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Technical Review and Prospect of Sludge Moisture Content Detection Methods

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Abstract

The moisture content of sludge is an important parameter in the process of sludge treatment and disposal, directly affecting the treatment efficiency, cost and final disposal method of sludge. This study reviews the commonly used methods for detecting the moisture content of sludge at present, including traditional drying method, microwave method, infrared method, capacitance method, ultrasonic method, etc., and compares the advantages and disadvantages as well as the applicable scope of each method. Meanwhile, the study explores and analyzes the application potential of emerging technologies in the detection of sludge moisture content, and looks forward to the future development trend, with the aim of providing reference for research and practice in the field of sludge treatment and disposal.

Keywords

Sludge Moisture Content; Detection Methods; Emerging Technologies; Development Trends.

1. Introduction

With the acceleration of urbanization and increasingly stringent environmental protection requirements, the amount of sludge generated by sewage treatment plants is increasing year by year[1]. The composition of sludge is complex, typically containing organic matter, inorganic matter, microorganisms, pathogens, and other toxic substances. It will cause severe environmental pollution and restrict the country's sustainable development strategy if not properly treated[2][3] Sludge is a solid waste generated during sewage treatment, and its moisture content is usually as high as more than 95%. High moisture content not only increases the volume and weight of the sludge, but also brings great challenges to the transportation, treatment and disposal of sludge[4]. The moisture content of sludge directly affects the effect of resource recycling and utilization, and the moisture content of about 60% can meet the resource treatment requirements such as sludge landfill and compost. Therefore, accurate and rapid detection of sludge moisture content is of great significance to optimize sludge treatment process, reduce treatment costs, and realize sludge resource utilization.

There are many methods for detecting sludge moisture content, from traditional drying methods to modern microwave methods, infrared methods, capacitance methods, ultrasonic methods, etc. Each method has its own unique advantages and limitations. This article will introduce and compare the various methods in detail, and explore the application potential of emerging technologies in sludge moisture content detection, in order to provide reference for related research and practice.

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2. Method for Detecting Sludge Moisture Content

The detection methods of sludge moisture content are mainly divided into two categories: direct method and indirect method[5]. The direct method is to remove moisture in the material through physical or chemical means, and to obtain moisture in the material based on the poor quality before and after. Because the direct method operates on the moisture in the material without interference from other external environments, the measurement accuracy is high and it is the most standard method for measuring moisture content, mainly including drying method and vacuum drying method; the other is the indirect method, which is a method of indirectly obtaining the moisture content of the material by measuring the physical quantity related to the moisture content of the material. It is generally summarized as resistance method, capacitance method, neutron method, infrared method and microwave method. Different detection objects can reasonably choose detection methods to improve the detection accuracy of moisture content.

2.1 Direct Method

2.1.1 Drying Method

The drying method is the most classic and accurate method to determine the moisture content of sludge. It is one of the most widely used sludge moisture content detection methods and is also the reference standard for verifying the accuracy of other detection methods (GB18918-2002). The principle of the drying method detection is to dry the sludge sample to a constant weight at 105° C, and calculate the moisture content based on the weight difference before and after drying. This method is simple to operate and accurate, but it takes a long time, usually takes more than 24 hours, and cannot meet the requirements of real-time detection. The moisture content of the measured sludge can be expressed by the following formula[6] :

$$M = \frac{m - m_1}{m} \times 100\% \quad (1)$$

Where M is the moisture content of the sludge, %, m represents the mass of the original sludge, g, m1 is the mass of the sludge after drying, g.

2.1.2 Vacuum Drying Method

The vacuum drying method is to heat and dry the sludge sample under a vacuum environment. Compared with the traditional drying method, vacuum drying method can significantly shorten the time, and can effectively reduce the loss of volatile organic compounds in sludge and improve the accuracy of the detection results[7]. It is mainly suitable for high testing time requirements and sludge samples contain heat-sensitive substances or easily oxidized substances. During the sewage treatment process of chemical enterprises, the sludge produced may contain volatile components such as organic solvents. The vacuum drying method can quickly obtain sludge moisture content data while ensuring the accuracy of detection, providing a reliable basis for the adjustment of production processes.

2.2 Indirect Method

2.2.1 Microwave Method

The microwave method is based on the principle that microwave energy is absorbed by water and parameters such as phase attenuation and resonant frequency change accordingly with the water content in the material[8][9]. Microwaves with strong penetration capabilities can not only measure the surface moisture of materials but also measure the internal moisture non-contact, making it an ideal moisture detection technology suitable for non-destructive, online and rapid detection. The microwave method mainly includes the free space method, transmission line method and resonant cavity method. The detection method of the free space method is to use a pair of horn antennas to

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measure the moisture of the material in free space. This technology is mainly applied to materials such as paper, grain and textiles, and has achieved good measurement results[10]. Since the free space method needs to pass through the material to be measured, the working frequency requirement is relatively high, generally between 10 GHz and 20 GHz. As the working frequency increases, it will lead to increased complexity of the measurement system, increased cost and reduced stability. It is inevitable to be disturbed by the external environment when microwave acts on free space. It is suitable for measuring substances with uniform moisture content distribution and relatively smooth surface. Different from the free space method, the microwave resonant cavity is based on loading materials with different moisture contents and detecting the changes in resonant frequency and quality factor. The selected frequency is usually around 2.4 GHz industrial microwave source. The microwave resonant cavity method has the characteristics of small volume, low price, high detection accuracy and strong sensitivity. The moisture content detection system developed by a Finnish company based on microwave resonant cavity technology is to transport the crushed biological solid into the cavity and calculate the moisture content of the measured material according to the calibration curve. It can detect the solid content from 0% to 50% and has high detection accuracy.

2.2.2 Infrared Method

Infrared method is based on the fact that moisture has a strong absorption band for infrared rays of specific wavelengths. By measuring the change in light intensity before and after the material to be measured, the moisture content of the material can be calculated[11]. Infrared method can achieve rapid non-contact measurement of sludge moisture content, with a wide range of measurable moisture content. However, the instrument is expensive, and other substances in the sludge also have the ability to absorb infrared rays. Moreover, the moisture content on the surface of the sludge and inside the sludge can be quite different, and the infrared method is difficult to measure the internal moisture content of the sludge. Therefore, the infrared method is not suitable for the detection of moisture content in municipal sludge. It is mainly applicable to the microbial composition and organic matter analysis of sludge.

2.2.3 Capacitance Method

The capacitance method treats the tested material as a dielectric and inserts electrodes into the tested sample, which together with the sample are considered as capacitors[12]. The dielectric constant of water is generally 30~80, while other dry substances are generally 1~5, so the change in dielectric constant can be regarded as the change in moisture content in the tested material. Even when there is a slight change in the moisture content of the tested material, the dielectric constant of the sample actually changes significantly, and the capacitance value of the sample changes accordingly. The capacitance method is based on this principle to measure the moisture content, as shown in formula (2):

$$C = \frac{\varepsilon s}{d} \tag{2}$$

Where C represents capacitance, F, ε represents relative dielectric constant, s and d represent the area and distance of the electrode plate respectively, mm2and mm. The capacitance method can achieve online rapid detection, and is simple, economical, and easy to maintain. However, it is greatly affected by the external environment, such as the thickness, tightness, volume, and temperature of the tested material, resulting in poor stability. In actual sludge treatment conditions, the environment is complex, and the properties and structure of sludge are varied, resulting in significant deviations in measurement results. Suitable for storage and transportation of oily sludge with low moisture content.

2.2.4 Ultrasonic Method

The ultrasonic method is used to determine the relationship between the propagation speed of ultrasonic waves in the tested sample and the moisture content[13]. This method is fast, non-

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destructive, and can achieve online detection, but it is greatly affected by factors such as sludge concentration and bubbles. Therefore, ultrasound is mainly suitable for measuring sludge interface or sludge thickness using the principle of ultrasound pulse in sludge treatment, and guiding sludge discharge operations.

2.2.5 Resistance Method

The resistance method is the earliest method applied to moisture content detection, and its detection principle is that the resistance value of the sample has a certain relationship with its moisture content for indirect measurement[14]. As a relatively mature detection method, the resistance method is widely used due to its simple operation and low cost. The resistance method involves clamping a sample with two electrodes. The thickness, tightness, temperature, and other parameters of the measured sample can affect the detection results, and the sampling is limited, making it suitable for offline measurement. Due to the presence of a large number of bacteria and pathogens in municipal sludge and the formation of honeycomb like structures during the drying process, as well as uneven distribution of moisture in the sludge, using the resistance method for contact measurement may corrode the electrodes, reduce the service life of the equipment, and also lead to lower accuracy in detecting the moisture content of the sludge.

3. Application of Emerging Technologies in Sludge Moisture Content Detection

With the advancement of technology, some emerging technologies are gradually being applied to the detection of sludge moisture content, demonstrating enormous potential.

3.1 Near Infrared Spectroscopy

Near infrared spectroscopy (NIRS) is a rapid and non-destructive analysis technology, which has been widely used in the detection of sludge moisture content in recent years. The technology uses the interaction between near-infrared light and organic matter and water molecules in sludge to establish a mathematical model between spectral information and water content, so as to achieve rapid and accurate determination of water content.

3.2 Terahertz Time-domain Spectroscopy

Terahertz time-domain spectroscopy is a new non-contact detection technology, which has the advantages of strong penetration and high resolution. This technology uses the interaction between terahertz wave and water molecules in sludge to obtain the information of sludge dielectric properties, so as to inverse the moisture content of sludge.

3.3 Nuclear Magnetic Resonance

Nuclear magnetic resonance (NMR) is an analytical technique based on the interaction between nuclear magnetic moment and external magnetic field, which has the advantages of non-destructive, fast and accurate. This technology makes use of the relationship between the nuclear magnetic resonance signal strength of water molecular hydrogen nucleus in sludge and water content to realize the rapid determination of sludge water content.

4. Technology Prospect

The detection technology of sludge moisture content will develop in a faster, more accurate and more intelligent direction in the future, Here are some possible trends:

4.1 Developing New Sensors

Develop new sensors with higher sensitivity and stronger anti-interference ability to improve the detection accuracy and stability. For example, the development of new sensors based on nano-materials and biosensors will provide new solutions for the rapid and accurate detection of sludge moisture content.

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4.2 Developing Multi Technology Fusion Detection Methods

A variety of detection technologies are combined to overcome the limitations of a single technology and improve the reliability of detection results. For example, the combination of microwave method and infrared method can simultaneously obtain the dielectric properties and spectral information of sludge to improve the accuracy of moisture content detection.

4.3 Intelligent Online Detection

Using artificial intelligence, big data and other technologies, an intelligent online detection system is developed to realize the real-time monitoring and automatic control of sludge moisture content. For example, the intelligent moisture content detection system based on machine learning algorithm can automatically adjust the detection parameters according to the historical data and real-time monitoring data, and improve the detection efficiency and accuracy.

5. Summary

The detection of sludge moisture content is an important link in the process of sludge treatment and disposal. Each detection method has its own advantages and disadvantages, and the appropriate method should be selected according to the actual needs. In the future, with the continuous development of new technologies, the detection technology of sludge moisture content will be more perfect, providing more reliable technical support for sludge treatment and disposal.

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