most other gas detection technologies: unlike infrared and PID technologies, electrochemical sensors are economical.

4.2 Disadvantages of electrochemical sensors

Limited temperature range: Because they are very sensitive to temperature, sensors are often internally temperature compensated to keep the temperature as stable as possible; Short life: Electrochemical sensors typically have a storage life of six months to one year, depending on the use Environment and gas being detected; high cross-sensitivity with other gases: Although this is an advantage, it is also a disadvantage. Some sensors are susceptible to interference from other gases. Therefore, it's important to know which gases may interfere with the sensor and detect potential errors early; the longer it is exposed to the target gas, the shorter its lifespan will be. Generally, life expectancy is one to three years. Low humidity and high temperatures can cause the sensor's electrolyte to dry out. Exposure to target gases or interfering gas crossovers can also deplete the electrolyte on the sensor.

5. Prospects for the application of electrochemical sensors in environmental detection

5.1 Development prospects

5.1.1 Multi-function and integration

Multifunctionalization and integration are important directions for the development of electrochemical sensors, and various sensors will be integrated into a system. For example, fuel cell sensors combine multiple sensors working together to achieve better performance.

5.1.2 Miniaturization and portability

The main advantages of electrochemical sensors are their small size and fast response, so sensors will become smaller and more portable in the future. At the same time, cost reduction is also an important direction in miniaturization and portability.

5.1.3 Intelligence and networking

Utilize the Internet of Things and cloud computing technology to realize sensor interconnection and data sharing. Through the optimization and processing of intelligent algorithms, sensor data can be better analyzed and intelligent detection and control can be achieved.

5.2 Outlook

At present, most electrochemical sensors can usually only study a single pollutant, but there is a lack of systematic research on an entire class of pollutants. Although the research is quite difficult, with the gradual innovation and improvement of electrochemical sensor technology, in the future it will be possible to implement on-site diameter inspection of sewage discharge and exhaust gas emissions from relevant enterprises, as well as the detection of suburban environments. Real-time monitoring of dynamic forms under human supervision, and for electrochemical biosensors, due to their characteristics of less environmental pollution, less sample consumption, and lower sample loss, electrochemical sensors are widely used in Real-time, in-situ, continuous monitoring, and other aspects have significant application potential and have achieved significant development prospects.

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