Study on Combustion Characteristics of the Blast Furnace Gas in the Constant Volume Combustion Bomb

LIU YONGQI, WANG HAIFENG and LI PING
School of Transportation and Vehicle Engineering
Shandong University of Technology
Zhangzhou Road 12#, Zibo 255049
CHINA

Abstract: - Blast furnace gas is the byproduct of smelting steel production process, and is the important secondary energy source. It is can be used as fuel for engines to generate electricity for most middle and small steel enterprises. In order to understand the combustion mechanism and provide the basis for the design of blast furnace gas engine, premixed laminar combustion experiments of the blast furnace gas-air mixture were performed in the constant volume combustion bomb. The effects of the equivalence ratio, the initial pressure, the initial temperature and the diverse components of blast furnace gas on laminar combustion velocity and flame transition velocity were investigated. The results indicate that the combustion velocity increases when the equivalence ratio is close to the academic air-fuel-ratio ($\Phi = 1.0$), and the maximum appears at the equivalence ratio of 1.15. Premixed laminar burning velocity of the blast furnace gas-air mixture decreases with increase in the initial pressure, and it increases with rising of initial temperature. An increase of the amount of combustible gas in various components blast furnace gas can augment the numerical value of the laminar burning velocity and help to combustion.

Key-Words: - Constant volume combustion bomb; Blast furnace gas; Combustion characteristic; Laminar burning; Burning velocity; Premixed burning

1 Introduction

Blast furnace gas is the byproduct of smelting steel production process in steel enterprises, and usually is composed of 22-26% CO, 16-19% CO_2, 1-4% H_2 and 58-60% of N_2 by volume. Because CO and H_2 are combustible, blast furnace gas is the important secondary energy source. In recent years, more and more attention is paid to the utilization of blast furnace gas along with the high opinion to environmental protection and the reduction energy consumption in China. It is regarded as an effective method to utilize blast furnace gas to generate electricity [1]. The technology using blast furnace gas as fuel for engines to generate electricity brings a new way for most middle and small steel enterprises to recycling and utilizing blast furnace gas.

Blast furnace gas is a kind of fuel with low heat value and various components. The combustion characteristics of blast furnace gas have important influences on the performances and stability of engines. However, to the best knowledge of the authors, no study has been carried out to systemically investigate the combustion characteristic of blast furnace gas in engines. In this study, basic experiments were performed to investigate the combustion characteristics of blast furnace gas in a constant volume combustion system, which facilitates understanding of the mechanism and provides the basis for the design of blast furnace gas engine.

2 Experimental Detail

2.1 Experimental apparatus

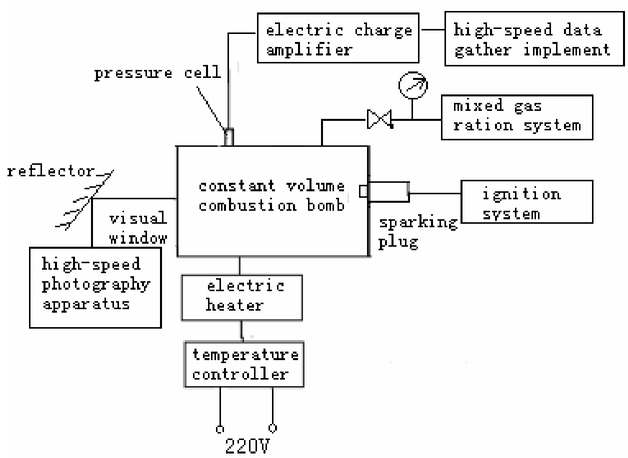

Fig. 1. Sketch of the experimental apparatus

As shown in Fig. 1, the constant volume combustion test equipment is composed of the constant volume combustion bomb body, temperature control system, mixture supply system, ignition system, synchronal time series control system and combustion data capture and analysis system etc. The constant volume combustion bomb is the combustion chamber, in which blast furnace gas and air mixture is burned. There is a quartz glass observation window at the side face of the bomb to facilitate capturing the burning images. The temperature control system was used to heat premixed gas to the needed temperature. Mixture supply system was used to confect various composition mixed gas that consists of blast furnace gas and air according to gas part pressure law. Ignition system was used to ignite the mixture, and synchronal time series control system was used to keep synchronization of data collection with the ignition moment. The processes of ignation and flame transmission inside constant volume combustion ws screened and recorded by a high-speed camera with an image intensifier. The prussure of buning gas was measured by a pressure sensor, and was carried to high-speed data collection system (DEWE2010).

2.2 Experimental procedure

Because the component and concentration of the blast furnace gas (BFG) is various, three kinds of typical blast furnace gas were tested in this paper, as shown in Table 1. The effects of the equivalence ratio Φ, initial pressure P_0, initial temperature T_0 and the components of the blast furnace gases on the laminar combustion velocity was investigated. The equivalence ratio Φ ranged from 0.7 to 1.4. Initial pressure P_0 ranged from 100 to 2000kPa. Initial temperature T_0 ranged from 300 to 700K.

Table 1. Three typical blast furnace gas

components	BFG1	BFG2	BFG3
CO	20%	25%	25%
CO_2	18%	18%	18%
H_2	0%	0%	2%
N_2	62%	57%	55%

2.3 Data Processing

For premixed laminar combusting of the mixtures in constant volume combustion bomb, spread flame transition speed can be given as follow by the relation of the flame radius and time [2]:

$$S_P = \frac{dr}{dt} \qquad (1)$$

in which, r is the flame radius obtained from the high-speed images, and t is time.

The expression of laminar burning velocity is

$$S_L = \frac{\rho_b}{\rho_u} S_P = \frac{\rho_b}{\rho_u}\frac{dr}{dt} \qquad (2)$$

In formula (2), S_P is spread flame transition speed. ρ_b is the burned gas density, which can be gotten by thermal equilibrium computational procedure. ρ_u is the unburned gas density, which is characteristic parameter of initial state.

Flame stretch rate α is defined that the logarithm of infinitely small area on the flame surface take derived number to time.

$$\alpha = \frac{d(\ln A)}{dt} = \frac{1}{A} \bullet \frac{dA}{dt} = \frac{2}{r} \bullet \frac{dr}{dt} = \frac{2}{r} S_P \qquad (3)$$

Laminar flame burning velocity and flame stretch rate are approximate linear relation[3], namely

$$S_L = S_{L\infty} - L\alpha \qquad (4)$$

in which, $S_{L\infty}$ (or S_b)is without stretch (plane) flame laminar burning velocity in the formula.

3 Results and Discussion

Fig. 1 shows the variable curve of the laminar flame radius with time for blast furnace gas 2-air mixture with $\Phi = 1.0$, P_0=100kPa and T_0=300K. It is clearly that the laminar flame radius increases slowly in the beginning, then increases rapidly, and increases gently in the end.

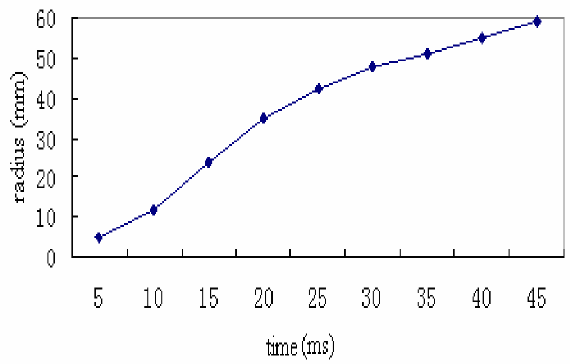

Fig.2. Laminar flame radius versus time

Fig.3 gives the variable curves of the combustion pressure with time for different equivalence ratio for blast furnace gas 2 and air mixture with P_0=100kPa and T_0=300K. It can be seen that the equivalence ratio of mixture has important effects on the pressure in chamber. For the equivalence ratio of 1.0 and 1.15, the pressures rise quickly, and the maximum appears at the equivalence ratio of 1.15. The burning pressure values of the very rich mixture such as $\Phi = 1.4$ and very lean mixture such as $\Phi = 0.7$ are obviously lower than that of the mixture with equivalence ratio of 1.15.

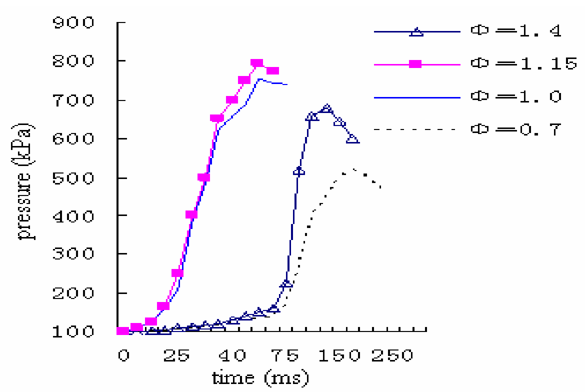

Fig.3. Combustion pressure versus time

Fig.4 illustrates the variable curves of the laminar burning velocity for blast furnace 2-air mixture with equivalence ratio. The initial condition is P_0=100kPa and T_0=300K. The laminar burning velocity increases when the equivalence ratio is close to the value of 1, and the maximum appears when the equivalence ratio is equal to 1.15. On the contrary, the laminar burning velocity of the very dense or very rare mixture decreases. The comparison of this study with other results of study [5] is also shown in the figure. They are similar.

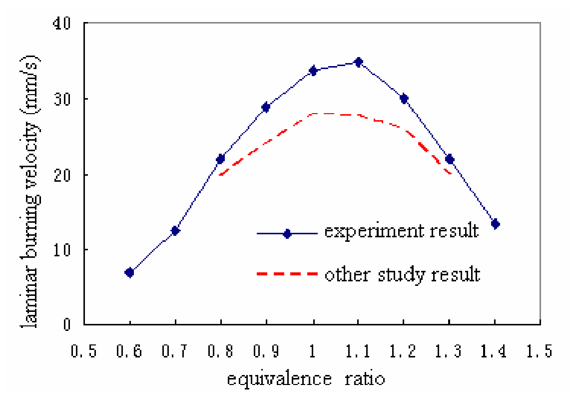

Fig.4. Laminar burning velocity versus equivalence ratio.

The relationship between the laminar burning velocity and the initial pressure at 300K is shown in Fig.5. The results indicate that the laminar burning velocity of the blast furnace-air mixture decreases with increase in the initial pressure when the initial temperature is constant. It's due to the integrated reflection of the diffusibility, the exothermic capacity and the chemic-reaction velocity.

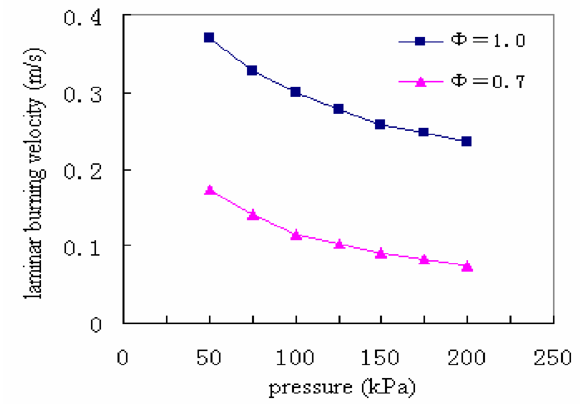

Fig.5. Laminar burning velocity versus initial pressure

Variation of the laminar burning velocity with initial temperature is shown in Fig.6, with the initial condition of P_0=100kPa and $\Phi = 1$. The laminar burning velocity increases with the increase in the initial temperature. The reason is that burned gas temperature T_b increases along with the increase of the reactant temperature or named initial temperature T_u , which results in the increase of laminar burning velocity S_L .

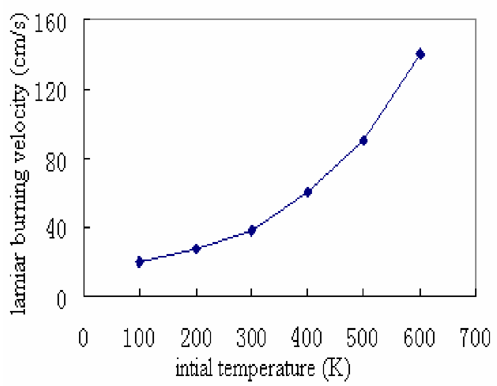

Fig 6 Laminar burning velocity versus initial temperature

Because of the changeable particularity of the blast furnace gas composition, the effects of components of blast furnace gas on combustion process should be studied. At the same time, the contents of CO and H_2 are mainly considered. Effects of the composition of the blast furnace gas on the laminar burning velocity is shown in figure 7, with the initial condition of $\Phi = 1.0$, P_0=100kPa and T_0=300K.

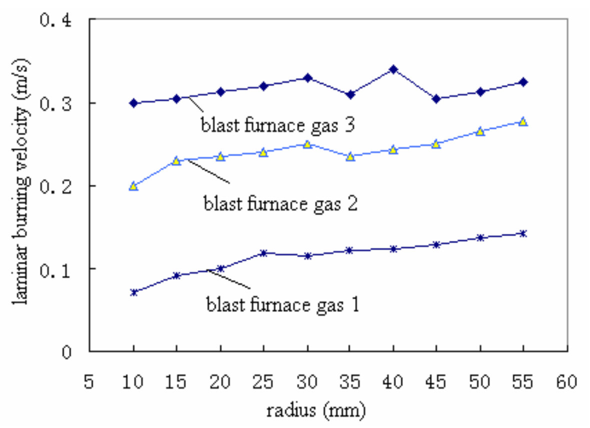

Fig.7. Laminar burning velocity versus composition of blast furnace gas

The results indicate that the more content of CO in blast furnace gas, the rapider the laminar burning velocity rises. The main flammable composition in the blast furnace gas is CO. N_2 and CO_2 in the blast furnace gas can be regarded as the residual waste gas. Therefore, that the content of CO is high means less quantity of the residual waste gas in the blast furnace gas. As well know, the smaller the residual waste gas, the larger the laminar burning velocity.

If some hydrogen is mixed, combustion will be further speeded. Laminar burning velocity increases to some extent with the increase in the proportion of mixed hydrogen. It is due to the quicker burning velocity of the hydrogen than that ofCO. Experimental results in an engine have already been proved that mixing hydrogen in fuel can help to combustion, increase the reaction rate and improve the burning velocity [7]. Thus the performance of combustion and emission of the engine can be improved.

It can also be found from Fig. 7 that, with the increase of the flame radius, laminar burning velocity puts up the trend that slowly increases generally, but the range increased is quite small for the certain composition of blast furnace gas-air mixture. The reason is that the quality of fired mixed gas increases with the increase in the flame radius, and the pressure and the temperature of unfired mixture increase gradually because of the unfired mixture is compressed by fired mixed gas. Otherwise, the laminar burning velocity reduces when the pressure of unfired mixture increases, but becomes large when the temperature increases. In this way, the common effects of the changes of pressure and temperature of unfired mixed gas makes the values of laminar burning velocity S_L or S_b demonstrate the not changing much but slowly increasing trend. The effect of temperature on laminar burning velocity is a little bigger than that of pressure after unfired area.

4 Conclusion

The premixed combustion of the blast furnace gas-air mixtures was investigated in the constant volume combustion experimental apparatus, and the effects rule of the equivalence ratio, the initial pressure, the initial temperature and the variable components of blast furnace gas on the laminar burning velocity was obtained. The results show that the laminar burning velocity is effected seriously by the equivalence ratio, and its maximum appears when the value of equivalence ratio is about 1.15. The laminar burning velocity decreases with the increase in initial pressure and it increases with the increase in initial temperature. The more amount of combustible gas (main to Carbonic oxide), the bigger laminar burning velocity or flame transition velocity is. The laminar burning velocity will increase with the increase in hydrogen fraction in mixtures. In a word, if the combustion becomes better, then the initial pressure should be decreased, the initial temperature should be increased, the combustible gas fraction in mixtures should be more much and appropriate equivalence ratio should be chosen.

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