Explosion characteristic of stoichiometric syngas/air premixed gas in the flow state

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Abstract. With increasing attention to energy efficiency and environmental protection, syngas has attracted great interest as a clean fuel with broad development prospects. In order to further study the effect of the initial gas flow on the explosion of syngas, an explosion experiment of stoichiometric syngas/air premixed gas was carried out in a 3 × 3 × 100 cm square explosion pipe. The composition of the syngas used in the experiment is 50CO:50H₂, the flow rate of the experiment gas is 0L/min-250L/min, and the Reynolds number (Re) is 0-9598.41. The experimental results show that the maximum explosion pressure \( P_{\text{max}} \) and the maximum explosion pressure rise rate \( (dP/dt)_{\text{max}} \) gradually increase with the increase of the initial flow rate and Re. The gas flow increases the flame area, and increase the combustion rate, thereby making the explosion more violent.

1. Introduction

At present, the burning of fossil fuels has caused many environmental problems, such as greenhouse effect, ozone depletion and other climate problems⁴. Syngas from coal gasification is considered to provide better energy efficiency and environmental performance. The main components of syngas are CO and H₂. The success of its industrial application depends not only on the economy, but also on the safety in production and use. Accidental leakage of syngas once encountered the ignition source is prone to cause combustion explosion and poisoning accident. In order to prevent and reduce such accidents, it is necessary to understand the explosion behavior of syngas explosion and its proper use.

A large number of experimental studies have been carried out on the basic explosive characteristics of syngas⁵-⁷. Sun⁵ studied the turbulent explosion characteristics of 50%H₂-50%CO syngas–air mixtures and stoichiometric syngas in a 28.73L fan-agitated explosion vessel in different turbulent environments. It is found that both the maximum explosion pressure and the maximum pressure rise rate increase with the increase of turbulence intensity.

The previous studies on the explosion characteristics of syngas mainly focus on the study of the static combustible mixture, while the research on the flow state of the fuel mixture is very few. In addition, the turbulence intensity can not be well calibrated by rotating speed (rad/min), and the gas distribution inside the container is not uniform.

In order to overcome the shortcomings of the present study, the explosion experiments of
stoichiometry premixed gas in flowing state were carried out by self-made experimental apparatus, and the variation law of the relevant explosion characteristic parameters was analyzed, in order to provide some theoretical basis for the study and accident prevention and control of syngas explosion.

2. Experimental setup and procedures

2.1. Experimental apparatus

The experimental equipment of syngas/air premix gas explosion characteristics under flowing state is shown in Figure 1, which mainly consists of 3 × 3 × 100 cm square explosion pipe, gas distribution system, ignition system, data acquisition system, loop cleaning system and exhaust gas treatment system.

![Figure 1. Schematic diagram of the experimental equipment](image)

The length-diameter ratio is 33.3, which is made up of a 15 cm long quartz glass pipe, 25 cm long and 50 cm square steel pipes connected by flanges. The inlet is filled with porous metal foam, which plays the role of uniform gas flow. The air was obtained from an experimental environment via Air compressor, and the syngas was 50CO: 50H₂. Purities of hydrogen and carbon monoxide were 99.995% and 99.9%. The ignition voltage is 180V and the ignition energy is about 13.8 J. The pressure sensor is located 45 cm from the inlet at the top of the pipe. The sensor is manufactured by Nanjing Aier Sensor Technology, the measuring range is 0-10MPa, the precision is 0.5%, the sampling rate is 100 kHz.

The experimental procedure is as follows: first clean the whole pipe with dry air, vacuum the explosion vessel, then start the mass flow controller, set the instantaneous flow rate of syngas and air, the premixed gas was continuously injected into the experimental pipe to form a steady flow field, and ventilate for 2 min. After the gas is mixed evenly, the premixed gas is ignited by the ignition system, and the test data are recorded. It should be noted that the inlet and outlet of the pipe are open during the explosion.

The experiment was carried out at 293 K, 0.1 MPa, and at least 3 times in each group to verify the repeatability and ensure the accuracy of the data.

2.2. Determination of Reynolds number

For a mixture of gases per unit volume, the density is calculated according to equation (1):

$$\rho_{mix} = m_{mix} = \rho_1 \phi_1 + \rho_2 \phi_2 + \cdots + \rho_n \phi_n$$

(1)

Where, $$\rho_{mix}$$ is the mixture gas density, kg/m³; $$m_{mix}$$ is the mixture gas mass, kg; $$\rho_n$$ is the mixture gas density, kg/m³; $$\phi_n$$ is the mixture gas volume fraction, %.

The viscosity of the gas mixture with k components can be calculated by Wilke's empirical equation

$$\mu_m = \sum_{i=1}^{k} \frac{x_i \mu_i}{\sum_{j=1}^{k} M_j} \sum_{i=1}^{k} x_i \Phi_{ij}$$

(2)

$$\Phi_{ij} = \left[ \frac{1 + \frac{M_i}{M_j}}{1 + \frac{M_j}{M_i}} \right]^{1/2}$$

(3)

Where, $$\mu_m$$ is the viscosity of the gas mixture, Pa·s; $$x_i$$ is the mole fraction of the gas mixture, %; $$\mu_i$$ is the viscosity of the gas mixture, Pa·s; $$M_i$$ is the molar mass of the gas mixture, g/mol. $$\rho_{H_2}$$ is
0.0838 kg/m³, $\rho_{CO}$ is 1.1649 kg/m³, $\rho_{air}$ is 1.205 kg/m³. According to equation (1), the $\rho_{mix}$ is 1.0395 kg/m³. $\mu_{H_2}$ is 9.0×10⁻⁶ Pa·s, $\mu_{CO}$ is 18.2×10⁻⁶ Pa·s, $\mu_{air}$ is 18.1×10⁻⁶ Pa·s. According to equation (2) and (3), the $\mu_m$ is 15.05×10⁻⁶ Pa·s. The Re of premixed gas can be obtained from $\rho_{mix}$ and $\mu_m$. The experimental gas flow parameters are shown in Table 1:

| Flow state          | Instantaneous flow rate (L/min) | Flow velocity (m/s) | Re       |
|---------------------|---------------------------------|--------------------|----------|
| Static state        | 0                               | 0                  | 0        |
| Laminar flow        | 10                              | 0.185              | 383.52   |
|                     | 30                              | 0.556              | 1152.64  |
|                     | 50                              | 0.926              | 1919.58  |
| Transition flow     | 70                              | 1.296              | 2686.72  |
|                     | 85                              | 1.574              | 3263.04  |
|                     | 100                             | 1.852              | 3839.36  |
| Turbulent flow      | 150                             | 2.778              | 5759.04  |
|                     | 200                             | 3.704              | 7678.72  |
|                     | 250                             | 4.630              | 9598.41  |

3. Results & Discussion

3.1. Explosion pressure

Figure 2. shows the explosion pressure of syngas/air premixed gas at different flow rates. Figure 3. shows the peak pressure $P_{\text{max}}$ of syngas/air premixed gas at different Reynolds numbers. As can be seen from the figure 2, the explosion pressure curve always rises from 0MPa to the $P_{\text{max}}$ very quickly, and then decreases slowly. The explosion becomes violent and the peak pressure increases gradually with the increase of flow rate. Figure 3 reveals that there has been a marked rise of $P_{\text{max}}$, which increases from 0.456MPa (Re=0) to 2.818MPa (Re=9598.41) with the increase of Re. In Figure 2(d), compared with the static explosion pressure curve (0L/min), the explosion time in the flow state is shortened as a whole, and the maximum explosion pressure increases greatly. This indicating that the flow of gas will promote the explosion flame area, resulting the increase of the combustion rate, shorten the explosion time, so that the explosion becomes more violent.

Figure 2. Explosion pressure of syngas/air premixed gas at different flow rate
3.2. Explosion pressure rise rate

Figure 4. shows the explosion pressure rise rate of syngas/air premixed gas at different flow rates. Figure 5. shows the maximum explosion pressure rise rate \((\text{dp/dt})_{\text{max}}\) of syngas/air premixed gas at different Reynolds numbers. What can be clearly seen in Figure 5, the \((\text{dp/dt})_{\text{max}}\) is the phenomenal growth with \(\text{Re}\). As the flow of gas increases the area of the explosion flame, and the larger flame will lead to a higher combustion rate, which means a faster rate of combustion formation, resulting in a faster increase in the explosion overpressure\(^7\). As can be seen from Figure 4(d), the \((\text{dp/dt})_{\text{max}}\) of the premix gas changes dramatically from static to flowing, which further demonstrate that gas flow will enhance the intensity of explosion and thus promote the combustion rate.

Figure 3. \(P_{\text{max}}\) of syngas/air premixed gas at different Reynolds numbers

Figure 4. Explosion pressure rise rate of syngas/air premixed gas at different flow rate
4. Conclusions

In order to evaluate the explosion risk of syngas/air mixtures, the explosion characteristics of premixed syngas/air mixtures with stoichiometric ratios under different flow conditions were studied experimentally. The main conclusions are as follows:

1. With the increase of initial flow rate and Reynolds number Re, the maximum explosion pressure $P_{\text{max}}$ increases gradually.

2. Compared with the static state, the $P_{\text{max}}$ and $(\text{dp/dt})_{\text{max}}$ increases significantly with the initial gas flow. This is because the flow of gas will promote the explosion flame area, increase the combustion rate, so that the explosion becomes more violent.

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