Research on Dilution Method Carbon Emission System

Xu Dai[1], Chaoping Sun[1], Wei Tang[1], Xiaojuan Yao[1], Xiaodong Wang[1], Honglie Wu[2] and Bin Sun[2,*]

[1] Huzhou Quality and Technical Supervision and Inspection Institute, Huzhou, 313099, China
[2] China Jiliang University, Hangzhou, 310018, China

Abstract. Carbon emissions are an important parameter for world environmental protection. Excessive CO2 emissions can cause problems such as the greenhouse effect, damage to ecosystems, and harm to human health. The current CEMS system lacks monitoring of carbon emissions and is greatly affected by environmental changes. It is explained that the dilution method is used to sample flue gas, which completely solves a series of problems caused by condensation water, reduces the operating cost of the CEMS system, and combines improved non-dispersive infrared spectroscopy and optical filtering technology to measure the carbon dioxide concentration in the flue gas. It can improve the accuracy of the measurement of carbon content in flue gas. The accuracy can reach 0.01. In combination with reality, it integrates a remote cloud service monitoring system, which improves the reliability and security of the system.

1 Introduction

A continuous emission monitoring system is a system used to monitor and analyze the composition and pollutant concentration of smoke generated during the combustion process, which is abbreviated as CEMS. With the development of environmental protection, the technology of CEMS is becoming increasingly mature and standardized. At present, the development of China's CEMS is rapid, but there are still problems, such as outdated technology, inaccurate accuracy, and high operating costs, especially in the monitoring of carbon emissions, which involve insufficient depth [1-2]. The vast majority of CEMS systems do not have the function of measuring carbon emissions.

Moreover, in most areas of northern China, there is a phenomenon of sampling gas condensation caused by low temperatures. The condensed water formed by gas condensation can corrode pipelines and affect the accuracy of final measurements. In order to eliminate the series of effects caused by condensed water, most areas will adopt the method of heating or insulating the sampling tube throughout the entire process. However, this method also brings the problem of greatly increasing operating costs. A CEMS system based on the dilution method was studied for this purpose. The principle of the dilution methodis to use a dilution probe to dilute the sampled gas, reduce the dew point, solve a series of problems caused by condensed water, and improve accuracy.

At present, the development of China's CEMS system will mainly focus on scattering methods suitable for measuring low concentrations of particulate matter. CEMS for gaseous pollutants will develop towards full spectrum light and linear spectroscopy technology, and the measurement range will gradually move towards low concentrations, pursuing higher accuracy and precision [3]. The dilution method CEMS system uses improved nondispersive infrared spectroscopy and optical filtering technology to measure the concentration of carbon dioxide in flue gas, with a measurement accuracy of ±0.1ppm and an error of less than 1%.

In addition, the dilution method CEMS system also integrates a remote cloud service monitoring system, which can remotely monitor the on-site environment and data and has both security alarm and data recording functions, improving the system's security, reliability, and flexibility.

2 Dilution measurement method

2.1 Design of dilution probe

The dilution probe is the core component of the dilution method. The dilution probe is the core component of the dilution method. All parts of the probe exposed to the flue gas are made of Inconel600 aluminum chromium-nickel alloy, which is heat-resistant and corrosion-resistant and can prevent the probe from being corroded in the flue gas. Although the dilution method can reduce the dew point of flue gas and eliminate corrosion, dissolution, and other problems caused by subsequent condensation water, before dilution, the key components of the dilution probe still need an aluminum heating module to prevent damage to the dilution probe caused by the condensation water generated before dilution [4].

* Corresponding author: bsun555@cjlu.edu.cn

The dilution probe adopts a unique sonic orifice design, which is characterized by the ability to control the gas flow through the sonic orifice at a constant rate when the system meets the minimum vacuum requirement of the sonic orifice. A Venturi tube is used as the air extractor behind the sonic orifice. The dilution gas is blown towards the throat of the Venturi tube to generate a large enough vacuum to suck in the flue gas, reaching the threshold required by the sonic orifice. As long as the instrument gas is continuously supplied, the sonic orifice and Venturi tube can work and maintain a constant dilution ratio.

The dilution pipeline and calibration pipeline are integrated into the dilution probe. The air passes through the dilution method air purification system to become dilution gas, which is responsible for generating sufficient vacuum inside the nozzle to suck in the smoke and dilute the smoke. The calibration gas is introduced into the critical small hole through the calibrator pipeline, passes through a path consistent with the flue gas, and enters the flue gas analysis system for calibration.

As shown in Figure 1, the internal structure of the dilution probe is shown. In order to prevent particles from entering the pipeline and causing blockage, a coarse filter and a glass wool filter are also arranged before the smoke enters the sonic small hole, respectively used to filter large and small particles.

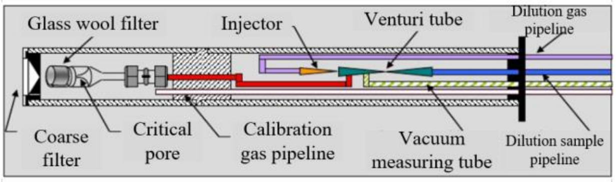

Figure 1. Internal structure diagram of dilution probe.

2.2 Confirm dilution ratio

The main purpose of the dilution method is to improve measurement accuracy and reduce the dew point of the flue gas sample to avoid condensation. To ensure accuracy, a constant dilution ratio is crucial. Only when the dilution ratio is constant can the data obtained by the flue gas analysis system be accurate. Thanks to the two atmospheric components of the Venturi tube and the sonic orifice, as long as the minimum vacuum degree is maintained, the gas flow rate through the sonic orifice is constant.

$$n = \frac{Q_1 + Q_2}{Q_2} \tag{1}$$

In Equation (1), n is the dilution ratio, $Q1$ is the dilution gas flow rate, and $Q2$ is the flue gas flow rate.

There are two main criteria for selecting the dilution ratio. The first criterion is that the measurement range of the monitoring instrument used should be consistent with the expected concentration (after dilution) of the actual extracted sample. The second criterion is that the dilution ratio should ensure that the sampling pipeline does not condense at the lowest ambient temperature.

3 System design of carbon emission CEMS using the dilution method

The dilution method carbon emission CEMS system is composed of five modules: sampling probe, remote cloud server control system, dilution air purification system, flue gas analysis system, and data acquisition system. The schematic diagram of the dilution method CEMS system is shown in Figure 2.

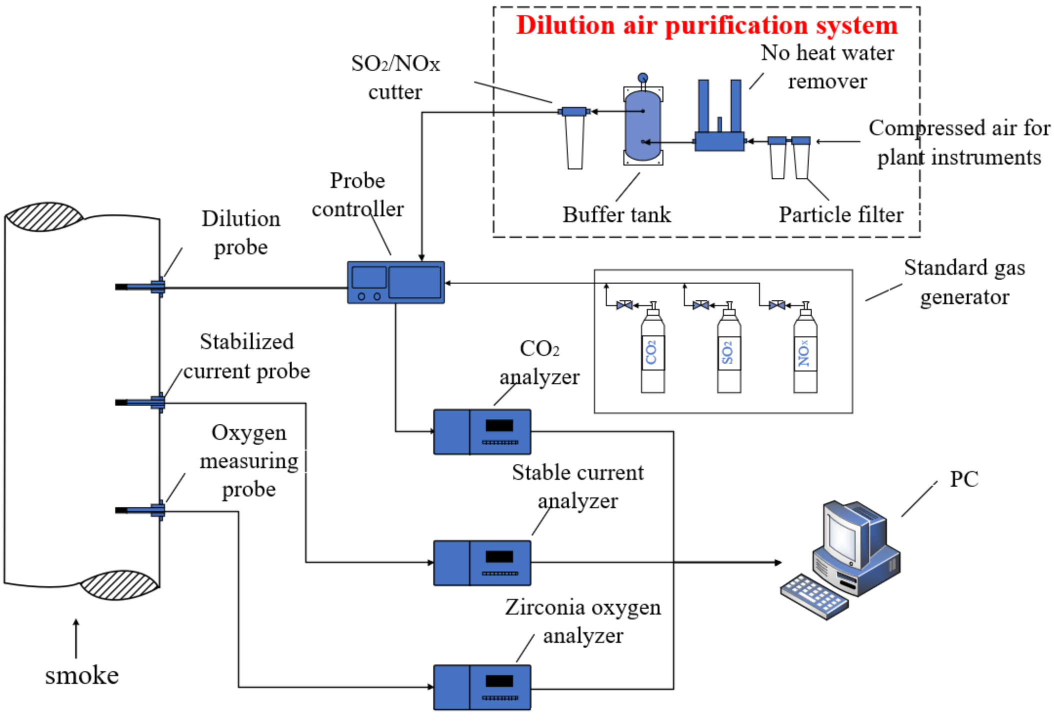

Figure 2. Structural diagram of the dilution method CEMS system.

3.1 Measurement principle of flue gas analyzer

The dilution method CEMS uses nondispersive infrared spectroscopy and optical filtering technology combined with fixed bandpass interference filters and quantum detectors to analyze the concentration of carbon dioxide in the airflow. This method has high measurement accuracy, a high degree of automation, and convenient output.

The principle of measuring the concentration of carbon dioxide in flue gas using infrared spectroscopy is based on the absorption characteristics of carbon dioxide toward infrared light. When passing through carbon dioxide molecules in smoke, certain specific frequencies of infrared light will be absorbed by the molecules, while the remaining frequencies will pass through the smoke. By measuring the intensity of infrared light transmitted and absorbed, the concentration of carbon dioxide in the flue gas can be inferred. This technology utilizes the absorption peaks of carbon dioxide molecules in the infrared wavelength range and calculates the concentration of carbon dioxide based on the absorption before and after comparing the samples.

Figure 3 shows a schematic diagram of the structure of a flue gas analyzer for infrared measurement of carbon dioxide concentration. The smoke enters the gas measurement capacity through a dilution probe. The infrared light source is processed by chopping and filtering before entering the gas measurement container. CO_2 absorbs a portion of the specific wavelength infrared light, which is then discharged into the atmosphere through a pressure sensor and flow meter through a centrifugal pump.

The infrared light is detected by the infrared detector, amplified by a signal amplifier, and output by a digital module.

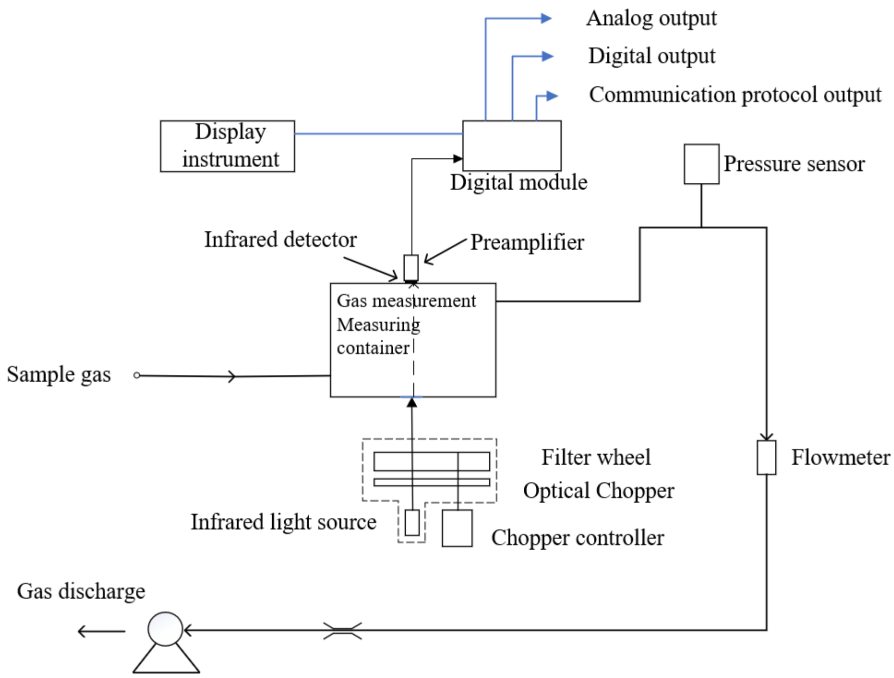

Figure 3. Structural diagram of infrared flue gas analyzer.

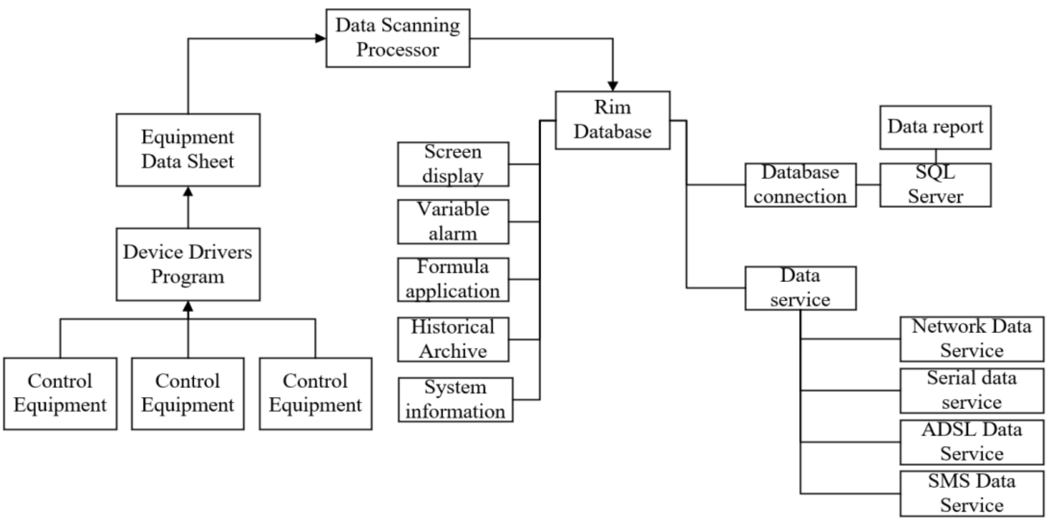

Figure 4. Data acquisition system flowchart.

3.2 Design of data acquisition system and remote cloud server

The data acquisition system in the dilution method CEMS system also realizes functions such as data acquisition, data conversion, data display, data storage, report printing, curve query, and data transmission. It also leaves an input window for material accounting, which can be manually inputted or remotely written to compare monitoring emissions and material accounting and store, compare, and create trends.

The workflow diagram of the data acquisition system is shown in Figure 4.

The design of a remote cloud server is to read analog output to the embedded touch screen through module ADAM-4017+, process and transfer data through the embedded touch screen, transfer the processed data to the USR-M100 module, and finally transmit it to the remote PC and mobile terminals to achieve remote control and monitoring.

4 Data processing

The calculation of carbon emissions depends on data such as flue gas flow rate and carbon dioxide concentration. The formula for calculating the average flow velocity VS of wet flue gas at the flue section is:

$$V_S = K_V \times V_P \tag{2}$$

In the formula, KV is the velocity field coefficient, and *VP* is the average wet exhaust flow velocity measured by the cross-sectional flow velocity CEMS. This formula derives the average flow velocity of the entire flue section from the smoke flow velocity near the sampling point. The formula for calculating the flow rate of flue gas is:

$$Q_S = 3600 \times F \times V_S \tag{3}$$

In the formula, *F* is the cross-sectional area of the flue section, and *QS* is the wet flue gas flow rate under actual working conditions. According to relevant standards, in the process of calculating emission rates, it is necessary to convert the wet flue gas flow rate under actual operating conditions to the dry flue gas flow rate under standard conditions. The conversion formula is as follows:

$$Q_{\mathrm{Sn}} = Q_S \times \frac{273}{273 + \mathrm{t_s}} \times \frac{B_\mathrm{a} + P_\mathrm{s}}{101325} \times (1 - X_{SW}) \tag{4}$$

In the formula, *QSn* is the flow rate of dry flue gas under standard conditions, *tS* is the flue gas temperature, *Ba* is the local atmospheric pressure, *PS* is the static pressure of the flue gas, and *Xsw* is the humidity of the flue gas. By multiplying this formula with the measured dry flue gas concentration of carbon dioxide in the flue gas, the real-time emission rate of carbon dioxide measured by the CEMS system can be obtained.

In addition, by updating the timestamp of the embedded touch screen as a benchmark to accumulate the real-time emission rate, the final emission amount can be obtained [5-6].

5 Measurement results and analysis

The experiment used a standard gas generator in the system to calibrate the dilution method CEMS system. Zero gas with 0% CO2 content (100% nitrogen) and calibration gas with 20% content were used for calibration. The data were compared and processed with the actual measured data.

The zero gas calibration test results are shown in Table 1.

Table 1. Zero gas calibration test results.

Calibration gas carbon content/ (%)	CO2 content measured/ (%)	relative error/ (%)
20	20.42	2.10
20	20.32	1.60
20	20.30	1.50
20	20.41	2.05
20	20.30	0.15
20	20.20	0.10

Table 2. Full-scale calibration test results.

Calibration gas carbon content/ (%)	CO2 content measured/ (%)	relative error/ (%)
0	0.02	0.08
0	0.05	0.2
0	-0.10	-0.4
0	0.06	0.24
0	0.02	0.08
0	0.05	0.2

As shown in the Table 2 above, the maximum zero drift of the system is 0.4%, the maximum relative error is 2.1%, and the accuracy level is 0.1. It can be seen that the dilution method can improve the measurement accuracy very well.

6 Conclusion

In response to the problems of high operating costs and poor measurement accuracy of existing CEMS systems, this article designs a carbon emission CEMS system based on the dilution method, which adopts the method of pre-treatment of flue gas samples by dilution method to reduce the dew point of flue gas and avoid the impact caused by the generation of condensation water. Through calculation, its operating cost is only one-third to half of that of the direct sampling method system. The measurement accuracy can reach 0.01%. The measured data can be wirelessly transmitted to remote clients through cloud servers. Real-time monitoring can be achieved. Through testing, the measurement accuracy and stability of the system are very reliable and have high practical value.

This CEMS system can be applied in most parts of the world and is minimally affected by climate. The CEMS system described above is not a complete picture. It also integrates monitoring systems for other pollutants such as SO2, NOX, etc. It is a complete gas pollutant monitoring system. In the future, we will continue to develop CEMS with higher accuracy and less environmental impact.

References

1. Yu Dan, Tang Ren, Wang Airong. Application status and problems of continuous monitoring of carbon dioxide emissions from domestic fixed emission sources [J/OL]. Heating Ventilating & Air Conditioning, 2023,54(2):1-8.
2. Shen Huamin, Jin Xiaolei, and Song Xianguang. Technical Comparison and Analysis of Automatic Online Monitoring System for Smoke [J]. Environment and Sustainable Development, 2006, (05): 47-49.
3. Li Qi. Dilution Method of Gas CEMS Online Monitoring System [J]. Automation Application, 2013, (11): 26-28.
4. Xiong Jian, Luo Peng, Wei Qingchun. Study on Sonic Nozzle for Flue Gas CEMS Dilution Sampling [J]. Process Automation Instrumentation, 2021, 42(02): 6-9+15.
5. Yanjun Z, Ruikun G, LiD. CEMS monitoring system of EPA based on WEB [C]//2010 International Conference on Intelligent Computation Technology and Automation. IEEE, 2010, 1: 914-917.
6. Dinh T V, Kim J C. Moisture removal techniques for a continuous emission monitoring system: A review [J]. Atmosphere, 2021, 12(1): 61.