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Development of a Gas Monitoring and Removal Device to Reduce the Effect of Extinction Coefficient

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Abstract

At present, the use of furnaces in the northern rural areas of China is very common, due to the insufficient burning of fuel (coal, wood, etc.), carbon monoxide (CO) and other toxic gases are produced, CO colorless and odorless, difficult to find in time, and bring huge safety risks to the life and health of residents. Based on the above problems, we developed a gas monitoring and removal device which could reduce the effect of extinction coefficient. The device was composed of ash settling area, gas disturbance area, spectral absorption identification area and gas removal area. After the air entered the device, the large-size particles were first settled to purify the solid particles in the gas, the gas was disturbed through the multi-layer separator to achieve the turbulent production of the gas, and then the gas was identified through the optical element of the direct absorption spectrum technology. When the toxic gas component reached the threshold, the spray device would automatically start for chemical removal to achieve the role of purifying the gas. At the same time, the device's alarm could be alerted by buzzer and flash to remind users to evacuate in time. By improving the optical device, the effect of extinction coefficient on measurement was reduced and the monitoring accuracy was improved.

Keywords

Atmospheric Monitoring, Carbon Monoxide, Direct Absorption Spectroscopy, Gas Removal, Extinction Coefficient

1. Introduction

In the rural areas of northern China, the stove is still the main way of heating in winter, and its use is relatively popular. However, due to the insufficient combustion of fuels (such as coal, wood, etc.), the furnace also releases toxic gases such as carbon monoxide (CO) while generating heat. The World Health Organization (WHO) pointed out that CO is a colorless, odorless, non-irritating toxic gas, which can rapidly combine with hemoglobin to form carboxyhemoglobin, resulting in tissue hypoxia and death in severe cases [1]. However, the gas was difficult to be directly detected by the human body, so it was easy to lead to carbon monoxide poisoning. According to the Chinese Center for Disease Control and Prevention, acute poisoning incidents caused by carbon monoxide poisoning have occurred frequently in recent years, especially during winter heating, with a considerable proportion of poisoning incidents in rural areas. Wang jun [2] showed that for rural areas, due to the lack of effective monitoring and early warning mechanism, as well as the limitations of medical resources and rescue conditions, it was often difficult to get timely and effective treatment in the event of carbon monoxide poisoning, which further aggravated the harm of poisoning.

To solve the problem of carbon monoxide poisoning caused by the use of furnace, the existing technical solutions mainly include the following: First, improve the combustion mode of furnace, improve the fuel combustion efficiency, so as to reduce the emission of harmful gases; Second, Zhu Fangyan raised indoor ventilation equipment which can be seen in **Figure 1**, can be installed to maintain indoor air circulation and reduce indoor carbon monoxide concentration [3]. The third is to monitor the concentration of carbon monoxide in the room in real time through the installation of carbon monoxide alarm, and immediately alarm once abnormal is found to remind residents to take measures in time [4].

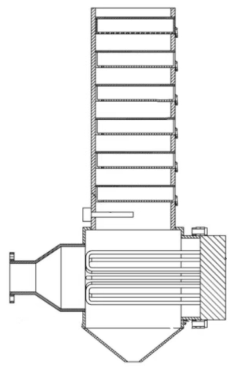

Figure 1. Catalyst carbon monoxide removal device.

However, these existing technical solutions have some limitations in practical application. For example, improving the way of furnace combustion requires high technical level and cost input, which is difficult to popularize widely in rural areas; Although indoor ventilation equipment can reduce carbon monoxide concentration, it was difficult to ensure indoor temperature in cold winter, which affected the normal life of residents. Although the carbon monoxide alarm could monitor the concentration of carbon monoxide in real time, it could not fundamentally solve the security risks caused by carbon monoxide. In addition, although traditional CO removal devices could monitor CO concentration to a certain extent, they often had defects such as slow response time and insufficient sensitivity [5]. As shown in **Figure 2**, the existing gas removal technologies mostly rely on physical adsorption or chemical reaction, but in practical applications, it is often difficult to achieve efficient and rapid gas removal, and the equipment was large and complex [6], which limits its popularization and application in rural families.

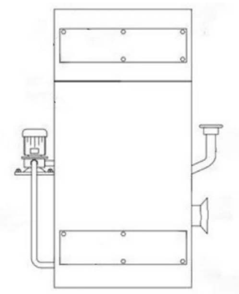

Figure 2. Carbon monoxide liquefaction removal unit.

Therefore, in order to solve this problem more effectively, this study proposed a gas monitoring and removal device based on direct absorption spectroscopy technology that can reduce the influence of extinction coefficient, aiming at reducing the incidence of carbon monoxide poisoning and ensuring the life safety of residents through an efficient gas identification and removal mechanism. The device not only had the characteristics of high sensitivity and fast response, but also could realize convenient operation and maintenance in rural families, and provide effective technical support for improving rural air quality.

2. Device Innovation Versus Prior Art

2.1. Limitation Analysis of Prior Art

Most of the existing gas monitoring technologies relied on electrochemical sensors, which had the limitations of slow response, easy to be affected by the environment and high maintenance cost. In addition, the limitations of traditional gas removal methods mainly lie in: first, monitoring and removal processes were often separated, resulting in overall low efficiency; Second, the equipment structure was complex and the maintenance cost was high; Third, the energy consumption in the treatment process was large, which was not in line with the development trend of energy conservation and emission reduction.

2.2. Device Innovation

2.2.1. Application of Direct Absorption Spectroscopy

It can be seen in **Figure 3** that the core of the technical solution was the application of direct absorption spectroscopy (DAS) to an integrated gas monitoring and removal device. Direct absorption spectroscopy was a method of gas concentration measurement based on the absorption characteristics of gas molecules to specific wavelengths of light. It had the advantages of high sensitivity, good selectivity and fast response speed. Direct absorption spectroscopy technology was used for gas identification. By changing the drive current of the laser, the wavelength of the laser could scan the single absorption spectral line of the gas to be measured, so as to obtain the direct absorption signal of the gas to be measured, and calculate the gas concentration by combining the Lambert-Beer law, the monitoring accuracy and response speed were improved [7] [8].

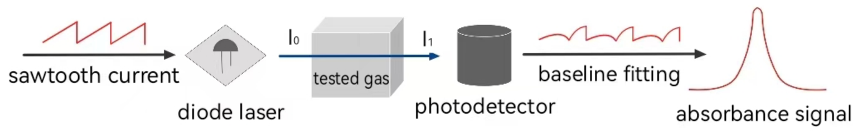

Figure 3. Optical technology detects gas flow.

2.2.2. Improvement of Optical Devices

Through the improvement of the optical device, the light source of a specific wavelength was emitted into the gas to be measured, and the absorption characteristics of the gas molecules were utilized to realize real-time monitoring of the gas concentration, reduced the influence of the extinction coefficient on the measurement, and improved the monitoring accuracy. We used special protective elements, such as optical cylinders and drying tubes, to minimize the impact of liquid fog environments on monitoring accuracy.

2.2.3. Combination of Gas Perturbation and Removal

On the basis of gas monitoring, we designed a dual mechanism of gas perturbation and removal. The gas is disturbed by a multilayer separator, and then identified by direct absorption spectroscopy. If the toxic gas component reaches the threshold, the spray device would automatically started for chemical removal. In addition, in order to realize the monitoring and removal of different gases, we also designed a tunable light source system, which could adjust the wavelength of the light source according to the need to adapt to the absorption characteristics of different gases.

2.2.4. Alarm and Early Warning Mechanism

The alarm of the device could be alerted by buzzer and flash to remind users to evacuate in time, which increased the safety of use.

3. Device Development

3.1. Overall Device Design

The device was composed of a box, carbon monoxide photoelectric sensor, hole plate, liquid tank, pump body, fan and other parts. The housing adopted high temperature heat resistance to ensure that it could withstand the temperature of the gas behind the furnace. The device was installed at the rear of the furnace in front of the air outlet and exhaust pipe. Purify and dust the gas before it was discharged into the atmosphere. It reduced soot pollution in rural areas and reduced the probability of carbon monoxide poisoning caused by furnaces in rural areas in winter.

The device was divided into two areas: the left ash settling area and the right gas purification area.

As shown in **Figure 4** and **Figure 5**, The gas at the back of the furnace entered the device through the intake pipe on the left side of the box, and the ash sedimentation area on the left side of the box was realized with large particle size. The ash could be removed by opening the side door (3). The gas at the back of the furnace entered the gas purification area on the right side through the orifice plate (29), and the orifice plate could conduct secondary barrier for the furnace ash to a certain extent. The right gas purification area was equipped with a carbon monoxide concentration photoelectric sensor. When the CO gas absorbed a specific wavelength of light and caused the signal to be abnormal, That was, when the concentration in the tank reached 50 mg/m^3, the liquid pump (5) would be pumped by the relay switch, and the removal agent ILS in the liquid tank (4) would spray the solution evenly to the gas purification area on the right side of the tank through the sprinkler head (37). The sprinkler head would swing left and right under the drive of the swinging arm (6). Under the gas purification zone was a cuprous chloride modified molecular sieve (28), which could physically adsorb carbon monoxide to achieve dual protection of physical adsorption and chemical reaction. The remaining liquid waste would be stored in the liquid waste tank (38) and could be removed periodically. The gas would be quickly pumped out under the drive of the fan (31).

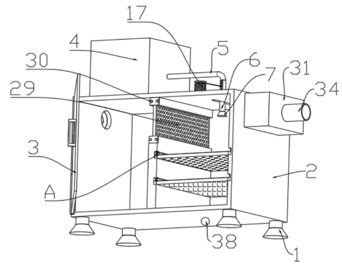

Figure 4. Device 3D modeling diagram.

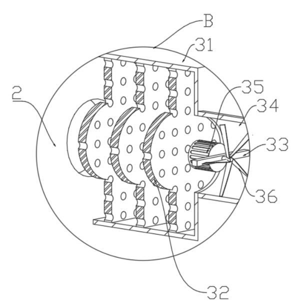

Figure 5. Fan interior detail drawing.

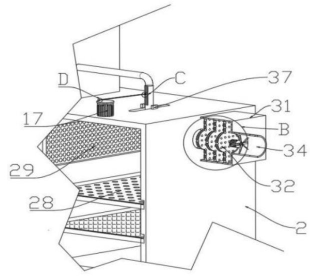

Figure 6. Device side view picture.

Figure 7. Gas monitoring area.

Finally, the purified gas was discharged to the outside through the right air outlet (34) discharge device.

Device side view picture could be seen in **Figure 6**. As shown in **Figure 7**, the size of a gas monitoring and removal device to reduce the effect of extinction coefficient is about the size of a furnace.

3.2. Main Hardware Components

3.2.1. Gas Sealing Box

As shown in **Figure 8**, The gas sealing box used in the device was a sealed container for storing gas, which had the functions of leak-proof, explosion-proof and corrosion-proof. The box was 500 mm long, 400 mm wide and 400 mm high. The box was rectangular, and the sealing facilities were installed in the box to ensure that the gas would not leak before purification to ensure safety. The gas sealing box was composed of the main body of the box, seals, valves, accessories and other components. The main body of the box was made of high-strength, corrosion-resistant SUH600 stainless steel, which had good sealing performance and could resist harsh environments such as high pressure and high temperature. The sealing parts were made of special elastic materials to ensure that the gas in the box does not leak. The valve was used to regulate the pressure and flow of gas to ensure the safe use of users. Accessories included pressure gauges, thermometers, pipes, etc., which could realize the monitoring and management of the gas seal box.

The box had been tested with the following advantages:

(1) High safety: the gas sealing box adopted a tight sealing structure to prevent gas leakage and effectively protect personnel and environmental safety.

(2) Corrosion resistance: The main body of the box was made of corrosion-

resistant SUH600 stainless steel, which could resist the corrosion of gas and extend the service life.

(3) Easy to operate: the gas seal box was equipped with easy-to-operate valves and accessories, which was convenient for users to operate and maintain.

Figure 8. Gas seal housing.

3.2.2. Photoelectric Sensor of Gas Concentration

As shown in **Figure 9** and **Figure 10**, The sensor adopted direct absorption spectroscopy. The laser wavelength changed linearly with the injection current. Direct absorption spectroscopy (DAS) used this characteristic to change the driving current of the laser, so that the wavelength of the laser could scan the single absorption spectral line of the gas to be measured, and the direct absorption signal of the gas to be measured could be obtained by detecting the intensity of the

Figure 9. Optical protection element.

Figure 10. Gas concentration photoelectric sensor.

emitted light. It could calculate the concentration of the gas. The laser was usually tuned with a sawtooth current, and the wavelength changed accordingly in a sawtooth waveform, thus performing periodic scanning. Because the light intensity of the laser also changed linearly with the injection. current, the light intensity also changed in sawtooth waveform during the scanning process. At the same time, the optical mirror cylinder and the drying tube were used to protect the laser, and the influence of the liquid fog environment on the monitoring accuracy was reduced to the greatest extent. According to the experiment, the change of the environmental extinction coefficient of the device was controlled within 3%.

3.2.3. Corrosion-Resistant Liquid Tank

As shown in **Figure 11**, Corrosion-resistant liquid tank had the advantages of corrosion resistance, high temperature resistance, stable structure, safety and reliability, environmental protection and energy saving, a variety of specifications, etc. It was an important equipment widely used in chemical industry, laboratory, medicine and other fields. The corrosion-resistant liquid tank was made of PVC material, meets environmental protection standards, and was reasonably designed, could be reused and recycled, reduce resource waste, reduce costs, and could safely store various corrosive liquids, such as acid and alkali, organic compounds, etc. High temperature resistance was considered in the design and manufacturing process, could be used in high temperature environment for a long time without being affected, suitable for storage of high temperature liquids or transport in high temperature environment. Corrosion resistant liquid tank adopted professional design, stable structure, strong durability, and leak-proof function, could effectively prevent liquid leakage or external pollutants into the box to ensure the safe storage of liquid. The corrosion-resistant liquid tank was equipped with multiple safety protection devices, such as fire and explosion-proof devices, leak detectors, pressure release valves, etc., which could detect and deal with liquid leakage or other dangerous situations in time to ensure the safety of operators and equipment. The device was equipped with a corrosion-resistant liquid tank capacity of 5L, a single box of reagents could meet the requirements of continuous use for 8 hours (do not consider reagent recycling).

Figure 11. Corrosion-resistant liquid tank.

3.2.4. Self-Priming Pump

As shown in **Figure 12**, The working principle of the self-priming pump was to generate centrifugal force through the rotation of the centrifugal impeller, the liquid was sucked into the pump body from the water inlet, and then through the accelerated movement of the blade, forming a high-speed rotating liquid, and then through the conversion of the pump body wall, producing a low pressure area, and then forming a natural suction which required the pump body and the effect of water absorption. In the water absorption stage, the self-priming pump needed to fill the pump body and water absorption pipe with liquid in order to work normally, the pump body and water absorption pipe should be sealed well, otherwise it would affect the self-priming effect. The advantages of self-priming pump mainly included energy saving, cost reduction, easy use and maintenance, automatic exhaust, no need to be equipped with special suction pipes, the suction range of self-priming pump was generally less than 7 meters, and the flow could be different according to the type and specifications of the pump. The corrosion resistant solution tank of this device had a volume of 5L, and ILS was selected after comprehensive consideration.

Figure 12. Self-priming pump.

3.2.5. Nozzle Array

As shown in **Figure 13**, Nozzle arrays played an important role in the field of gas removal applications, mainly for gas purification, waste gas treatment, air purification, deodorization, dust removal and other related processes. Through reasonable layout and design of nozzle array, gas and liquid could be effectively contacted, mixed and reacted to achieve efficient gas dust removal and purification effect. The device adopted linear array, and the self-priming pump sucked out the reagent and distributed it to each nozzle according to the normal distribution law to maximize the probability of carbon monoxide removal.

Figure 13. Nozzle arrays.

3.2.6. Cuprous Chloride Modified Molecular Sieve

As shown in **Figure 14**, Cuprous chloride modified molecular sieve was an important environmental protection material, had excellent adsorption properties and catalytic activity, could be used to absorb carbon monoxide (CO) and other harmful gases. The modified molecular sieve with cuprous chloride had larger specific surface area and pore size structure, which made it has larger adsorption capacity and faster adsorption speed. The pore structure of the molecular sieve could provide a large number of active adsorption sites, which was conducive to the contact and reaction between CO gas and the catalyst, so as to achieve efficient adsorption and conversion. The introduction of cuprous chloride could increase the active site on the surface of molecular sieve, promote the REDOX reaction, and accelerate the adsorption and conversion process of CO. The absorption and conversion of CO by cuprous chloride modified molecular sieve was helpful to reduce the concentration of harmful gases in the furnace gas and protect the environment and human health. Cuprous chloride could be used as a catalyst to participate in the oxidation reaction of CO and convert it into carbon dioxide, which reduced the harm of carbon oxide to the environment. By using molecular sieve in combination with cuprous chloride modification, more efficient CO adsorption and conversion could be achieved, thus effectively purified the toxic gas in the furnace gas.

Figure 14. Cuprous chloride modified molecular sieve.

3.2.7. Fan

As shown in **Figure 15** and **Figure 16**, The ventilation system of the device was extractive ventilation, and the extractive ventilator was installed on one side of the pipeline. Its main principle was forming a negative pressure area in the intake vent and the pipeline. Due to the existence of negative pressure, the gas in the distribution room flowed to the box through the pipeline, which was conducive to the diffusion of CO, increasing the amount of CO through the adsorption device and improving the adsorption efficiency. Ventilator according to its structure and working principle could be divided into centrifugal ventilator and axial ventilator two kinds. The centrifugal fan was driven by the motor to rotate the impeller, so that the air between the blades rotated with the rotation of the blades to obtain centrifugal force. The airflow direction was cut to the rotation direction of the blades, and it had the characteristics of large exhaust air volume and high wind pressure. The axial flow fan was the impeller rotation, the air flow along the cylindrical surface of equal radius, the air flow direction was perpendicular to the rotation direction of the blade, with large flow, low wind pressure, small volume characteristics. According to the requirements of small air demand and low wind pressure, the device was selected as the axial flow fan.

3.2.8. Other Components

As shown in **Figure 17**, the device used emergency stop switch, indicator light,

Figure 15. Fan inside picture.

Figure 16. Fan outside picture.

Figure 17. Buzzer warning light.

knob switch, etc. The indicator light could remind residents of the CO concentration alarm through the sound alarm, which was convenient for residents to evacuate and evacuate. Scram switches and knob switches made the device more maneuverable and simple.

4. Experiment and Data Analysis

4.1. Experimental Design

The fuel was ignited near the air inlet, the open flame contact device was used, and the CO threshold was set to 30ppm for device performance inspection.

The main contents of the experiment were as follows:

(1) The open flame contact device was used to test the heat resistance of the device.

(2) By monitoring the gas generated after combustion, when the threshold was reached, it was tested whether there was a removal agent emitted.

(3) Compare with the CO detector to check the numerical difference between the detection value of the device and the CO high-precision detector.

(4) Monitor whether the concentration of gas discharged from the device met the established requirements.

4.2. Experimental Data and Analysis

4.2.1. Heat Resistance Test

It can be seen in **Table 1** that the device adopted open flame test to measure the fuel open flame temperature every 5 seconds and check whether the functions of the device are normal. The data were shown in **Table 1**.

Table 1. Heat resistance test data.

Time (s)	0	5	10	15	20
Temperature (˚C)	75	88	91	96	107
Condition	Normal	Normal	Normal	Normal	Normal
Time (s)	25	30	35	40	45
Temperature (˚C)	114	118	123	140	148
Condition	Normal	Normal	Normal	Normal	Normal

According to the test results of heat resistance, it could be seen that the device could work normally at daily fire temperature. Special occasions had a higher demand for heat resistance, and new heat-resistant materials could be used.

4.2.2. Precision Test

The concentration test was carried out through the CO sensor to observe whether the alarm alarm was timely after reaching the threshold and start the self-priming pump for gas removal. We set the wind speed of the fan to 2.5 m/s. As shown in **Figure 18**, shown, the horizontal axis was the number of experiments, and the vertical axis was the instantaneous CO concentration. The threshold was 31 ppm.

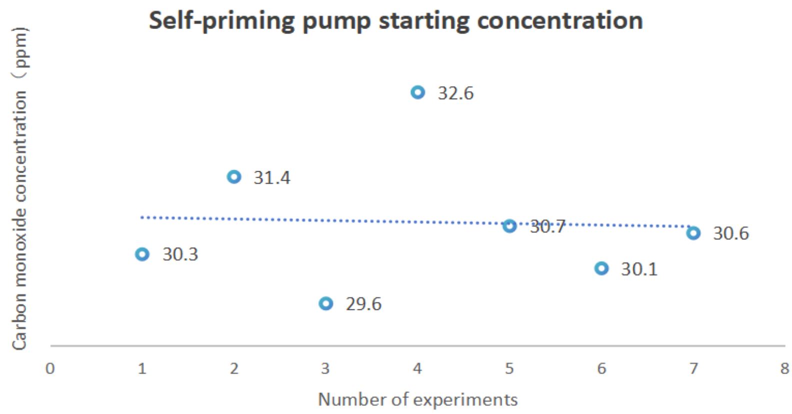

Figure 18. Self-priming pump starting concentration.

5. Application of Device

The application of the device was mainly for civil, industrial and scientific research fields. In the civilian aspect, the device could be installed behind the furnace in the resident's home to timely monitor and remove the CO generated by the furnace. In the industrial sector, a variety of gases could be monitored by changing the monitor or changing the wavelength of light. In the field of scientific research, the device could be used to monitor the local atmospheric environment and obtain more detailed meteorological data.

6. Conclusions

The device mainly uses direct absorption spectroscopy technology to identify the gas composition in the flowing air, and removes the gas through the chemical action of related reagents. The alarm could play an early warning role for users. Through the analysis of experimental data, the device had the following advantages:

(1) The application of direct absorption spectroscopy technology, high accuracy, fast response.

(2) It improved optical components to reduce the impact of extinction coefficient on accuracy.

(3) The application scenario was rural, and multiple scenarios could be warned, which was practical and widespread.

In the later stage, we will do further research on the gas removal reagent and the degree of gas disturbance of the device, so as to further improve the monitoring effect. At the same time, how to better reduce the impact of extinction coefficient on measurement results is also worth further research.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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