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Identification and Correction of Cross-interference of Mixed Gases in Tunnels

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Abstract

In gas detection, the coexistence of multiple gases is prone to cause cross-interference, which seriously affects the accuracy of detection data. This paper focuses on the gas cross-interference problem of electrochemical sensors. It first explains the definition and mechanism of gas cross-interference, then designs two sets of interference experiments for typical engineering scenarios: CO and H₂, H₂S and SO₂, to analyze the impact of interfering gases on the detection of target gases. Finally, combined with the linear response characteristics of sensors and the computing power constraints of embedded systems, a gas concentration calibration model is established. Experimental verification shows that the algorithm can reduce the relative error of CO detection from 19.7% to 2.4% and that of H₂S detection from 14.8% to 3.8%. Moreover, the model is simple with small computational complexity and easy to implement in embedded systems, providing a practical solution for improving the detection accuracy of gas sensors in complex environments.

KEYWORDS

Gas cross-interference, Electrochemical sensor, Compensation algorithm, Mixed gas detection

1 | INTRODUCTION

During gas detection, multiple gases often coexist. Different gases tend to cause cross-interference to the sensor, which directly affects the accuracy of detection data and becomes a key issue restricting the practical application of the system. Only by effectively solving the cross-interference problem of mixed gases can the reliability of detection results be ensured.

Therefore, this paper will focus on analyzing the cross-interference effect between different gas components in electrochemical sensor detection, find methods to reduce cross-interference through experiments, and eliminate the interference effect through this targeted scheme.

2 | DEFINITION OF GAS CROSS-INTERFERENCE PROBLEM

Gas cross-interference, also known as gas cross-sensitivity, is one of the key indicators for sensor performance evaluation in the field of gas detection. Its core connotation is as follows: when a gas sensor conducts quantitative or qualitative detection on a specific target gas, affected by the interaction mechanism between the sensor's sensitive material and gas molecules, the sensor not only generates a specific response (such as a change in electrical signal) to the preset target gas, but also produces a non-specific response to other non-target gas components present in the detection environment.

This non-specific response will be directly superimposed on the detection signal of the target gas, causing the finally output detection data to deviate from the true value, thereby interfering with the accuracy, stability and reliability of the target gas concentration measurement results.

3 | ANALYSIS OF GAS CROSS-INTERFERENCE MECHANISM

The gas detection mechanism of electrochemical sensors centers on the redox reaction of target gases on the electrode surface. Its working principle is specified as follows: When the target gas enters the electrochemical detection chamber of the sensor and comes into contact with the electrode surface, a preset redox reaction occurs under the catalytic action of the electrode and in a specific electrolyte environment; this reaction process is accompanied by electron transfer, which in turn generates an electrical signal (such as Faraday current or changes in electrode potential) that has a linear correlation with the concentration of the target gas; by detecting this electrical signal and conducting data conversion and analysis in combination with a calibration model, quantitative analysis of the target gas concentration can be achieved.

However, the electrode reaction process of such sensors has significant selectivity limitations: the occurrence of redox reactions is directly related to the redox potential of substances, and a variety of different substances often have similar redox potentials. This means that when there are interfering substances with redox potentials close to that of the target gas in the detection environment, these substances will form a competitive relationship with the target gas on the electrode surface and jointly participate in the redox reaction; the side reactions caused by interfering substances will also generate electrical signals, and these signals will overlap with the characteristic electrical signals of the target gas. In this case, the total electrical signal output by the sensor cannot accurately distinguish and reflect the concentration information of a single target gas, leading to deviations in the measurement results of the detection equipment and ultimately causing the cross-interference phenomenon in the gas detection process.

4 | DESIGN AND VERIFICATION OF GAS CROSS-INTERFERENCE

When determining the compensation algorithm, this paper focuses on three factors: 1) Engineering applicability: H_2 and SO_2 are the main interferences for CO and H_2S gas detection respectively; 2) Computational resource constraints: The processor used for detection has limited computing capacity, making it difficult for complex nonlinear models (such as neural networks) to run in real time; 3) Response characteristics of the sensor: Within the target concentration range, the sensor's response curve itself has good linearity. Based on the above considerations, this paper adopts a first-order linear regression model as the compensation correction algorithm. This method has a simple model, small calculation load, and is easy to implement on embedded systems. Subsequent experiments have proven that it can reduce the error to an acceptable range for engineering applications and meet the detection accuracy requirements.

4.1 | Carbon Monoxide (CO) Gas Interference Experiment

In the construction of tunnels (especially mine tunnels in coal-measure strata), CO and H_2 are often generated simultaneously during blasting operations or insufficient combustion (oxidation) of coal. The mixed existence of these two gases under conditions of insufficient ventilation (oxygen deficiency) is a common working condition. Therefore, studying the cross-interference

relationship between them is a key prerequisite for the practical engineering application of this platform.

Meanwhile, the carbon monoxide sensor selected in this paper is of the electrochemical type. Referring to the cross-interference gas table provided by the sensor manufacturer, it can be seen that H_2 is the most significant interfering gas for this model of electrochemical carbon monoxide sensor, which will significantly affect the accuracy of CO concentration detection.

Based on the commonality of the scenario and the significance of interference, this paper finally determines to take CO as the research object for detection and H_2 as the research object for interference, so as to conduct a targeted analysis of their cross-interference mechanism and design a compensation scheme.

Before the experiment, calibrate the CO sensor and H_2 sensor with standard gases respectively. Use the CO sensor to measure the CO standard gas alone, and record the result as the "CO standalone measurement value". Use the H_2 sensor to measure the H_2 standard gas alone, and record the result as the " H_2 measurement value". Then, use the CO sensor to measure the mixed standard gas of CO and H_2 , and record the result as the "CO sensor measurement value for mixed gas". Measure three groups of concentrations, with 20 measurements taken for each concentration group. The experimental results are shown in Figure 1 below.

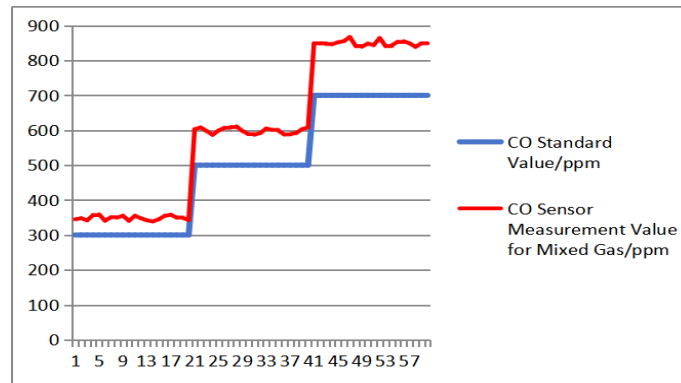


FIGURE 1 The Interference Effect of Hydrogen on Carbon Monoxide Sensors

It can be seen from the experimental results in the figure above that the carbon monoxide sensor shows an obvious deviation when measuring the mixed gas of carbon monoxide and hydrogen, with an error of 19.7%. The reason for this interference is that hydrogen has high reducibility, which will react with the electrodes in the electrochemical sensor and generate a signal similar to that from the reaction of carbon monoxide, leading to a deviation in the display part of the sensor.

To reduce the impact of such cross-interference on gas detection, this paper proposes a compensation and correction method for gas cross-interference, which uses the reading of the H_2 sensor to recalibrate the CO sensor.

Calibrate the sensor's indicated value before each measurement. At this point, the indicated value of the sensor when measuring the corresponding single gas is the gas concentration value, which can be used to infer the sensor's indicated value when measuring the mixed gas.

$CO(Ture)$ refers to the actual concentration of carbon monoxide gas, $CO(Measure)$ refers to the value measured by the carbon monoxide sensor for the mixed gas, and $H_2(Measure)$ refers to the value measured by the hydrogen sensor.

$$CO(Ture) = A \times CO(Measure) + B \times H_2(Measure) + C \quad (1)$$

Based on the linear regression fitting of the experimental data, it is obtained that:

$$CO(Ture) = 0.567 \times CO(Measure) + 0.568 \times H_2(Measure) + 37.187 \quad (2)$$

Substitute the measured data into Formula (2) to obtain the CO measured value after applying the interference formula. Compare this value with the CO standard value; the data results are shown in Figure 2 below.

It can be seen from the experimental results in the figure above that after substituting the interference formula, the relative

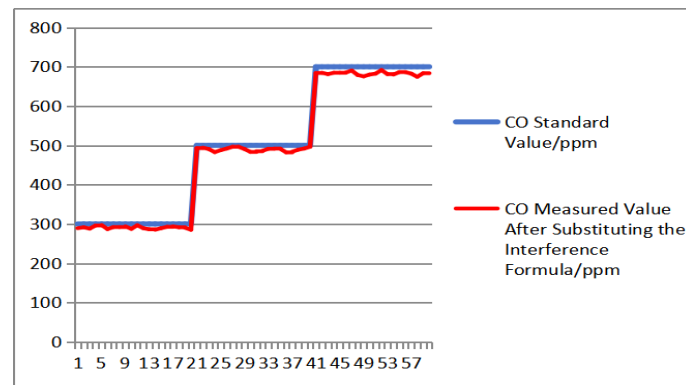


FIGURE 2 Comparison of CO Data After Reducing Interference

error of the CO sensor in measuring the mixed gas has decreased from 19.7% to 2.4%. From the detection results, the impact of cross-interference has been significantly reduced, which indicates that this method can effectively suppress the interference of the interfering gas (H_2) on the sensor of the measured gas (CO).

4.2 | Hydrogen Sulfide (H_2S) Gas Interference Experiment

In tunnel environments with sulfur-rich soil, hydrogen sulfide (H_2S) and sulfur dioxide (SO_2) coexist when blasting occurs. The hydrogen sulfide sensor selected in this paper is of the electrochemical type. Referring to the cross-interference gas table provided by the sensor manufacturer, it can be seen that SO_2 is the most significant interfering gas for this model of electrochemical hydrogen sulfide sensor, and it will significantly affect the accuracy of H_2S concentration detection. Based on the commonality of the scenario and the significance of interference, this paper finally determines to take hydrogen sulfide as the detection research object and SO_2 as the interference research object, so as to conduct a targeted analysis of their cross-interference mechanism and design a compensation scheme.

Before the experiment, calibrate the H_2S sensor and SO_2 sensor with standard gases respectively. Use the H_2S sensor to measure the H_2S standard gas alone, and record the result as the " H_2S standalone measurement value"; use the SO_2 sensor to measure the SO_2 standard gas alone, and record the result as the " SO_2 measurement value"; then use the H_2S sensor to measure the mixed standard gas of H_2S and SO_2 , and record the result as the " H_2S sensor measurement value for mixed gas". Measure three groups of concentrations, with 20 measurements taken for each concentration group. The experimental results are shown in Figure 3 below.

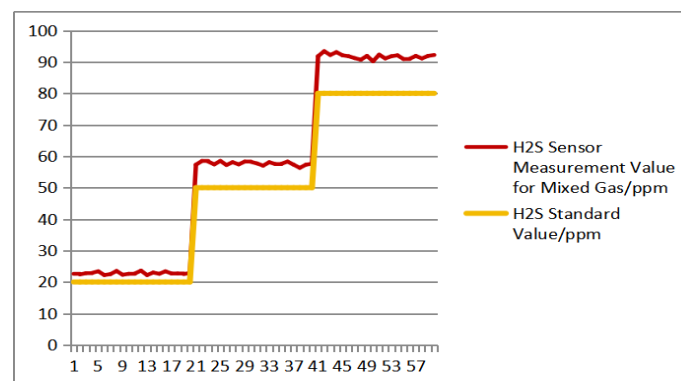


FIGURE 3 The Interference Effect of Sulfur Dioxide on Hydrogen Sulfide Sensors

It can be seen from the experimental results in the figure above that the hydrogen sulfide (H_2S) sensor shows an obvious deviation when measuring the mixed gas of hydrogen sulfide and sulfur dioxide (SO_2), with an error of 14.80%. The reason for

this interference is that sulfur dioxide and hydrogen sulfide have similar chemical properties; under certain conditions, sulfur dioxide will undergo a redox reaction on the sensor electrode surface and compete with hydrogen sulfide, thereby affecting the sensor's accurate measurement of hydrogen sulfide.

This research proposes a compensation and correction method for gas cross-interference, which uses the reading of the SO_2 sensor to recalibrate the H_2S sensor.

Calibrate the sensor's indicated value before each measurement. At this point, the indicated value of the sensor when measuring the corresponding single gas is the gas concentration value, which can be used to infer the sensor's indicated value when measuring the mixed gas.

$H_2S(Ture)$ refers to the actual concentration of hydrogen sulfide gas, $H_2S(Measure)$ refers to the value measured by the hydrogen sulfide sensor for the mixed gas, and $SO_2(Measure)$ refers to the value measured by the sulfur dioxide sensor.

$$H_2S(Ture) = D \times H_2S(Measure) + E \times SO_2(Measure) + F \quad (3)$$

Based on the linear regression fitting of the experimental data, it is obtained that:

$$H_2S(Ture) = 0.976 \times H_2S(Measure) - 0.173 \times SO_2(Measure) + 0.124 \quad (4)$$

Substitute the measured data into Formula (4) to obtain the H_2S measured value after applying the interference formula. Compare this value with the H_2S standard value; the data results are shown in Figure 4 below.

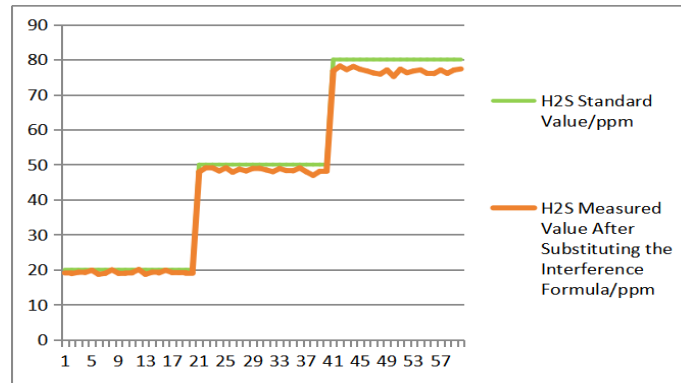


FIGURE 4 Comparison of H_2S Data After Reducing Interference

It can be seen from the experimental results in the figure above that after substituting the interference formula, the relative error of the H_2S sensor in measuring the mixed gas is reduced to 3.76%, which indicates that this method effectively reduces the interference effect of SO_2 on the H_2S sensor.

5 | SUMMARY OF THIS PAPER

This paper systematically expounds the core principle of cross-interference in gas sensors and introduces the causes of cross-interference in sensors based on electrochemical principles. Subsequently, to address the above interference issue, targeted physical verification experiments were designed and conducted. The degree of influence of interfering gases on the target sensor was analyzed using the control variable method, and quantitative analysis was realized.

Based on the interaction law between the aforementioned measured gases and their corresponding interfering gases, this paper further proposes an effective compensation and correction algorithm. It has been verified that this algorithm can significantly reduce the impact of cross-interference on detection results, providing a practical solution for improving the detection accuracy of gas sensors in complex environments.

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Bowen Li is currently pursuing a Master's degree at the School of Artificial Intelligence and Automation, Wuhan University of Science and Technology (WUST). He holds the title of Engineer, and his main research direction is gas detection.