

# Effect of Equivalent Ratio and Hydrocarbon Ratio on Explosive Characteristics of Synthetic Gas

Lin Hu <sup>a</sup>, Pinkun Guo <sup>b\*</sup>

Jiangsu Key Laboratory of Hazardous Chemicals Safety and Control, College of Safety Science and Engineering, Nanjing Tech University, Nanjing, 211816, China

<sup>a</sup> 18478320642@163.com, <sup>b</sup> guopinkun@163.com

**Abstract.** With the development of society, the importance of energy is increasing day by day, and more and more people realize the importance of energy for social development. Therefore, people began to explore energy utilization, energy exploitation, clean energy and other fields. Therefore, in order to use coal resources cleanly and efficiently and reduce the damage to the environment, the development of clean coal technology is particularly important. As a kind of clean energy, syngas has been paid more and more attention, so people pay more and more attention to the safety application of syngas. This paper explores its influence on syngas explosion by changing the equivalent ratio of syngas and the ratio of hydrogen and hydrogen. The results show that the maximum explosion pressure of syngas occurs near the equivalent ratio 1.2, the maximum explosion pressure rise rate reaches the maximum near the equivalent ratio 1.5, and the maximum explosion pressure time reaches the minimum near the equivalent ratio 1.5. The change of hydrocarbon ratio does not shift the equivalent ratio of the above result, but only changes its value. The prediction equations for predicting the maximum explosion pressure under different equivalent ratios are obtained

**Keywords:** Equivalent ratio; hydrocarbon ratio; Syngas; Explosion characteristics

## 1. Introduction

Many researches have been made on the explosion characteristics. Tran et al. [1] used ANSYSFluent to numerically study the explosion characteristics of syngas/air mixture in a three-dimensional cylindrical geometry model. The results show that the maximum explosion pressure occurs at the equivalent ratio of 1.2, and the explosion time is the shortest at the equivalent ratio of 1.6. The increase in H<sub>2</sub> content in the fuel mixture increases the maximum explosion pressure and significantly reduces the explosion time. Xie et al. [2] studied the influence of CO/H<sub>2</sub> ratio on explosion parameters. The results show that the normalized explosion pressure and the normalized adiabatic explosion pressure show different trends with the increase of CO/H<sub>2</sub> ratio. The normalized explosion pressure decreases with the increase of CO/H<sub>2</sub> ratio in syngas mixture, but the normalized adiabatic explosion pressure increases. At the same time, Xie[3] also conducted a study on the influence of equivalent ratio on explosion characteristics. The results show that the explosion pressure first increases and then decreases with the increase of equivalent ratio. As the combustible mixture becomes more concentrated, the maximum pressure rise rate continues to increase. Su et al. [4] quantitatively measured the explosion characteristics and radical spectral radiation intensity of syngas with different equivalent ratios and hydrogen components. The results showed that with the increase of equivalent ratios, the peak values of explosion pressure, pressure rise rate, OH\* spectral intensity and spectral intensity rise rate first increased and then decreased. The peak value decreases gradually. Wei et al. [5] studied the explosion characteristics of syngas/air mixtures with different equivalent ratios and different fuel compositions in a closed spherical vessel. The results show that the combustion duration decreases first and then increases slightly with the equivalent ratio, and the variation trend of the combustion duration with the equivalent ratio is closely related to the fuel composition. Liang et al. [6] studied the explosion limit of H<sub>2</sub>/CO/O<sub>2</sub> mixture. The results show that with the further addition of H<sub>2</sub>, the explosion limit evolves to the limit of pure H<sub>2</sub>, and when its percentage in the fuel exceeds 50%, the explosion limit is almost the same as that of pure H<sub>2</sub>. Yao et al. [7] studied the effect of hydrogen volume

fraction on flame propagation structure and overpressure wave. The results show that the overpressure growth rate and maximum overpressure increase with the increase of hydrogen volume fraction. In this paper, the effects of equivalent ratio and hydrocarbon ratio on the explosive characteristics of syngas are discussed, which provides theoretical basis for the safe use of syngas.

## 2. Experimental setup and data processing

### 2.1 Experimental setup

The experimental equipment in this paper mainly consists of 27L cylindrical explosive vessel, gas distribution system, ignition system, data acquisition system, synchronous control system, cleaning and waste gas treatment system. The experimental device is a movable window with high strength glass on both sides of the front and back, which can be used to record the flame speed and flame propagation characteristics. A pressure test port is provided on the device. Ignition and pressure sensor data acquisition are controlled by synchronous controller. Place the alcohol lamp in front of the output end of the gas duct, and use the method of burning to deal with the exhaust gas; Use a shield to block exhaust gases and prevent toxic gases from flowing into the air. Each experiment was repeated three times. The experimental device is shown in Fig.1

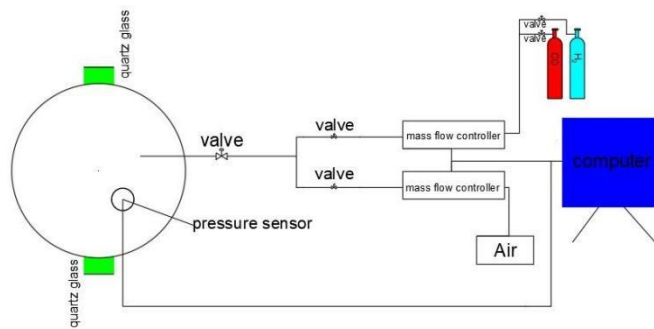


Fig. 1 Diagram of experimental device

### 2.2 Equivalent ratio and hydrocarbon ratio definition

This experiment mainly studies the explosion characteristics of synthetic gas/air in a closed container with equivalent ratio and hydrocarbon ratio. The equivalent ratio is calculated according to formula (1)[8]:

$$\Phi = \frac{F/A}{(F/A)_{stoic}} \quad (1)$$

Where,  $(F/A)$  is fuel to air volume ratio,  $(F/A)_{stoic}$  is stoichiometric fuel to air ratio. Set the equivalent ratio sizes to 0.8, 1.0, 1.2, 1.5, 2.0, and 2.5.

The hydrocarbon ratio is defined as the ratio of the volume fraction of CO and H<sub>2</sub> in the gas that passes through the combustible gas, and the calculation method is shown in (2):

$$\frac{CO}{H_2} = \frac{V_{co}}{V_{H_2}} \quad (2)$$

Where,  $V_{CO}$  is the volume fraction of carbon monoxide in combustible gas and  $V_{H_2}$  is the volume fraction of hydrogen in combustible gas. Set the carbon/hydrogen ratio CO/ H<sub>2</sub> to 35:65, 50:50, 65:35, 80:20, 95:5.

### 2.3 Data processing

The explosion pressure is affected by the pressure oscillation and the electromagnetic pulse during ignition. It is necessary to obtain the original data of pressure and temperature through the acquisition system of Origin software for processing, and select appropriate window points for

smoothing the pressure-time and pressure-temperature curves in the closed container. By comparing the original data with the smooth data, FFT filter is selected to smooth the data and the comparison diagram between the original data and the smooth data is obtained, as shown in Fig. 2.

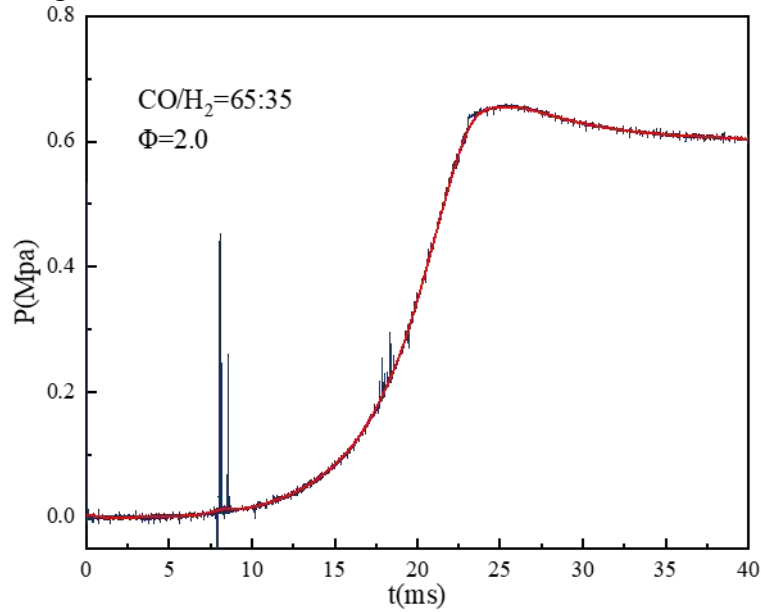


Fig. 2 Data comparison diagram

Further processing extracts the data from the graph as shown in the Fig. 3

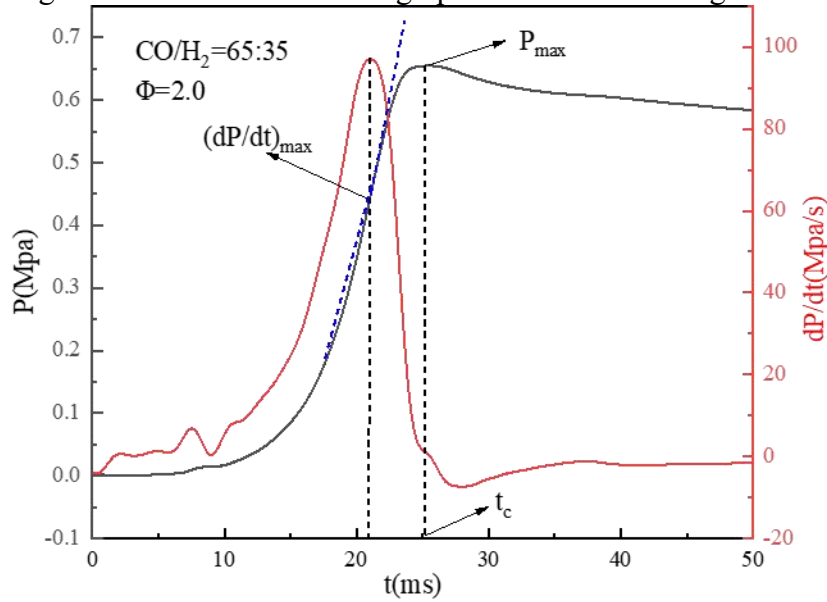


Fig. 3 Data extraction diagram

### 3. Results and discussion

#### 3.1 Effect of equivalent ratio and hydrocarbon ratio on explosion pressure

It can be seen from Fig. 4 that with the constant increase of the equivalent ratio, the explosion pressure increases first and then decreases, and the peak value of the maximum explosion pressure appears near the equivalent ratio 1.2. And different CO/H<sub>2</sub> have similar change rules for the change of equivalent ratio. In theory, the maximum explosion pressure of premixed gas occurs near equivalent ratio 1.0, but studies have shown that the adiabatic flame temperature of syngas occurs when equivalent ratio is relatively large [9], because in the actual process, because the container is not insulated, part of the heat will be lost, resulting in the maximum explosion pressure peak appearing near equivalent ratio 1.2.

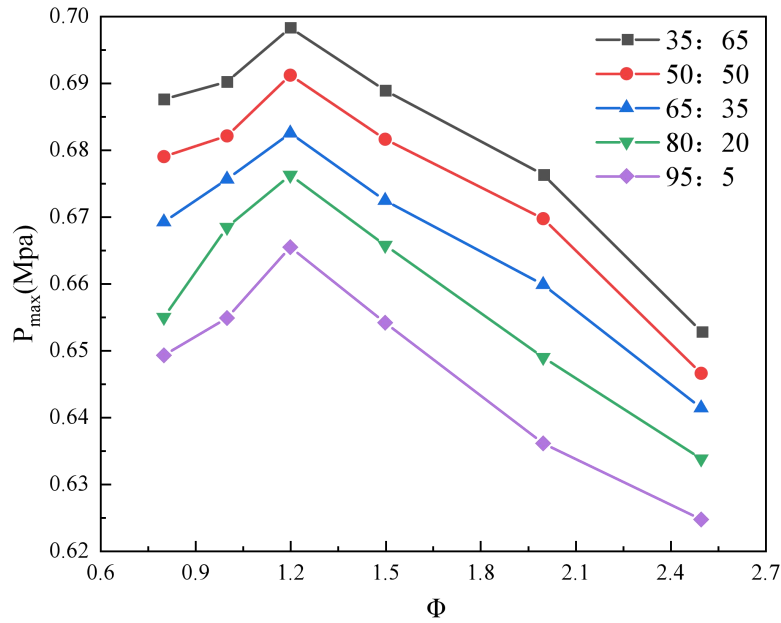


Fig. 4 Maximum explosion pressure diagram

### 3.2 Effect of equivalent ratio and hydrocarbon ratio on maximum explosion pressure rise rate

The effect of equivalent ratio and hydrocarbon ratio on  $(dP/dt)_{\max}$  is shown in Fig. 5. It can be seen from Fig. 5(a) that with the increase of the equivalent ratio, the rise rate of the maximum explosion pressure first increases and then decreases, and the peak value of the rise rate of the maximum explosion pressure appears near the equivalent ratio 1.5. This is because the maximum combustion speed of laminar flame appears near the equivalent ratio 2.0, while the maximum explosion pressure appears near the equivalent ratio 1.2. In the competition between the two, the peak rise rate of the maximum explosion pressure appears near the equivalent ratio 1.5.

As can be seen from Fig. 5(a), with the increasing of CO/H<sub>2</sub> ratio under the same equivalent ratio, the rise rate of the maximum explosion pressure decreases. The peak of the maximum explosion pressure rise rate decreased from 150 Mpa/s at 35:65 to about 30 Mpa/s at 95:5. The reason for this phenomenon is the same as the above trend of maximum explosion pressure. It is due to the change of H<sub>2</sub> content in the CO/H<sub>2</sub> ratio that the maximum explosion pressure rise rate appears this change trend. At the same time, it should be noted in Fig. 5 (b) that the downward trend changes to a certain extent when the equivalent ratio is 2.0 and 2.5. At the equivalent ratio of 2.0, with the increase of the CO/H<sub>2</sub> ratio, the rise rate of the maximum explosion pressure begins to be greater than that of the equivalent ratio 1.2. The main reason is that the maximum explosion pressure rise rate is affected by two aspects, that is, laminar flame combustion speed and explosion pressure. When the CO/H<sub>2</sub> ratio is 35:65, there is a higher H<sub>2</sub> content, so the explosion pressure of equivalent ratio 1.2 is greater than that of equivalent ratio 2.0 when the CO/H<sub>2</sub> ratio is 35:65. When the CO/H<sub>2</sub> ratio is 35:65, the combustion speed of the laminar flame with equivalent ratio 2.0 is higher than that of the laminar flame with equivalent ratio 1.2. The maximum explosion pressure is affected by the explosion pressure and the laminar flame combustion speed, and there is a competitive relationship between the two. Due to the high content of H<sub>2</sub> in the CO/H<sub>2</sub> ratio at this time, the influence of explosion pressure dominates the competition between the explosion pressure and laminar flame, and the maximum explosion pressure rise rate is more influenced by the explosion pressure, which leads to the maximum explosion pressure rise rate of 1.2 equivalent ratio is greater than the equivalent ratio 2.0 when the CO/H<sub>2</sub> ratio is 35:65. With the increase of CO/H<sub>2</sub> ratio, H<sub>2</sub> content in syngas gradually decreases. In this process, laminar flame combustion speed gradually occupies a dominant position in competition with explosion pressure, and laminar flame with equivalent ratio 2.0 has the highest combustion speed and the shortest explosion time. Therefore, when the CO/H<sub>2</sub> ratio increases, the maximum explosion

pressure rise rate of equivalent ratio 2.0 begins to be greater than that of equivalent ratio 1.2.

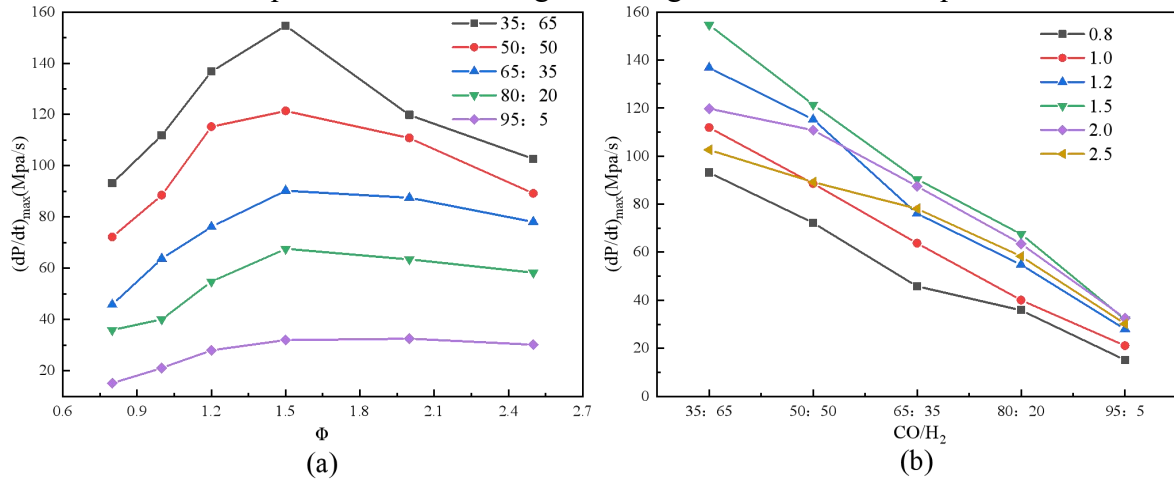


Fig. 5 Maximum explosion pressure rise rate diagram

### 3.3 Effect of yield ratio and hydrocarbon ratio on time to reach maximum explosion pressure

The time to reach the maximum explosion pressure is defined as  $t_c$  in Fig. 3, and the influence of equivalent ratio and hydrocarbon ratio on  $t_c$  is shown in Fig. 6.

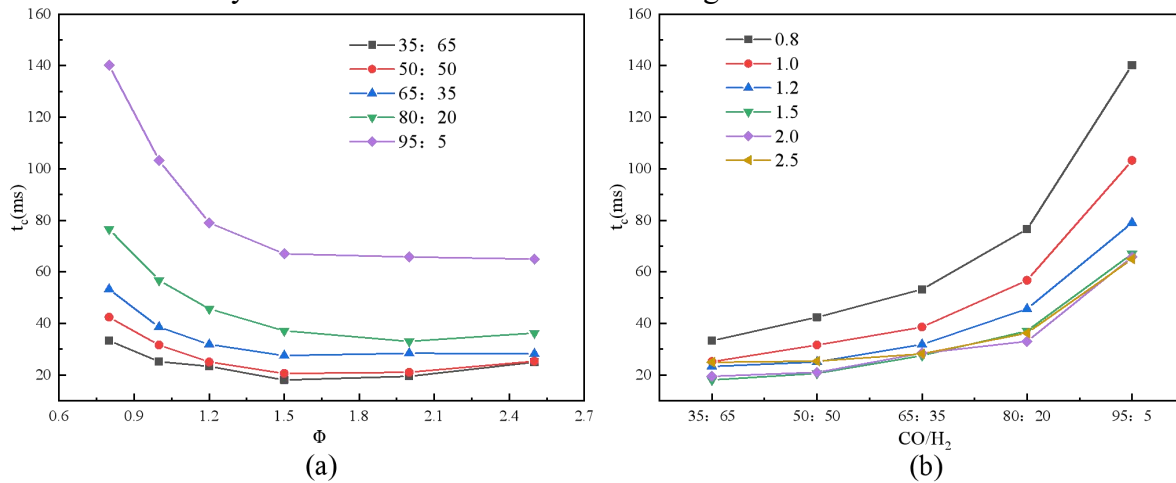


Fig. 6 Time to peak pressure

It can be seen from Fig. 6(a) that with the increase of the equivalent ratio, the time to reach the peak pressure shows a trend of first decreasing and then slightly increasing, and the time to reach the peak pressure is at least near the equivalent ratio 1.5, which is consistent with the rise rate of the maximum explosion pressure. The main reason is that the combustion speed of laminar flame is lower than that of high equivalent ratio at low equivalent ratio, which results in the time to reach peak pressure being longer than that of high equivalent ratio. At the same time, the main reason for the slow increasing trend of the minute pressure time after the equivalent ratio is 1.5 is the same as the decreasing trend of the maximum explosion pressure rising rate after the equivalent ratio is 1.5. Because of the competition between laminar flame combustion speed and explosion pressure, the time to reach the maximum explosion pressure reaches the minimum value when the equivalent ratio is 1.5. After equivalent ratio 1.5, the combustion speed of laminar flame increases slightly, and decreases after equivalent ratio 2.0, which results in an increase in the time to reach the maximum explosion pressure. At the same time, it can be seen from Fig. 6(b) that with the increase of CO/H<sub>2</sub> ratio, the time to reach the maximum explosion pressure keeps increasing. The main reason is that with the increase of CO/H<sub>2</sub> ratio, H<sub>2</sub> content in syngas decreases and CO content increases. In the combustion of syngas, H<sub>2</sub> content affects the combustion speed of laminar flame. Syngas with higher H<sub>2</sub> content has a higher laminar flame combustion speed. Therefore, with the increase of CO/H<sub>2</sub> ratio, the combustion speed of laminar flame decreases, and the time to reach the maximum

explosion pressure also increases. Therefore, with the increase of CO/H<sub>2</sub> ratio, the time to reach the maximum explosion pressure is increasing.

### 3.4 Maximum explosion pressure prediction equation

The total amount of syngas is defined as 1, so the CO/H<sub>2</sub> ratios of 95:5, 80:20, 65:35, 50:50, and 35:65 are respectively H<sub>2</sub> content 0.05, 0.2, 0.35, 0.5, and 0.65, expressed by V. The linear fitting of the maximum explosion pressure was carried out to obtain the fitting equation of the maximum explosion pressure with each equivalent ratio and H<sub>2</sub> content, as shown in Fig. 7.

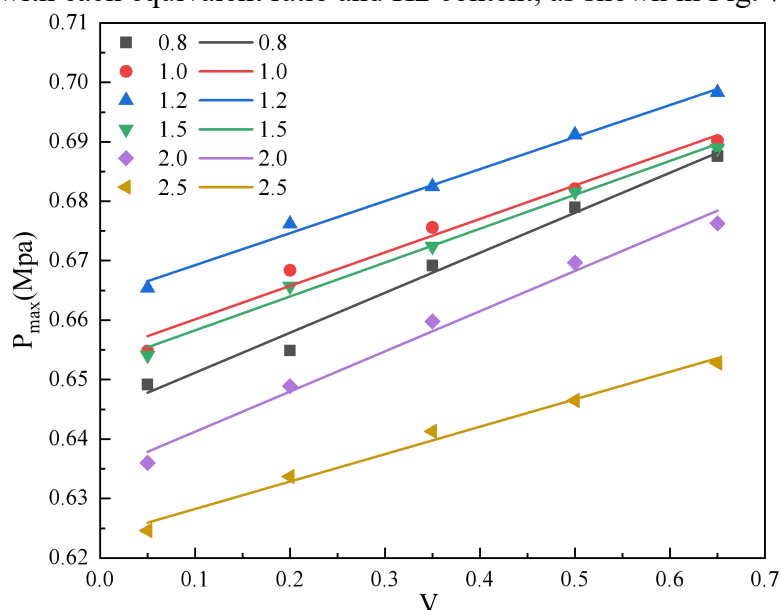


Fig. 7 Fitting the curve graph

The fitting linear function relationship in Fig. 7 is as follows:

$$P = a + b \times V \quad (3)$$

where P is the maximum explosion pressure, V is the H<sub>2</sub> content, and a and b are real numbers.

In Table 1, the fitting equations with H<sub>2</sub> content under different equivalent ratios are obtained.

Table 1. Fit the data table

$\Phi$	Fitting equation	a	b	R <sup>2</sup>
0.8	$P=0.64444+0.06727V$	0.64444	0.06727	0.98685
1.0	$P=0.6545+0.05633V$	0.6545	0.05633	0.97762
1.2	$P=0.66387+0.05387V$	0.66387	0.05387	0.99342
1.5	$P=0.65295+0.057V$	0.65295	0.057	0.99247
2.0	$P=0.63448+0.0676V$	0.63448	0.0676	0.98701
2.5	$P=0.62363+0.04613V$	0.62363	0.04613	0.9889

The R<sup>2</sup> values of the fitting formula and linear fitting in the table are close to 1, indicating that the fitted line can match the experimental results well. Therefore, the fitting equation can be used to predict the maximum explosion pressure with the change of H<sub>2</sub> content in syngas under different equivalent ratios.

## 4. Summary

In this paper, 27L cylindrical vessel was used to explore the effects of synthetic gas equivalent ratio and C-H ratio on the explosion characteristics of synthetic gas by changing the two. The main conclusions are as follows:

1. No matter how the CO/H<sub>2</sub> ratio in syngas changes, the explosion pressure of syngas/air premixed gas changes with the equivalent ratio to reach the maximum at the equivalent

ratio 1.2, the maximum explosion pressure rise rate reaches the maximum at the equivalent ratio 1.5, and the time to reach the maximum explosion pressure is also the shortest at the equivalent ratio 1.5.

2. with the increase of CO/H<sub>2</sub> ratio, H<sub>2</sub> content decreases, the maximum explosion pressure, the maximum explosion pressure rise rate decreases, and the time to reach the maximum explosion pressure increases. The main reason is the change of H<sub>2</sub> content.
3. The prediction equation for the change of maximum explosion pressure with H<sub>2</sub> content between equivalent ratio 0.8-2.5 is obtained, which can accurately predict the value of maximum explosion pressure

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