Design of CO_2 on-line Monitoring System for Boiler Flue Gas

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Abstract. For air pollution, monitoring the CO_2 concentration in boiler flue gas is an important issue. In this work an online CO_2 monitoring system based on infrared and sensor technology is designed. The system takes S7-1500 PLC as the control unit. Temperature and humidity are collected by sensors as the flue gas environment. The sample gas enters the gas chamber after filtration. Near infrared spectroscopy was used to detect the CO_2 concentration of the sample gas. Finally, the CO_2 concentration in flue was obtained by conversion. The hardware and data processing methods of CO_2 monitoring system are designed. Experiments show that the system can complete the automatic sampling and detection of CO_2 gas.

Key words-CO_2 detection; Spectral detection; On-line detection;

1.Introduction

In recent years, with the development of industry, air pollution and global warming[1] are becoming more and more serious. At present, the main power generation mode in our country is thermal power generation. Large amount of CO_2 generated by combustion of coal-fired boiler[2]. At present, the negative impact of Greenhouse Effect has seriously threatened human health and safety and hindered the development of the global economy[3]. So the intensity of CO_2 emissions has attracted more and more attention. Our country has actively participated in the global carbon reduction action. The emission strives to reach the peak by 2030. Strives to achieve the carbon neutralization "double carbon" goal by 2060. In order to monitor CO_2

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emission from boiler flue gas, it is particularly important to design a CO_2 gas monitoring system with high accuracy and reliability.

At present, there are many methods used to measure CO_2 gas, but electrochemical formula, heat conduction type, capacitance type, solid electrolyte type and other methods have some shortcomings, such as low detection accuracy, slow response, short service life and so on. The European Union on-line Emission Monitoring system (CEMS) for thermal power plants uses direct measurement of flue gas velocity, CO_2 concentration and humidity and other parameters to realize CO_2 emission monitoring[4]. Jin Ani[5] put forward a CO_2 online monitoring system for coal-fired units. The business architecture is composed of four levels: data acquisition, data monitoring, business analysis and interactive display. It can provide the total CO_2 emission and CO_2 emission intensity index for power plant operation managers in real time. In recent years, infrared spectroscopy has developed rapidly. Chen Yongcheng[6] adopts non-dispersive infrared absorption method to measure and calculate the CO_2 and flow rate in real time through a 660th MV Supercritical Unit Coal-fired Unit. the real-time flue gas emission rate has been obtained. Based on the principle of infrared absorption, Wang Niying[7] designed and set up a set of side-flow CO_2 concentration monitoring system. In the case of frequent changes in CO2 concentration, it can also achieve better measurement results. Based on infrared spectroscopy, Wang Biao[8] developed a set of CO_2 gas detection system based on a new VCSEL laser. The experimental results show that the minimum detection limit is 90×10^{-6} ppm. The long-term change of the detection results is less than 2.6%. Hodgkinson J, Smith R[9] designed a micro gas sensor to detect the concentration of CO_2. injection molding technology was used to achieve good results. Sun Yiping[10] not only optimized coal blending resources through coke oven regression experiment, but also contributed to reducing environmental pollution.

Infrared spectroscopy has been widely used because of its good adaptability, fast determination, non-pollution and direct determination of samples. But it is rarely used for on-line monitoring of flue gas. Through the literature, an infrared detection system for CO_2 concentration in flue gas is designed. The feasibility of the test system is verified by experiment.

2.Detection principle

The basic principle of absorption spectrum monitoring is Lambert Beer's law. This law applies to the detection of common gases, liquids and solids. The gas in the flue contains various components, the absorption degree of light by different gases is different. And the intensity of light received by the sensor is also different due to the different concentration of the same gas. According to this principle, the gas concentration of flue gas is measured by infrared emission of a certain wavelength of light beam through the gas chamber，and the mathematical model can be established by using Lambert-Beer's law, As shown in formula (1):

$$I(\lambda)=I_0(\lambda)\times\exp\left[-\delta(\lambda)\times C\times L\right] \qquad (1)$$

In formula (1), $I(\lambda)$ is the incident spectrum of the light source, $I(\lambda)$ is the transmission spectrum after passing through the gas, C represents the concentration of the gas, L is the optical path length of the absorbed gas, and$\delta(\lambda)$ represents the absorption cross section of the gas. The optical path length L and the gas absorption cross section$\delta(\lambda)$ are fixed values. It can be determined by certain experiments in advance，Then the original spectral intensity of the light source and the transmission spectral intensity of the gas can be deduced from the original spectral intensity of the light source and the transmission spectral intensity of the gas. This is the theoretical basis for the measurement of gas concentration by absorption spectroscopy, then the concentration C of the gas to be measured is:

$$C = \frac{ln\frac{I_0(\lambda)}{I(\lambda)}}{\delta(\lambda)L} \qquad (2)$$

The relative light intensity（I_r）of the measured gas is：

$$I_r = ln\frac{I_0(\lambda)}{I(\lambda)} = L\sigma(\lambda)C \qquad (3)$$

Formula (3) substitute (2), you can get:

$$C = \frac{I_r}{\sigma(\lambda)L} \qquad (4)$$

From this, the concentration of the measured substance is obtained.

3.System design

The on-line detection system of flue CO_2 gas is composed of main control module, sampling module, display module, infrared detection module, sample gas processing module and temperature and humidity flow detection module. Firstly, the tail gas is collected and sampled, and the temperature and humidity in the flue are monitored by the sensor. The flow sensor is used to monitor the flue flow in order to calculate the carbon emission in the later stage. The sample gas was processed by drying, preheating, temperature and humidity collection and sent to the near infrared spectrometer for component detection. The CO_2 concentration of sample gas was obtained by PLC operation, and then the CO_2 concentration in flue was converted into CO_2 concentration according to the change of humidity and volume. In the system, the display module and the communication module are used to realize the display and communication functions. The overall design block diagram is shown in figure 1.

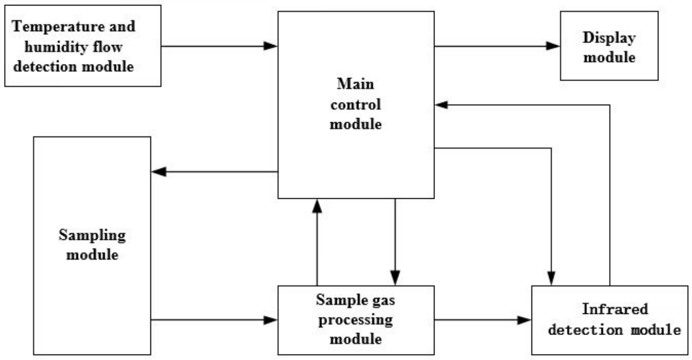

Figure 1. System structure block diagram

The main control module is PLC, which can realize the automatic operation of each module. The temperature humidity and flow detection module mainly uses sensors to detect the temperature, humidity and gas flow in the flue. The display module displays the data collected by the sensor to view the temperature and humidity of the gas in real time. The sampling module is mainly used to collect the gas in the flue so as to facilitate the subsequent treatment of the gas. The sample gas treatment module in the system can realize the processing of the collected gas. For instance, the electronic condenser can be used to separate the steam from the measured gas. The gas enters the gas chamber after the sample gas treatment module. CO_2 concentration is detected by the infrared detection module.

4.System hardware design

According to the design scheme, the system include the sampling control system, the filtration system and the detection system. The flow chart of detection process is drawn according to the scheme, as shown in figure 2.

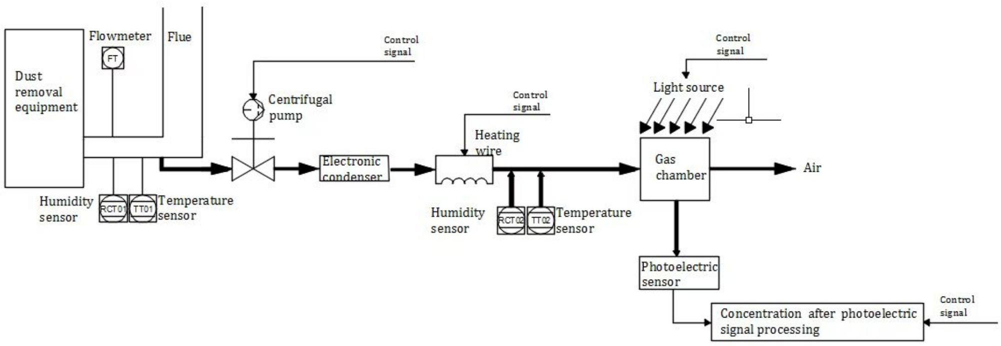

Figure 2. Flow chart of CO_2 detection process

The design uses PLC as the core controller to control all the sensors. The overall system design controller connection structure is shown in figure 3.

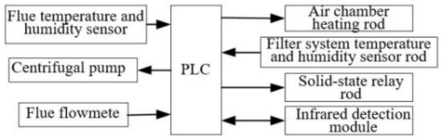

Figure 3.PLC control structure diagram

4.1 Design of PLC main Control system

Considering the high reliability and strong anti-interference ability of PLC, it can run under the unfavorable conditions of temperature and humidity. According to the control requirements of CO_2 monitoring system, there are 6 input signals and 4 output signals set by the control system. Siemens S7-1500 series PLC can be selected as the main controller. Several modules are selected, including distributed I / O module, digital input module, digital output module and timer module.

The ports of PLC are equipped with temperature and humidity sensors to sample the temperature and humidity of the flue, and the corresponding indicator lights are displayed.

4.2 The Construction of Experimental system

According to the design scheme and hardware selection, the physical diagram of the experimental system for on-line detection of CO_2 concentration is shown in figure 4.

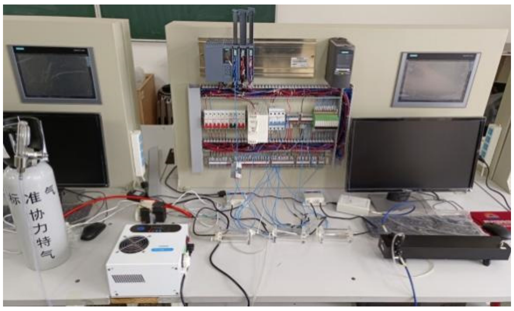

Figure 4. Physical diagram of the experimental system

5.System test

At room temperature and pressure, ADSX was tested systematically by using mixed gas of CO_2 concentration 0%, 10%, 20%, 30%, 40% and 50% respectively. Test indicators include temperature, humidity, repeatability test and stability test. Through many experimental tests of different mixed concentrations, the position of CO_2 absorption peak can be obviously found by the experimental data. The experimental results are shown in figure 5.

Based on the experimental data, the model is built and the concentration prediction formula is inverted. The curve obtained after data processing is shown in Figure 6. The prediction model formula is as follows:

$$C = -0.00031385 I_r + 5.8546 \qquad (5)$$

In the formula, C is the gas concentration.

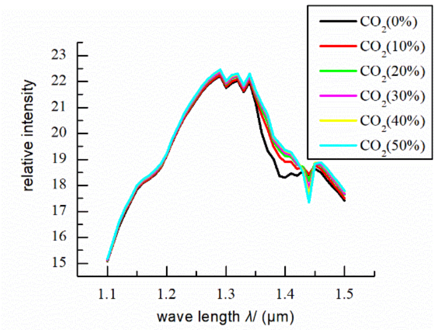

Figure 5. Test results of different concentrations

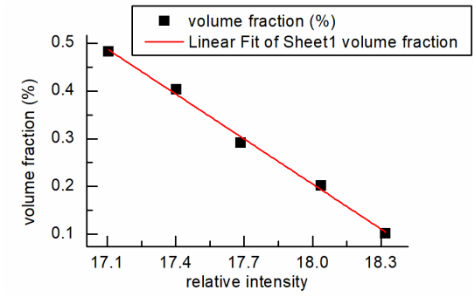

Figure 6. Concentration prediction

Substitute the absorbance measured by different concentration experiments into formula (5). The predicted values of CO_2 concentration obtained are shown in Table 1.

Table 1. Experimental prediction results

Gas concentration(%)	Relative light intensity	Predicted concentration(%)	Error(%)
10	18 362.00	9.17	8.30
20	18 072.17	18.26	8.70
30	17 639.83	31.83	6.10
40	17 406.83	39.15	2.10
50	17 104.00	48.62	2.76

6.Conclusions

This paper designs a CO_2 online monitoring system. PLC is used as the main control chip. Realize detection with the cooperation of various sensors. The test experiment is realized by using different concentrations of gas. The predicted concentration error values under different concentration experiments are calculated respectively, the maximum is 8.7%. The experiment proves that the system can be used for CO_2 online monitoring

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