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A Comprehensive Review of Gas Detection Methods and Equipment in the Industrial Field

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Abstract: With the rapid development of industry, gas detection plays a crucial role in ensuring safe production, environmental protection, and the optimization of industrial processes. This paper comprehensively reviews the common gas detection methods and their corresponding equipment in the industrial field, analyzes the working principles, characteristics, application scenarios, and limitations of various methods and equipment. At the same time, the future development trends of gas detection technologies and equipment are prospected, aiming to provide a reference for the selection and optimization of gas detection schemes in the industrial field.

Keywords: Gas Detection; Industry; Detection Technology

1. Introduction

Industrial production processes involve the use, generation, and emission of numerous gases. Some of these gases are flammable and explosive, such as hydrogen and methane; some are toxic, such as carbon monoxide and hydrogen sulfide; and others can cause environmental pollution, such as sulfur dioxide and nitrogen oxides. Accurately and timely detecting the types and concentrations of these gases is of great significance for ensuring the safety of personnel, preventing accidents, ensuring the stable operation of industrial production, and meeting environmental protection regulatory requirements. Gas detection technologies have developed rapidly in the past few decades, and a variety of detection methods and various types of detection equipment have emerged to meet the needs of different industrial scenarios.

2. Common Gas Detection Methods

2.1 Electrochemical Detection Method

2.1.1 Working Principle

Electrochemical gas sensors operate based on the principle of electrochemical reactions. The sensor usually consists of a working electrode, a counter electrode, and a reference electrode, with an electrolyte filling in between. When the target gas diffuses into the sensor, an oxidation or reduction reaction occurs on the working electrode, generating a current proportional to the gas concentration. By measuring the magnitude of this current, the concentration of the gas can be determined. For example, for the detection of carbon monoxide gas, carbon monoxide is oxidized to carbon dioxide on the working electrode, while releasing electrons. The electrons flow to the counter electrode through the external circuit, forming a current.

2.1.2 Characteristics

Advantages: High sensitivity, capable of detecting low concentrations of gases; relatively good selectivity, specific gases can be detected by selecting appropriate electrode materials and electrolytes; fast response speed, generally able to give detection results in a short time; relatively simple structure, low cost, convenient for miniaturization and integration, suitable for use in portable gas detection equipment.

Disadvantages: The sensor has a limited lifespan, generally 1 - 3 years. As the usage time increases, the performance will gradually decline; it is greatly affected by environmental factors such as temperature and humidity, and temperature compensation and humidity correction are required, otherwise, the detection results will be inaccurate; it is relatively sensitive to impurities in the gas and is prone to poisoning, thus affecting the performance and lifespan of the sensor.

2.1.3 Application Scenarios

Widely used in the detection of toxic and

harmful gases in industrial environments, such as the detection of carbon monoxide and hydrogen sulfide gases in coal mines; the monitoring of ammonia, chlorine and other gases in chemical production workshops; and in the field of occupational health, used to detect the concentration of harmful gases in the working environment of workers to ensure the physical health of workers.

2.2 Catalytic Combustion Detection Method

2.2.1 Working Principle

Catalytic combustion gas sensors utilize the thermal effect principle of catalytic combustion. There is a catalytic combustion element in the sensor. When a combustible gas comes into contact with the surface of the catalytic element, flameless combustion occurs under the action of the catalyst. The heat generated by the combustion raises the temperature of the catalytic element, resulting in a change in its resistance value. The change in resistance value is proportional to the concentration of the combustible gas. By measuring the change in resistance value, the concentration of the combustible gas can be detected. For example, for methane gas, a combustion reaction occurs on the surface of the catalytic element, generating carbon dioxide and water, and releasing heat at the same time.

2.2.2 Characteristics

1.Advantages: High sensitivity to combustible gases, capable of detecting low concentrations of combustible gases; good linearity, the detection results show a good linear relationship with the gas concentration, facilitating data processing and analysis; relatively good stability, less affected by environmental factors, and the change in temperature and humidity within a certain range has little impact on the detection results; long service life, generally up to 3 - 5 years.

2.Disadvantages: Poor selectivity, responsive to all combustible gases, unable to distinguish between different types of combustible gases; requires a heating element, high power consumption, not conducive to the long - term use of portable devices; during the detection process, impurities may be adsorbed on the surface of the catalytic element, resulting in catalyst poisoning and affecting the detection accuracy, and regular calibration and maintenance are required.

2.2.3 Application Scenarios

Mainly used for the detection of combustible gases in industrial, such as the monitoring of combustible gas leaks in the production unit areas, storage tank areas, and gas transmission pipelines of petrochemical enterprises; the detection of combustible gases in gas stations and gas filling stations; and in coal mining, the detection of the concentration of gas (mainly methane) in underground mines to prevent gas explosion accidents.

2.3 Infrared Absorption Detection Method

2.3.1 Working Principle

Different gas molecules have selective absorption characteristics for infrared rays of specific wavelengths. Infrared absorption gas detection equipment uses this principle. By emitting infrared rays of specific wavelengths, allowing them to pass through the environment containing the target gas, and then detecting the change in the intensity of the absorbed infrared rays. According to the Lambert - Beer law, the degree of infrared absorption is proportional to the gas concentration, so the concentration of the target gas can be calculated. For example, carbon dioxide gas will absorb infrared rays at a specific wavelength (4.26μm). By detecting the attenuation of the intensity of infrared rays at this wavelength, the concentration of carbon dioxide can be determined.

2.3.2 Characteristics

3.Advantages: Good selectivity, capable of accurately detecting specific types of gases without being interfered by other gases; high measurement accuracy, capable of achieving high - precision measurement of gas concentration; fast response speed, capable of real - time monitoring of gas concentration changes; non - contact detection, will not pollute the detected gas environment, suitable for some special occasions, such as gas detection in harsh environments such as high temperature, high pressure, and strong corrosion.

4.Disadvantages: High equipment cost, requiring high - precision infrared light sources, detectors, and complex optical systems; high requirements for optical components, easily affected by impurities such as dust and water vapor, resulting in a decrease in detection accuracy, and regular cleaning and maintenance are required; limited detection

range, and dilution treatment may be required for the detection of high - concentration gases.

2.3.3 Application Scenarios

Widely used in the monitoring of industrial waste gas emissions, used to detect the concentrations of sulfur dioxide, nitrogen oxides, carbon dioxide and other gases to ensure that enterprise emissions meet environmental protection standards; in the chemical production process, monitoring the concentration of specific gases in reaction kettles, pipelines and other parts to achieve the optimization control of the production process; in the field of greenhouse gas monitoring, used to measure the concentrations of greenhouse gases such as carbon dioxide and methane in the atmosphere, providing data support for climate change research.

2.4 Semiconductor Detection Method

2.4.1 Working Principle

Semiconductor gas sensors are based on the characteristic that the electrical conductivity of semiconductor materials changes with the gas concentration. When the target gas is adsorbed on the surface of the semiconductor material, a chemical reaction occurs with the oxygen ions on the surface of the semiconductor, resulting in a change in the electron density of the semiconductor material, thereby changing its electrical conductivity. By measuring the change in electrical conductivity, the concentration of the gas can be detected. For example, for the detection of hydrogen gas, when hydrogen is adsorbed on the surface of some semiconductor materials (such as tin oxide), it reacts with the oxygen ions on the surface, increasing the number of electrons in the semiconductor and increasing the electrical conductivity.

2.4.2 Characteristics

5.Advantages: High sensitivity, highly responsive to a variety of gases; fast response speed, capable of quickly detecting changes in gas concentration; simple structure, low cost, easy to make into miniaturized sensors; relatively low working temperature, generally between 200 - 400℃, low energy consumption.

6.Disadvantages: Poor selectivity, easily interfered by other gases, resulting in inaccurate detection results; poor stability, as the usage time increases, the sensor performance will drift, and regular calibration is required; relatively sensitive to environmental conditions, changes in temperature, humidity, etc. will affect the detection accuracy.

2.4.3 Application Scenarios

Often used for the detection of combustible and harmful gases in home and industrial environments, such as the detection of combustible gases such as natural gas and liquefied gas in household gas alarms; the preliminary screening and monitoring of low - concentration harmful gases in industrial production workshops. Due to its low cost and small size, it can be used for large - scale layout to achieve multi - point monitoring.

3. Common Gas Detection Equipment

3.1 Portable Gas Detector

3.1.1 Equipment Composition and Working Mode

A portable gas detector usually consists of a sensor module, a signal processing module, a display module, an alarm module, and a power supply module. The sensor module is responsible for detecting the gas concentration and converting it into an electrical signal for output; the signal processing module amplifies, filters, and performs analog - to - digital conversion on the electrical signal output by the sensor, and then transmits the processed digital signal to the display module and the alarm module; the display module displays the detected gas concentration value in real - time; the alarm module emits sound and light alarm signals when the gas concentration exceeds the preset threshold, reminding the user to take corresponding measures. The power supply module provides power support for the entire device, generally using rechargeable batteries for easy carrying and use. The portable gas detector is easy to operate. The user only needs to turn it on and bring it close to the gas environment to be detected to quickly obtain the detection result.

3.1.2 Application Scenarios and Advantages

Suitable for occasions where gas detection needs to be carried out at any time and place, such as industrial equipment inspection, emergency rescue sites, gas detection before confined space operations, etc. Its advantages are small size, light weight, easy to carry, and can be detected by the staff holding it; it can respond quickly and give detection results in a short time, providing a basis for on - site

decision - making; it has multiple gas detection functions and can be equipped with multiple different types of sensors to detect the concentrations of multiple gases at the same time; it is equipped with sound and light alarm functions, which can promptly remind the staff of potential dangers.

3.2 Fixed Gas Detector

3.2.1 Equipment Installation and Operating Principle

Fixed gas detectors are generally installed at fixed positions in industrial 场所, such as workshop walls, pipeline brackets, etc. Its operating principle is similar to that of a portable gas detector. It also detects the gas concentration through a sensor and then transmits the signal to the controller for processing and display. The difference is that fixed gas detectors usually use more stable and durable sensors to meet the needs of long - term continuous operation. The controller can connect multiple detectors to achieve gas monitoring of a large - area area. At the same time, the controller can also be integrated with the enterprise's automation control system. When the detected gas concentration exceeds the standard, it automatically triggers related equipment (such as ventilation equipment, emergency cut - off valves, etc.) to take corresponding safety measures.

3.2.2 Role in the Industrial Environment

In the industrial environment, fixed gas detectors play an important role in real - time monitoring and accident prevention. For example, in petrochemical enterprises, by installing fixed gas detectors at key parts such as production units and storage facilities, the leakage of combustible or toxic and harmful gases can be detected in a timely manner, avoiding the occurrence of fire, explosion, and poisoning accidents. Its long - term stable operation can provide continuous safety protection for the enterprise, and the monitoring data can be recorded and analyzed to provide data support for the enterprise's safety production management.

3.3 On - Line Gas Analysis System

3.3.1 System Architecture and Function

An on - line gas analysis system is a complex gas detection device, usually consisting of a sampling system, a pretreatment system, an analytical instrument, and a data processing and control system. The sampling system is responsible for collecting gas samples from the industrial production process and transporting them to the pretreatment system; the pretreatment system filters, dehumidifies, stabilizes the pressure, etc. of the collected gas samples to meet the requirements of the analytical instrument; the analytical instrument uses various advanced detection technologies (such as infrared spectroscopy analysis, gas chromatography analysis, etc.) to analyze the components and concentrations of the processed gas samples; the data processing and control system processes, stores, and displays the data output by the analytical instrument, and controls the production process according to the preset parameters. The on - line gas analysis system has the characteristics of high accuracy, high reliability, and strong real - time performance, and can continuously and accurately monitor and analyze the gases in the industrial production process.

3.3.2 Significance for Industrial Production Process Monitoring

For the monitoring of industrial production processes, the on - line gas analysis system is of great significance. In chemical production, through the real - time monitoring of the gas components and concentrations in the reaction process, the reaction conditions can be adjusted in a timely manner, the production process can be optimized, and the product quality and production efficiency can be improved; in the metallurgical industry, the analysis of the gases in the furnace can help operators understand the reaction conditions in the furnace, achieve precise control, and reduce energy consumption and production costs; in the environmental protection field, the on - line gas analysis system can monitor the industrial waste gas emissions in real - time, ensure that the enterprise emissions meet the standards, and reduce environmental pollution.

4. Selection Criteria for Gas Detection Methods and Equipment in the Industrial Field

4.1 Selection Based on the Type of Gas to be Detected

Different gases have different physical and chemical properties. Therefore, it is necessary to select appropriate gas detection methods and equipment according to the type of gas to be

detected. For combustible gases such as hydrogen and methane, the catalytic combustion detection method and the semiconductor detection method are more commonly used; for toxic and harmful gases such as carbon monoxide and hydrogen sulfide, the electrochemical detection method has high sensitivity and selectivity; for some gases that require high - precision detection, such as carbon dioxide and sulfur dioxide, the infrared absorption detection method is more suitable. At the same time, for some gases, a combination of multiple detection methods may be required to improve the accuracy and reliability of detection.

4.2 Selection Based on Detection Environment Requirements

The industrial detection environment is complex and diverse, including factors such as temperature, humidity, pressure, dust, and corrosiveness. In high - temperature and high - pressure environments, it is necessary to select detection equipment that can adapt to such harsh conditions, such as sensors and equipment casings made of high - temperature and high - pressure resistant materials. In a humid environment, the tolerance of the detection method and equipment to humidity needs to be considered, or corresponding dehumidification measures need to be taken. For environments with dust and corrosive gases, the equipment needs to have good dust - proof and corrosion - resistant properties. For example, in coal mines, due to the presence of a large amount of dust and gas, gas detection equipment with explosion - proof and dust - proof functions needs to be selected.

4.3 Selection Based on Detection Accuracy and Range Requirements

Different industrial application scenarios have different requirements for gas detection accuracy and range. For some occasions that are more sensitive to gas concentration changes, such as chemical production process control, high - precision detection equipment is required to ensure the stability of the production process and the qualification of product quality. For some occasions that only need to roughly understand the gas concentration range, such as general industrial safety monitoring, detection equipment with relatively low accuracy but a large range can be selected. When selecting, it is necessary to determine appropriate detection accuracy and range according to actual needs to avoid wasting resources by over - pursuing high accuracy or a large range.

4.4 Selection Based on Cost and Maintenance Requirements

The cost of gas detection equipment includes equipment procurement cost, operation cost, and maintenance cost. When selecting, these factors need to be comprehensively considered. Generally speaking, portable gas detectors have a relatively low cost and are suitable for small - scale and temporary detection needs; fixed gas detectors and on - line gas analysis systems have a high cost but are suitable for long - term and continuous monitoring tasks. At the same time, different detection methods and equipment have different maintenance requirements. For example, electrochemical sensors need to be regularly replaced with electrolytes and calibrated, and catalytic combustion elements need to be regularly cleaned and maintained to ensure their performance. When selecting, the enterprise's maintenance capabilities and cost budget need to be considered, and equipment that is easy to maintain and has a low maintenance cost should be selected.

5. Development Trends of Gas Detection Technologies and Equipment

5.1 Intelligent Development

With the rapid development of artificial intelligence, big data, Internet of Things and other technologies, gas detection technologies and equipment are developing towards intelligence. Intelligent gas detection equipment can automatically identify gas types, analyze detection data, predict equipment failures and gas leakage risks. Through the combination with Internet of Things technology, remote monitoring and control can be realized, and the detection data can be transmitted to the cloud or enterprise management platform in real - time, facilitating managers to view and analyze at any time and place. At the same time, using big data analysis technology, historical detection data can be mined to provide decision - making support for enterprise safety production management.

5.2 High Sensitivity and High Selectivity

In order to meet the increasingly stringent industrial safety and environmental protection requirements, gas detection technologies are constantly developing towards high sensitivity and high selectivity. Researchers are committed to developing new sensor materials and detection methods to improve the detection ability of low - concentration gases and reduce the interference of other gases. For example, sensor materials prepared by nanotechnology have a larger specific surface area and higher activity, which can significantly improve the sensitivity and selectivity of sensors.

5.3 Miniaturization and Integration

Miniaturization and integration are another important development trend of gas detection equipment. Integrating multiple gas detection functions into a small device can not only reduce the cost, but also improve the detection efficiency and portability. At the same time, miniaturized sensors and devices can be more easily embedded into various industrial equipment and systems to achieve real-time and in-situ monitoring of gas. For example, electrochemical sensors, catalytic combustion sensors and semiconductor sensors are integrated into one chip to make a multifunctional gas detection chip, which can be widely used in portable gas detectors and IOT gas monitoring nodes.

5.4 Multi Technology Integration

In the future, gas detection technology will show the trend of multi technology integration. Different detection methods have their own advantages and disadvantages. Through the organic combination of various detection technologies, we can learn from each other and improve the accuracy and reliability of gas detection. For example, the combination of infrared absorption detection method and gas chromatography can not only make use of the fast and non-contact detection characteristics of infrared absorption method, but also realize the accurate analysis of complex gas components with the help of the high separation ability of gas chromatography. In addition, the gas detection technology can be integrated with other technologies such as optics, acoustics, and heat to develop more novel and efficient detection methods and equipment.

6. Conclusion

Gas detection in the industrial field is of great significance for ensuring safe production, protecting the environment and optimizing the production process. This paper summarizes the common gas detection methods in the industrial field, including electrochemical detection, catalytic combustion detection, infrared absorption detection and semiconductor detection, and analyzes their working principle, characteristics, application scenarios and limitations. At the same time, common gas detection equipment such as portable gas detector, fixed gas detector and online gas analysis system and their applications in industrial environment are introduced. When selecting gas detection methods and equipment, it is necessary to comprehensively consider the types of detection gases, detection environment requirements, detection accuracy and range requirements, cost and maintenance requirements and other factors. With the continuous progress of science and technology, gas detection technology and equipment are developing in the direction of intelligence, high sensitivity and high selectivity, miniaturization and integration, and multi technology integration. In the future, gas detection technology will play a more important role in the industrial field and provide strong support for the sustainable development of industry.

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