ABSTRACT: Addressing the issue of suffocation and casualties caused by a large amount of poisonous CO gas generated after a gas explosion, research involving an experimental system for the removal of CO using a Cu−Mn elimination agent was studied. The influence of O₂ concentration, temperature, and CO concentration on the elimination performance of the agent after a gas explosion was studied. The quantitative relationship between the amount of CO eliminated, the elimination rate, the O₂ concentration, and temperature was analyzed. Further analysis was completed regarding the influence of O₂ concentration, temperature, and CO concentration on the thermal effect in the elimination process. The results showed that the elimination agent had a rapid effect on the removal of CO. When the ratio of CO concentration to O₂ concentration was closer to the stoichiometric ratio, the elimination performance of the agent after a gas explosion was studied. The quantitative relationship between the amount of CO eliminated, the elimination rate, the O₂ concentration, and temperature was analyzed. Further analysis was completed regarding the influence of O₂ concentration, temperature, and CO concentration on the thermal effect in the elimination process. The results showed that the elimination agent had a rapid effect on the removal of CO. When the ratio of CO concentration to O₂ concentration was closer to the stoichiometric ratio, the elimination and reaction were more complete, the time to complete elimination was shorter, and the peak temperature was higher. As the temperature increased, the time to reach the elimination limit became longer, the elimination rate decreased, the reaction was slower, and the peak temperature was lower. As the concentration increased, it was observed that the higher the peak temperature, the longer it took to reach the peak time. The results of the study provide a theoretical support for the catalytic oxidation of CO using the Cu−Mn eliminator after a coal mine gas explosion.

1. INTRODUCTION

Accidents due to coal mine gas explosions frequently occur because of the harsh production environment, which seriously threatens the safety of coal mine production. After a gas explosion, a large amount of poisonous CO gas is generated, with the maximum concentration reaching about 7−8% of air, which far exceeds the minimum concentration of 0.0024% allowed in a normal work environment. In gas explosion accidents, about 70−80% of underground personnel are suffocated due to excessive CO concentrations. After a gas explosion, the rapid elimination of the generated CO can quickly reduce the amount of time emergency responders need to wait, which is of great significance for post-disaster rescue in coal mines.

The commonly used CO elimination methods mainly include a cryogenic process, COSORB, a pressure swing adsorption, catalytic oxidation, and porous media adsorption. The cryogenic process, COSORB, and pressure swing adsorption methods require a high-pressure environment and specialized equipment to complete. Also, the porous media adsorption method takes a long time and the gas can too easily desorb in a high-temperature environment. Therefore, considering the special environment after a gas explosion in a coal mine, catalytic oxidation was selected as the best method to study for this purpose. The catalytic oxidation method for CO elimination is convenient, fast, economical, and environmentally friendly.

In recent years, there has been much research on the catalytic oxidation of CO with solid catalysts. Research has mostly been focused on the development, characterization, and simple performance comparison of different catalysts. However, there is little research on the influence of environmental factors on catalytic performance. When conducting catalytic oxidation experiments, most researchers consider low-temperature catalytic oxidation without considering the mine temperature after the gas explosion, the gas concentration, and other severe post-disaster conditions. The characterization index is usually simply based on the CO conversion rate, but there are certain limitations with using a single conversion rate and the performance comparison cannot fully reflect the CO elimination effect generated by a gas explosion. The actual coal mine gas explosion environment is more complicated, the gas composition and CO concentration at different locations are not the same, and the mine is in a high-temperature state.

After a coal mine gas explosion, there is a large amount of CO present, and ventilation equipment can be seriously damaged.
There could be no external power supply for a short time, and there are harsh conditions that require CO elimination. Considering economic factors, nonprecious metal catalysts, such as Cu-supported catalysts, were used as elimination agents for the experiment. Cu\(^{2+}\) is selective for CO and forms a complex with CO molecules. The addition of Mn improves the catalytic performance\(^{15}\) because it increases the surface oxygen vacancies in the elimination agent.

Based on this, to meet the needs of safe production in coal mines, the environment after a mine gas explosion must be considered. An independently developed CO removal experimental system and a synthesized Cu–Mn elimination agent can be used to more effectively study the different O\(_2\) concentrations and different temperatures after the gas explosion. The influence of different CO concentrations on the elimination performance and the analysis of the thermal effect during the elimination process are also important parameters that must be considered.

A new characterization of the elimination agent was proposed, a calculation method for the removed CO volume and elimination rate was established, the quantitative relationship between the removal volume ratio of the concentrated sulfuric acid to MnSO\(_4\) in the removal process are also important parameters that must be considered.

The specific surface areas of the samples were measured by nitrogen adsorption–desorption at 77 K on an ASAP2020 (Micromeritics Instruments Ltd., Shanghai, China) instrument. Specific surface areas were calculated using the Brunauer–Emmett–Teller (BET) method and were found to be 172.7514 m\(^2\)/g.

### 2.2. Experimental System

The CO elimination experiment was carried out with an independently built experimental system. The experimental system was divided into five parts as shown in Figure 2: (1) gas distribution system \([1, 2]\); (2) elimination system \([8, 9]\); (3) temperature and pressure acquisition system \([4, 5, 7, 14]\); (4) gas analysis system \([12, 13, 14]\); and (5) exhaust system \([3, 6]\). After the experiment, the exhaust gas was discharged into the atmosphere, and the tank was evacuated to reduce the carbon monoxide residue. The experimental platform diagram is shown in Figure 2.

The pressure gauge (Yashuo Machinery Technology Company Limited, Suzhou, China) used in the experimental platform has a range of −0.1000 to 1.1013 MPa and an accuracy of 0.05%. The temperature sensor contains a Pt (100) (Taizhou Shanghai Instrument Company Limited, China) thermocouple, with a range of −50 to 200 °C, and an accuracy of 0.1% FS. The pressure transmitter (Beijing Chengchuang Tiansheng Automation Technology Company Limited, China) has a range of 0–2,500 MPa, an accuracy of 0.5% FS, and an 18-channel paperless recorder (Hangzhou Meikong Automation Technology Company Limited, China), to monitor the temperature and pressure. The gas analysis (ShenZhen Sennic Technology Company Limited, China) was carried out by using a gas analyzer, which was used with the condenser. The condenser (ShenZhen Sennic Technology Co., Ltd.) the gas to 5 ± 1 °C and dries it until there is no damage to the sensor. At the same time, the gas was extracted from the elimination tank at a flow rate of 200 mL/min and sent to the gas analyzer. After the analysis was completed, the gas was returned to the test chamber. The gas analyzer included an infrared CO sensor, range 0–10%, accuracy 2% FS; infrared CO\(_2\) sensor, range 0–20%, accuracy 2% FS; and electrochemical O\(_2\) sensor, range 0–25%, accuracy 3% FS. The resolution of each gas sensor is 0.01%, the error is ±0.1%, and the response time is 5 s.

### 2.3. Experimental Design and Product

The experiment used pure CO (99.999%), O\(_2\) (99.999%), and N\(_2\) (99.999%). A mixed gas of a certain concentration and pressure was prepared in the plenum chamber. After the elimination agent was placed in the reaction chamber, the elimination system was pumped under vacuum and then the mixed gas was introduced into the test chamber with an absolute pressure of 0.1013 MPa for the experiment. A gas analyzer was used to monitor and record changes in CO concentration, CO\(_2\) concentration, and O\(_2\) concentration during the experiment and explore the effects of O\(_2\) concentration, gas explosion temperature, and CO concentration on elimination. The influence on the elimination agent’s performance and the thermal effect were also analyzed. The experiment scheme is shown in Table 1, and the drying and the experimental processes are shown in Figures 3 and 4, respectively.

If the concentration of the experimental mixed gas is the same, the gas distribution process can be omitted, and the experiment can be carried out directly.

### 2.4. Calculations of Experimental Data

The experimental results use the elimination volume and elimination rate to reflect the performance of the elimination agent. The...

![Figure 1. Cu–Mn elimination agent and elimination schematic diagram of the catalysis of CO to CO\(_2\).](image-url)
elimination volume refers to the volume of CO removed per unit mass of the elimination agent at a certain temperature and concentration when the reaction is performed on the solid−gas interface. The size of the elimination volume will directly reflect the utilization rate of the elimination agent. The larger the elimination volume, the higher the utilization rate of the agent.

The instantaneous elimination rate refers to the amount of CO removal per unit, and the size of the instantaneous elimination rate will intuitively reflect the removal rate of CO per unit mass of the elimination agent. The average elimination rate is the volume of CO eliminated from the beginning of the experiment to the end of the experiment, and the formula for this is

$$S = \frac{c'' - c' V}{m}$$  \hspace{1cm} (1)

where $S$ is the amount of CO removed, cm$^3$·g$^{-1}$; $c''$ is the CO gas concentration at time $t_2$, %; $c'$ is the CO gas concentration at time $t_1$, %; $V$ is the volume of the elimination system, cm$^3$; and $m$ is the mass of the elimination agent, g.

The formula of the total elimination volume is

$$S_t = \frac{c_t - c_0 V}{m}$$  \hspace{1cm} (2)

where $S_t$ is the total elimination volume, cm$^3$·g$^{-1}$; $c_t$ is the CO gas concentration at final time, %; and $c_0$ is the CO gas concentration at the initial time, %.

The instantaneous elimination rate formula is

$$v = \frac{dS}{dt}$$  \hspace{1cm} (3)

where $v$ is the elimination rate, cm$^3$·g$^{-1}$·s$^{-1}$, and $t$ is the time, s.

Analysis of the thermal effect of the elimination process, expressed by the temperature difference from the initial state:

$$\Delta T = T_t - T_0$$  \hspace{1cm} (4)

where $T_t$ is the temperature at time $t$ and $T_0$ is the temperature at the initial time.

Table 1. Experiment Scheme

| experiment no. | CO concentration (%) | O$_2$ concentration (%) | elimination agent amount (g) | temperatures (°C) |
|---------------|----------------------|-------------------------|----------------------------|------------------|
| 1             | 1                    | 19.80                   | 15                         | 0                |
| 2             | 3                    | 19.40                   | 15                         | 0                |
| 3             | 5                    | 19.00                   | 15                         | 0                |
| 4             | 7                    | 18.60                   | 15                         | 0                |
| 5             | 7                    | 1.00                    | 15                         | 0                |
| 6             | 7                    | 5.00                    | 15                         | 0                |
| 7             | 7                    | 10.00                   | 15                         | 0                |
| 8             | 7                    | 15.00                   | 15                         | 0                |
| 9             | 7                    | 18.60                   | 30                         | 0                |
| 10            | 7                    | 18.60                   | 30                         | 100              |
| 11            | 7                    | 18.60                   | 30                         | 200              |
| 12            | 7                    | 18.60                   | 30                         | 300              |

Figure 2. Schematic diagram of the experimental system. 1, pressure gauge; 2, plenum chamber; 3, valve; 4, pressure sensor; 5, temperature sensor; 6, vacuum pump; 7, data recorder; 8, test chamber; 9, reaction chamber; 10, constant temperature water box; 11, temperature controller; 12, condenser; 13, gas analyzer; and 14, computer.

Figure 3. The drying process.
The temperature change rate is

\[ \nu_T = \frac{dT}{dt} \]  

(5)

3. RESULTS AND DISCUSSION

3.1. Blank Experiment. The empty elimination system was evacuated and filled with 0.1013 MPa mixed gas, where the CO concentration was 7% and the O2 concentration was 18.6%. The temperature of the chamber was controlled at 25 °C. Initially, the gas activity was the highest. Under the experimental conditions, there were no changes in the concentration of each gas and a temperature increase was observed. Therefore, the reaction activity of the chamber body and the temperature sensor material used and the spontaneous reaction of CO and O2 can be ignored under the experimental conditions.

3.2. Effect of O2 Concentration. To study the influence of O2 concentration on the CO removal performance under the condition of different O2 concentrations, the nos. 4, 5, 6, 7, and 8 experimental mixed test gases were injected into the experimental system. The change in CO concentration was measured using the analyzer as shown in Figure 5.

Since the experiment was carried out in winter, the ambient temperature was about −15 °C and the gas temperature was 0 °C when the mixed gas entered the gas analyzer. In the experimental design, CO concentration was calculated under the standard state; hence, the test concentrations were different from the designed concentrations. However, the difference does not affect the exploration that affects the elimination performance.

It can be seen from Figure 5 that when the O2 concentrations were 6.02%, 9.84%, 15.08%, and 18.77%, the elimination agent completely removed CO. The complete elimination times were 1586, 1733, 1883, and 2125 s, when the O2 concentration was 1.53%. When the elimination agent dropped the CO to a concentration of 0.77% in 753 s, the removal ceased. There were two obvious inflection points in the change of CO concentration. The first inflection point appeared in 17 s, and the CO concentration decreased. The second inflection points were 1.12%, 0.37%, 0.52%, 1.29%, and 1.64%. When the O2 concentration was 6.02%, the CO concentration was at least
0.37%, and when the O₂ concentrations were 9.84%, 15.08%, and 18.77%, the CO concentrations increased to 0.52%, 1.29%, and 1.64%. When the O₂ concentrations were 1.53%, the O₂ concentration fell below 15.08%, the concentration was 1.12%. It is known that the CO removal process using this elimination agent was chemical adsorption, followed by catalytic oxidation. The catalytic oxidation reaction is as follows:

\[
2\text{CO} + \text{O}_2 \xrightarrow{\text{elimination agent}} 2\text{CO}_2
\]  

(6)

Since the experimental system is a closed system, the elimination process is regarded as a constant volume process, 
\[
\frac{\Delta c_{\text{CO}}}{\Delta c_{\text{O}_2}} = \frac{\frac{c_{\text{CO}}}{n_{\text{CO}}}}{\frac{c_{\text{O}_2}}{n_{\text{O}_2}}} = \frac{2}{1} = 2,
\]

where \(c\) is the gas concentration, \(n\) is the amount of gaseous substance, and \(\eta\) is the stoichiometric number.

The CO concentration was 7% after the CO elimination process was complete. The CO concentration of the variation was 
\[
\Delta c_{\text{CO}} = 7%,
\]

and the required O₂ concentration was 
\[
\Delta c_{\text{O}_2} = \frac{\Delta c_{\text{CO}}}{2} = \frac{7}{2} = 3.5%.\]

\[
\Delta c_{\text{CO}} = \frac{c_{\text{CO}}}{n_{\text{CO}}} = \frac{2}{}\text{when the catalytic oxidation reaction was the fastest, and the closer the ratio of CO to O}_2\text{concentration is to 2, the more complete the reaction. This explains the concentration difference of each concentration at the inflection point.}

According to formula 1, the cumulative amount of removal in each working condition of the elimination process was calculated, as shown in Figure 6.

It can be seen from formula (2) that the final elimination volume was only related to the initial and final CO concentrations and the quality of the elimination agent. The results of Figures 5 and 6 show that when the O₂ concentrations were 6.02%, 9.84%, 15.08%, and 18.77%, CO was fully eliminated. The final elimination volume was 10.6017 cm³·g⁻¹. When the O₂ concentration was 1.53% and because the O₂ concentration was lower than 3.5%, the CO did not react completely, and the final elimination volume of 9.1878 cm³·g⁻¹ did not reach the complete elimination volume.

According to formula (3), the instantaneous elimination rate can be obtained by a first-order derivation of the elimination volume, as shown in Figure 7. The peak elimination rate and the required time change with the quality of the elimination volume are shown in Figure 8.

It can be seen from Figures 7 and 8 that the O₂ concentration had a small effect on the instantaneous elimination rate, but it can also be seen that when the O₂ concentration was 6.02%, the peak instantaneous elimination rate was 0.76 cm³·g⁻¹·s⁻¹. When the O₂ concentration was 18.77%, the peak elimination rate was the lowest at 0.69 cm³·g⁻¹·s⁻¹, and the time required to reach the peak was the longest, 27.85 s. This was because when the O₂ concentration was 6.02%, the \(\frac{\Delta c_{\text{CO}}}{\Delta c_{\text{O}_2}}\) was closest to 2, meaning the chemical reaction rate was the fastest. Because the elimination process is a dual process of chemical adsorption and catalytic oxidation, when the chemical reaction rate increased, the corresponding elimination rate also increased. When the O₂ concentration was 18.77%, the O₂ concentration was the maximum O₂ concentration value for the working conditions. The corresponding CO molecules around the elimination agent were relatively small, the elimination rate slowed down, and the
The time to reach the peak instantaneous elimination rate changed slowly.

The temperature change during the elimination process was reflected in the elimination progress to a certain extent. Since the elimination experimental system is not an adiabatic system, as the elimination rate decreased, the external environment temperature had an increasing influence on the temperature change within the reaction chamber, and the temperature change reached its peak. Later, it was mainly the environmental temperature that played a leading role. Therefore, in the experiment, we only study the temperature change from the beginning of the elimination to the peak temperature. The temperature change during the elimination process is shown in Figure 10, and the temperature change rate is shown in Figure 11.

It can be seen from Figure 9 that the different O₂ concentrations all reach the temperature peak at 335 s, indicating that the O₂ concentration did not affect the elimination progress because of the relationship between the heat release and temperature:

$$q = \int_{1}^{2} c_{p} \, dT$$

In the experiment, the elimination process is a constant volume process; hence, $c_{p}$ is the same and the temperature reaches a peak value, i.e., the heat release reaches a peak value, and the reaction progress remains the same. When the O₂ concentrations were 1.53%, 6.02%, 9.84%, 15.08%, and 18.77%, the temperature peaks were 18.51, 25.69, 22.64, 19.81, and 15.08%.
17.03 °C, respectively, and \( \Delta T_{O_2=6.02\%} > \Delta T_{O_2=9.84\%} > \Delta T_{O_2=15.08\%} > \Delta T_{O_2=18.77\%} > \Delta T_{O_2=9.84\%} \). This was because the rate of change in the temperature was closer to the stoichiometric ratio, so the more violent the reaction and the higher the temperature, due to more heat released.

It can be seen from Figure 10 that when the \( O_2 \) concentrations were 1.53%, 6.02%, and 9.84%, the rate of change for the temperature, \( d\Delta T/dT \), showed a trend of first increasing and then decreasing, creating a peak at 51 s. The peaks of \( d\Delta T/dT \) were 0.1127, 0.1460, and 0.1239 °C·s\(^{-1}\), respectively. At this time, the elimination reaction was the most intense. According to Sun et al. (in press), this is because when the mixed gas entered the experimental system, the elimination agent chemically adsorbed CO molecules first, and then the molecules underwent catalytic oxidation. During the chemical adsorption process, the CO molecules attached to the pores of the elimination agent and heat accumulated, and then they underwent a catalytic oxidation reaction causing the temperature rate change to reach a peak. When the \( O_2 \) concentrations were 15.08% and 18.77%, the rate of change in the temperature peaked at 1 s and then decreased with the increase of time. The peaks were 0.1437 and 0.1167 °C·s\(^{-1}\), respectively. When there were too many \( O_2 \) molecules, the relative CO molecules around the elimination agent decreased, and the catalytic oxidation was carried out at the same time as chemical adsorption; hence, the reaction rate was the fastest at the initial time. According to the peak temperature change, when the \( O_2 \) concentration was 6.02%, the peak value was the highest and the elimination reaction was the most intense.

### 3.3. Effect of Temperature

To study the influence of the temperature after a gas explosion on the performance of the elimination agent, the elimination agent was sealed and placed in a dry box. Due to the mine temperature and duration of temperature after the gas explosion, the elimination agent was heated to 0, 100, 200, and 300 °C, and the drying time was 5 min. The elimination experiments at different temperatures were carried out for the mixed gases in experiments nos. 9, 10, 11, and 12 (Table 1). Figure 12 shows the CO concentration change measured using the gas analyzer.

As shown in Figure 11, the CO concentration curve still had two inflection points. The first inflection point for the CO concentration appeared at different times and different temperatures, and its appearance time increased as the temperature rose. The temperatures were 0, 100, 200, and 300 °C, and the time was 14, 16, 19, and 21 s, respectively. This was because a high temperature will deactivate part of the active substances on the surface of the scavenger, and the higher the temperature, the more the inactive substances, and the lower the scavenging activity. After the surface of the scavenger was deactivated, the CO molecules needed to enter the inner layer of the scavenger to activate the scavenger. The higher the temperature, the more time it took, and the time for the inflection point of the CO concentration was delayed.

Subsequently, a second inflection point appeared in the CO concentration plot. As the temperature increased, the concentration at the inflection points increased, and the concentrations were 0.29%, 0.34%, 0.48%, and 0.71%. This was because higher the temperature, the greater the extent of deactivation for the active substance on the scavenger, resulting in a decrease in the CO elimination effect and an increase in the concentration of the second inflection point of CO. The temperature also affected the complete elimination time. As the temperature increased, the complete elimination time also increased. When the temperature was 300 °C, the elimination agent was not fully eliminated. This was due to the excessive inactivation of the active substance on the scavenger, resulting in an excessive amount of CO molecules that could not be fully eliminated. When the temperatures were 0, 100, 200, and 300 °C, the complete elimination times were 487, 571, 675, and 740 s, respectively.

Considering the characteristics of the elimination agent and the prevention and control of CO gas generated by a gas explosion, the explosive point should be estimated first, and the elimination agent should be doubled in the high-temperature area of the gas explosion near the explosive point to achieve the full effect of CO elimination.

The cumulative amount of elimination at different temperatures was calculated by formula (1), and the results of the calculation are shown in Figure 12.

It can be seen from Figure 13 that there are still two inflection points in the plot for the change of the elimination amount, and the first inflection point appeared at the same time as the one in the CO concentration curve. As the temperature increased, the extent of elimination based on the second inflection point decreased sequentially. When the temperatures were 0, 100, 200, and 300 °C, the elimination amounts based on the second inflection point were 4.9737, 4.9705, 4.8137, and 4.5966 cm\(^3\)·g\(^{-1}\). When the temperature was 300 °C, the elimination agent could not fully remove CO at 5.0162 cm\(^3\)·g\(^{-1}\), and the final elimination amount was lower than other temperature elimination amounts. When the temperatures were 0, 100, and 200 °C, the final elimination amount was 5.1403 cm\(^3\)·g\(^{-1}\) of all conditions. In the middle period of elimination, the low-temperature entire curve was higher than the high-temperature curve. This was also caused by the deactivation of the active substance on the elimination agent as a result of high temperature. The higher the temperature, the more the deactivation of the active components and the worse the eliminating effect.

The instantaneous elimination rate in the elimination process was calculated according to formula (3), as shown in Figure 13.
It can be seen from Figure 13 that high temperature has a greater impact on the elimination rate. The higher the temperature, the smaller the elimination rate, and the more time it takes to reach the same elimination rate. When the temperatures were 0 and 100 °C, the elimination rate curves were similar, but when the temperature was 100 °C the curve was shifted backward by about 1 s relative to the curve at 0 °C. The time required to eliminate the peak rate and reach the peak is shown in Figure 15.

It can be seen from Figure 14 that the peak elimination rates at temperatures of 0, 100, 200, and 300 °C were 0.4611, 0.4504, 0.4009, and 0.3942 cm³·g⁻¹·s⁻¹, and the time points required to reach those peaks were 24, 25, 28, and 31 s, respectively. When the temperature was 100 °C, there was little difference between the CO concentration and elimination amount, the elimination rate and the peak elimination rate, and the temperature at 0 °C. This indicated that 100 °C was not enough to deactivate the elimination agent in a large area. The temperature at 300 °C had a greater impact on the performance of the elimination agent.

This indicated that the high temperature caused the deactivation of the elimination agent, i.e., the higher the temperature, the more severe the deactivation.

The elimination process at each temperature change is shown in Figure 15, and the temperature rate change is shown in Figure 16.

It can be seen from Figure 15 that different temperatures all reach a peak temperature at 592 s. From Section 3.2, the relationship between temperature, heat release, and reaction

Figure 13. Change in the CO elimination rate over time when the temperatures were 0, 100, 200, and 300 °C.

Figure 14. Peak elimination rate and the change in required time related to the quality of the elimination volume when the temperature was 0, 100, 200, and 300 °C.

Figure 15. Change in temperature over time when the temperature was 0, 100, 200, and 300 °C.

Figure 16. Rate change in temperature over time when the temperatures were 0, 100, 200, and 300 °C.
process was reported, as shown in Figures 17 and 18.

The rate change of the temperature rate during the elimination was repeated here. Only the analysis of the temperature and the elimination rate during the process, will not have previously analyzed the CO concentration, the amount of the elimination system for each experiment. Since Sun (in press) 10.89, 9.01, 7.21 °C, and $\Delta T_{T=0} > \Delta T_{T=100} > \Delta T_{T=200} > \Delta T_{T=300}$ °C, respectively. This was because the higher the temperature, the more the active material was deactivated, and the reaction proceeds. When the reaction was incomplete, the temperature peak was low.

The rate change curve for the temperature was processed by noise reduction, as shown in Figure 16. When the temperature was 0 °C, the rate curve showed a trend that first increased and then decreased and gradually became stable, and the peak was 0.0584 °C-s⁻¹ at 42 s. At this time point, the elimination reaction was the most intense. At temperatures of 100, 200, and 300 °C, the rate curve showed a trend of first decreasing and then increasing, with peaks at 0.0334, 0.0261, and 0.0232 °C-s⁻¹ corresponding to 194, 205, and 157 s, respectively. The change in the temperature was different. Therefore, the high temperature deactivated the active substance on the surface of the elimination agent. When the mixed gas was introduced, the elimination agent was not active initially, and the temperature changed slowly. When the CO molecules entered the inner layer of the elimination agent, a peak appeared at this time. The reaction was violent, and it took 155, 159, and 121 s for the reaction progress is the same. When the reaction was incomplete, the temperature peak was low.

### 3.4. Effect of CO Concentration

To study the effect of CO concentration on the performance of the elimination agent, under the conditions of different O₂ concentrations, mixed gases from experiments nos. 1, 2, 3, and 4 (Table 1) were injected into the elimination system for each experiment. Since Sun (in press) has previously analyzed the CO concentration, the amount of elimination, and the elimination rate during the process, will not be repeated here. Only the analysis of the temperature and the rate change of the temperature rate during the elimination process was reported, as shown in Figures 17 and 18, respectively.

![Figure 17](https://doi.org/10.1021/acsomega.1c02019)

**Figure 17.** Temperature changes over time when the concentrations of CO were 1.29%, 3.13%, 5.16%, and 7.19%.

It was seen from Figure 17 that the higher the CO concentration, the higher the temperature. Unlike the above two conditions, the higher the CO concentration, the longer it took to reach the peak. This was because CO molecules were the main reactant in the elimination process. When the concentration of CO was higher, the more the CO molecules existed in the elimination system, the more heat accumulated; therefore the higher the temperature, the longer it took to reach the elimination limit. When the CO concentrations were 1.29%, 3.13%, 5.16%, and 7.19%, the temperature peaks were 2.445, 3.369, 5.740, and 6.065 °C, and the time points to reach the peak temperatures were 339, 485, 780, and 833 s, respectively.

As shown in Figure 18, when the CO concentrations were 1.29% and 3.13%, the temperature rate curve showed a downward trend. When the CO concentrations were 5.16% and 7.19%, the temperature rate curve first increased and then decreased, with peaks at 0.0208 and 0.0329 °C-s⁻¹ at 61 and 35 s, respectively. This was because the gas mixes for experiment nos. 1, 2, 3, and 4 were all O₂ sufficient. According to Sun et al. (in press), 15 g of the agent cannot completely remove more than 7% of the CO gas in the elimination system. This is due to the deactivation of the elimination agent. Eliminate the limitation of capacity, not caused by the lack of O₂. Therefore, when the CO concentrations were 1.29%, 3.13%, 5.16%, and 7.19%, the elimination agent reached a limit and the process stopped. When the CO concentrations were 1.29% and 3.13%, there were relatively few CO molecules in the elimination system, and the CO molecules were eliminated without entering the inner layer of the elimination agent. The reaction was also violent. The temperature increased rapidly at 1 s, peaks were seen at 0.0300 and 0.0402 °C-s⁻¹, and then the temperature increased slowly. When the CO concentrations were 5.16% and 7.19%, there were
relatively many CO molecules, and the CO molecules needed to enter the inner layer of the elimination agent to be eliminated. During this process, the temperature increased until the maximum reaction rate was reached, and the temperature reached a peak.

4. CONCLUSIONS

To solve the problem of suffocation and casualties caused by the generation of a large amount of poisonous CO gas after a coal mine gas explosion, a CO elimination experiment was carried out using the self-developed CO elimination experimental platform, and the following conclusions were drawn:

1. The influence of O₂ concentration on the elimination performance of CO in the process was studied. There are two turning points for the change of CO concentration and the change of elimination amount. The first inflection point occurred at the same time. Because the elimination process involved catalytic oxidation, when the ratio of the CO concentration to the O₂ concentration was close to the stoichiometric ratio, the elimination was more complete. The lower the CO concentration at the first inflection point, the shorter the complete elimination time, resulting in a more violent reaction, and a higher temperature peak.

2. The effect of temperature on the elimination performance after a gas explosion was studied. As the temperature increased, the deactivation of the elimination agent increased, and the time for the first inflection points of the CO concentration change and elimination curves increased. The second inflection point decreased when the elimination rate decreased, and the time to reach the elimination limit became longer, the reaction was slow, and the lower the temperature peak.

3. The analysis of the thermal effect on the concentration of CO generated by a gas explosion during the elimination process was also carried out. As the CO concentration increased, the higher the temperature peak, the higher the CO concentration, and the longer it took to reach a peak.

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Notes
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