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Research Article

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Study on Suppression of Explosion and Flame Propagation of (H_2-CO) Premixed Gas by Ultra-Fine Water Mist

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Abstract: In order to improve the suppression effect of ultra-fine water mist on the explosion of (H_2-CO) syngas, an experimental platform for premixed gas explosion was built, and the influence of water mist and carbon dioxide on the flame propagation behavior and overpressure peak value of premixed gas explosion in pipeline was studied, and the explosion suppression mechanism was discussed by using chemical kinetic software. The results showed that the explosion overpressure and maximum pressure rise rate of H_2-CO syngas decreased after adding CO_2/ ultra-fine water mist. When CO_2/ superfine water mist works together, it can better inhibit the flame instability in the initial stage of H_2-CO explosion, and the inhibition effect on flame propagation is better than that of a single inhibitor, which can effectively prevent the flame from accelerating or even detonating, indicating that when CO_2/superfine water mist works together, it can effectively reduce the explosion sensitivity and explosion intensity of premixed gas, and effectively inhibit the ignition of H_2-CO synthesis gas and the explosion chain reaction.

Keywords: Ultrafine water mist; Syngas explosion; inert gases; Flame velocity

1. Introduction

In recent years, the efficient and clean utilization of coal has gradually attracted the attention of countries all over the world. For China, where coal is the main energy source, the clean utilization of coal is particularly important under the development background of low-carbon cycle. At present, coal gasification synthesis gas is considered as a typical clean alternative energy source. The main components of synthesis gas are H_2 and CO, with a small amount of inert components such as CO_2 and N_2. With the increasing use of synthetic gas, its safety is particularly important. If the synthetic gas leaks, it will easily cause poisoning, fire or explosion, which will lead to heavy losses of property and heavy casualties. Therefore, in order to improve the safety of syngas in practical application, it is necessary to systematically study the suppression methods of syngas explosion.

Scholars at home and abroad have made fruitful work on the study of the mechanism and propagation characteristics of premixed gas explosion [1-5]. Chen Peng have shown that the methane/air premixed gas explosion will have a phenomenon of flame countercurrent and continuous acceleration due to the influence of obstructions[6]. Wen studied the combined effect of obstacles and water mist on methane-air explosion in semi-closed pipeline, and found that the inhibitory effect of water mist on gas explosion first weakened and then increased with the increase of the distance between obstacles and ignition and the number of obstacles [7]. In order to suppress the propagation effect of premixed gas explosion, water mist or water mist containing additives is widely used to prevent gas explosion because of its high heat absorption rate, cleanliness and environmental protection. Pei Bei et al. found that CO_2 can effectively make up for the shortcoming of enhanced explosion effect caused by insufficient superfine water mist by studying the synergistic effect of CO_2 and superfine water mist on methane/air premixed gas explosion [8-9]. Ji Hong et al. studied the characteristics of ultra-fine water mist with different fog flux to degrade and inhibit methane explosion by using semi-closed pipeline. The results showed that the degradation rate of methane was faster with the increase of fog flux. The explosion overpressure and average pressure rise rate in the pipeline all showed a downward trend [10].

To sum up, ultra-fine water mist has gradually become a positive alternative to suppress flammable gas explosion. However, there are few reports on the synergistic application of inert gas and ultra-fine water mist in the field of syngas explosion suppression, and the research on the synergistic explosion suppression mechanism of inert gas and ultra-fine water mist is relatively scarce. Based on the self-built explosion propagation and explosion suppression experimental system, this paper carried out experimental research on explosion suppression of syngas by CO_2 and ultrafine water mist, in order to obtain an ultrafine water mist explosion suppression agent with optimized water mist characteristics and the ability to destroy free radicals, and to provide prevention and control ideas for developing efficient explosion suppression technology of syngas.

2. Materials and Methods

In order to carry out the experiment of CO_2/ ultra-fine water mist suppressing (H_2-CO) premixed gas explosion, an experimental system for explosion propagation and suppression of premixed gas in pipeline was simulated and built, as shown in Figure 1. The system consists of premixed gas configuration unit, pipeline premixed gas explosion unit, explosion overpressure and flame information acquisition unit and ultra-fine water mist atomization unit. The pipeline premixed gas explosion unit consists of a plexiglass pipeline with a length of 500 mm and a cross section of 50×50 mm^2 and an ignition system. The left end of the pipeline is sealed with PVC film, which is used as the pressure relief port when the premixed gas explodes. The ignition system adopts the ignition electrode made of ceramic tungsten rod material and HE119 series high-energy igniter, the ignition distance is 5 mm, the discharge voltage is 6 KV, and the working frequency is 50 HZ. The water mist atomization system consists of an ultrasonic atomization device, a sealed resin water storage tank and a water mist guide pipe, in which the atomization rate of the piezoelectric ceramic atomization sheet is about 0.42 mL/min and the working frequency is 1700 kHz.

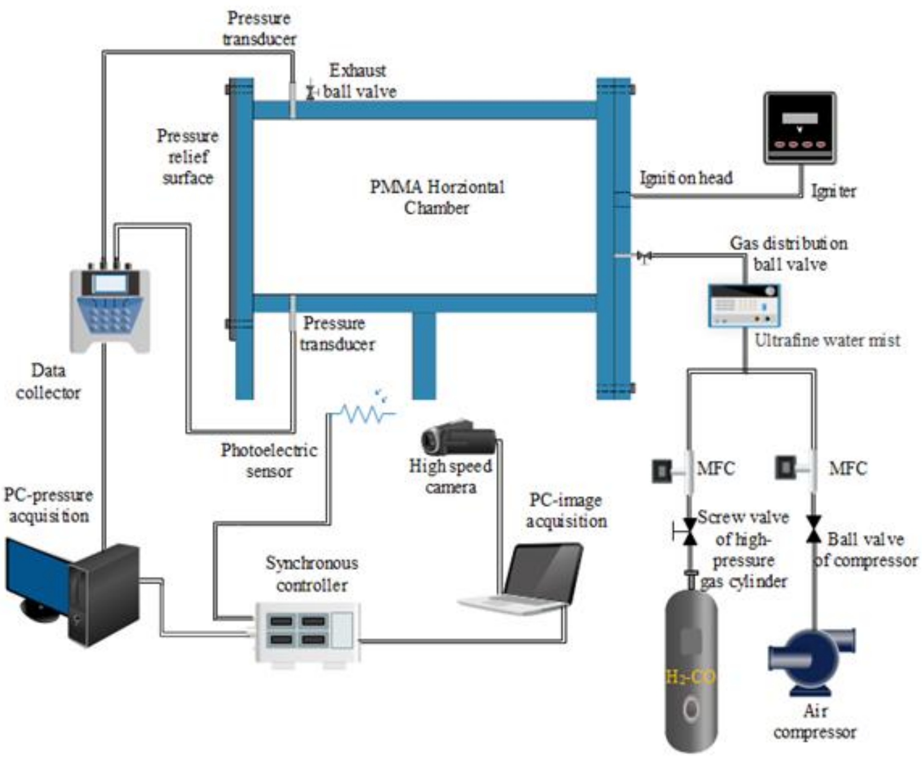


Figure 1: Experimental system of premixed gas explosion in pipeline

Setting the fog-passing time as 20s, 40s, 60s and 80s respectively, the corresponding concentrations of four kinds of water mist in the pipeline are calculated to be 78, 132, 189 and 247mL/m^3 respectively, and the volume fraction of CO_2 in the pipeline is 17.8% and 27.8% respectively. The main gas components of synthesis gas include: 50.9% H_2 and 47% CO, accompanied by a small amount of hydrocarbon gas. Before the experiment, the PVC film was attached to the end of the pipeline, then the inlet valve and outlet valve were opened at the same time, and LBPG with 4 times the volume of the pipeline was introduced into the pipeline, and the inflation time was set at 8 min to ensure the complete gas replacement in the pipeline. Keep the air inlet valve between the pipeline and the ultrasonic atomization device in an open state. After the ultrasonic atomization device is started, the water mist droplets generated in the water storage tank are brought into the explosion tube through the diversion pipe, and the ventilation time of the diversion pipe is controlled, and the corresponding water mist quantity is introduced according to different working conditions. After the premixed combustible gas and ultra-fine water mist are all introduced, close the air inlet valve and air outlet valve, start the igniter, and collect explosion pressure data at the same time.

3. Results & Discussion

Influence of CO_2/ ultrafine water mist on explosion pressure of syngas

Figure 2 shows the overpressure curves of two CO_2 volume fractions under different ultra-fine water mist flux conditions. As shown in the figure, after the premixed gas in the tube is ignited, the overpressure shows an increasing trend and quickly reaches the first peak, that is, the exhaust pressure, which is the second form of pressure oscillation. From the situation that the ultra-fine water mist suppresses the explosion pressure in the pipe, when there is no water mist in the pipe, the maximum explosion pressure corresponding to the two volume fractions of 17.8% and 27.8% is 57.6kPa and 53.5 kPa, respectively. It can be seen that the explosion pressure is not obviously affected with the increase of carbon dioxide. However, with the increase of water mist flux, the peak pressure gradually decreases and the maximum pressure rise rate decreases. Taking Figure 2(b) as an example, compared with the condition without water mist, the maximum explosion pressure of the four fog fluxes decreased by 9.9%, 21.1%, 31.7% and 40.9% respectively, and the arrival time of the maximum explosion pressure and the maximum pressure rise rate was prolonged. This is because with the increase of water mist concentration, the energy consumed by water mist endothermic evaporation in the reaction process increases, and the evaporated water vapor dilutes the surrounding oxygen concentration, further weakening the reaction intensity, resulting in the decrease of the maximum explosion pressure and the maximum pressure rise rate, and the arrival time of the pressure peak and the maximum pressure rise rate is prolonged.

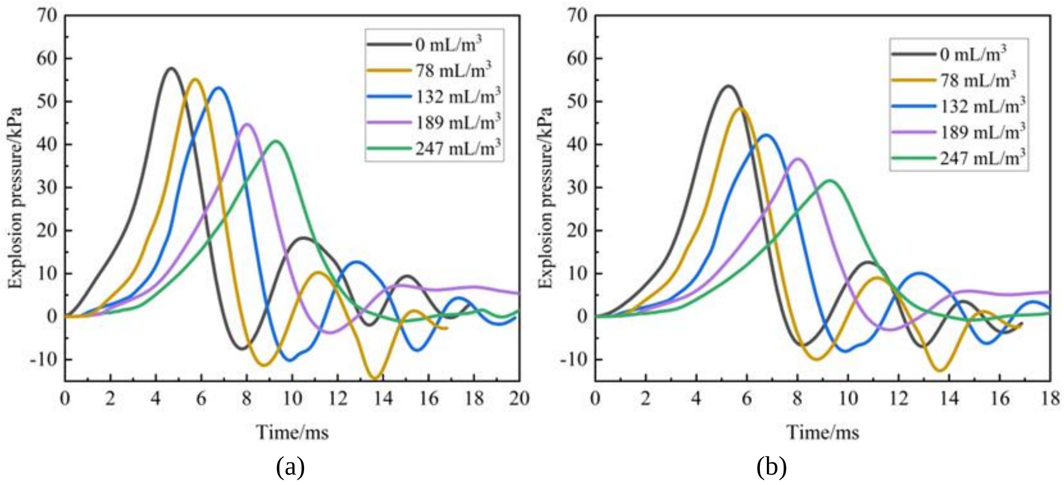


Figure 2: Explosion overpressure curve of syngas (H_2-CO) under different flux of CO_2/ultrafine water mist

In order to compare the synergistic explosion suppression effect of CO_2/ superfine water mist more intuitively, the overpressure peak value and corresponding peak time under corresponding working conditions are extracted, as shown in Table 1 and Table 2. From Table 1 and Table 2, it can be seen that, compared with the experimental group without ultra-fine water mist, when CO_2/ ultra-fine water mist system suppresses the explosion, the influence of the change of mist flux on the overpressure peak and the peak occurrence time of syngas explosion is obviously enhanced. When the fog flux is 247 mL/m^3, for example, the overpressure peaks corresponding to the two CO_2 volume fractions are 40.7 kPa and 31.6 kPa, respectively, which are 29.3% and 40.9% lower than those of the experimental group without fog. The peak arrival time of overpressure is 9.26 ms and 9.33 ms, respectively, which is 95.7% and 75.1% later than that of the experimental group without water mist. Compared with CO_2 alone, with the increase of water mist flux, the overpressure of syngas explosion decreases obviously. It can be concluded that with the increase of fog flux, the explosion suppression effect of CO_2/ water mist system shows an obvious enhancement trend.

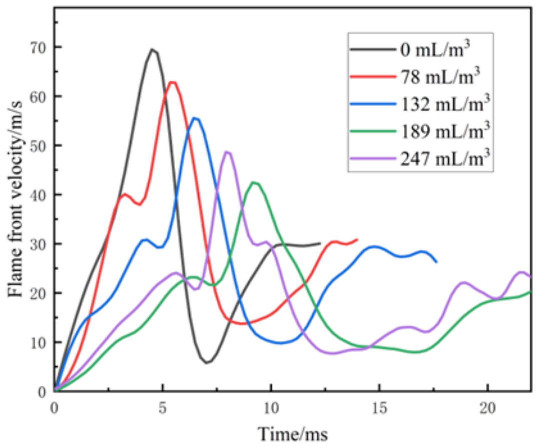
Table 1: Explosion pressure characteristics under different water mist amounts when CO_2 volume fraction is 17.8%

Fog flux /mL/m³	Explosive overpressure			Peak time characteristic		
	Maximum pressure /kPa	Descending size /kPa	Descending proportion /%	Peak time /ms	Extension /ms	Extended proportion /%
0	57.6	0	0	4.73	0	0
78	55.1	2.5	4.3	5.66	0.93	19.6
132	53.1	4.5	7.8	6.86	2.13	45.0
189	44.6	13.0	22.5	8.06	3.33	70.4
247	40.7	16.9	29.3	9.26	4.53	95.7

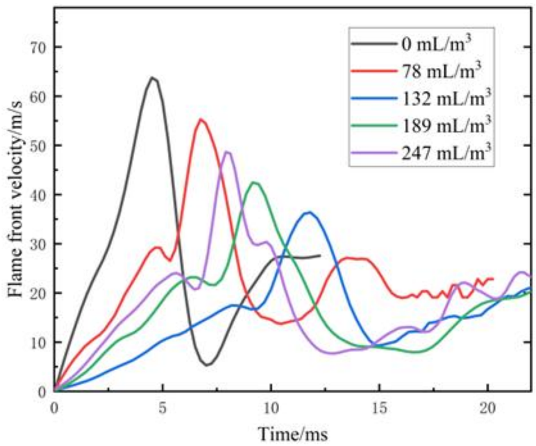
Table 2: Explosion pressure characteristics under different water mist amounts when CO_2 volume fraction is 27.8%

Fog flux /mL/m³	Explosive overpressure			Peak time characteristic		
	Maximum pressure /kPa	Descending size /kPa	Descending proportion /%	Peak time /ms	Extension /ms	Extended proportion /%
0	53.5	0	0	5.33	0	0
78	48.2	5.3	9.9	5.80	0.47	8.8
132	42.2	11.3	21.1	6.80	1.47	27.6
189	36.5	17.0	31.7	7.93	2.60	48.8
247	31.6	21.9	40.9	9.33	4	75.1

Effect of CO_2/ Ultrafine Water Mist on Flame Velocity of Syngas



(a)



(b)

Figure 3: Flame Velocity Curve of Synthetic Gas (H_2-CO) under Different Fluxes of CO_2/ Ultrafine Water Mist

Figure 3 shows the influence of the synergistic effect of ultra-fine water mist and different volume fractions of CO_2 on the propagation velocity of syngas flame front, revealing the variation law of the velocity of syngas flame front with the position of flame tip under different ultra-fine water mist concentrations. The flame front velocity of syngas with two volume fractions of CO_2 shows a trend of increasing greatly at first, then decreasing, and then increasing slightly under the action of ultrafine water mist with different atomization amounts. After ignition, the flame tip speed increases exponentially in the finger stage, because the flame surface area increases exponentially through the side wall during the transition from hemispherical to finger stage, and when the flame changes from hemispherical to finger stage, the flame tip speed increases again until the maximum pressure peak. As the flame skirt contacts the wall, the front area gradually decreases and the propagation speed decreases. When the "tulip" flame is formed, the speed of the flame tip increases again, and the speed trajectory oscillates obviously, and then the oscillation amplitude gradually weakens.

In order to compare the synergistic explosion suppression effect of CO_2/ superfine water mist more intuitively, the maximum flame speed and corresponding peak time under corresponding working conditions are extracted, as shown in Table 2 and Table 3. When 17.8% CO_2 participated in explosion suppression alone, the maximum flame speed was 69.5 m/s, and the maximum flame speed was 62.8 m/s, 55.5 m/s, 48.6 m/s and 42.4 m/s under the influence of water mist system with different fog flux, which decreased by 9.6%, 20.1% and 42.4 m/s respectively. With the increase of water mist quantity, the maximum speed appeared obviously delayed, and the maximum speed was 5.3 ms, 6.4 ms, 7.9 ms and 9.3 ms respectively under the influence of four kinds of water mist quantity. According to the above trends, it can be seen that with the increase of water mist, the suppression effect of CO_2/ ultrafine water mist on syngas explosion is gradually enhanced. The reason is that the cooling effect of water mist usually depends on the evaporation capacity of water mist, and the smaller particle size of ultrafine water mist means that the contact area between water mist and flame is significantly increased, thus improving the efficiency of heat transfer. The evaporation rate is significantly accelerated in unit time, thus absorbing more heat and reducing the flame temperature.

Table 3: Flame velocity characteristics under different water mist amounts when CO_2 volume fraction is 17.8%

Fog flux /mL/m^3	Flame velocity characteristics			Peak time characteristic		
	Maximum flame speed /m/s	Descending size / m/s	Descending proportion /%	Peak time /ms	Extension /ms	Extended proportion /%
0	69.5	0	0	4.5	0	0
78	62.8	6.7	9.6	5.3	0.8	17.7
132	55.5	14.0	20.1	6.4	1.9	42.2
189	48.6	20.9	30.1	7.9	3.4	75.5
247	42.4	27.1	38.9	9.3	4.8	106.7

Table 4: Flame velocity characteristics under different water mist amounts when CO_2 volume fraction is 27.8%

Fog flux /mL/m^3	Flame velocity characteristics			Peak time characteristic		
	Maximum flame speed /m/s	Descending size / m/s	Descending proportion /%	Peak time /ms	Extension /ms	Extended proportion /%
0	63.7	0	0	4.5	0	0
78	55.3	8.4	13.2	6.7	2.2	48.9
132	49.1	14.6	22.9	7.9	3.4	75.5
189	42.1	21.6	33.9	9.1	4.6	102.2
247	36.3	27.4	43.0	11.8	7.3	162.2

4. Conclusion

(1) Different concentrations of CO_2 have little influence on the explosion pressure, flame propagation velocity and flame structure of synthesis gas (H_2-CO). Comparing the explosion suppression effects of two different concentrations of CO_2, the explosion overpressure only decreased by 4.1 kPa and the maximum flame speed decreased by 8.3%.

(2) CO_2/ ultrafine water mist has an important influence on the explosion pressure and flame propagation speed of synthesis gas (H_2-CO). With the increase of fog flux, the explosion pressure and flame propagation speed

decrease, the pressure rise rate decreases, and the arrival time of the maximum explosion pressure and flame speed is delayed, especially when the CO_2 concentration is 27.8%, the explosion suppression effect is more significant.

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