Simulation on Operational Characteristics of a Valveless Self-excited Pulse Combustor of the Helmholtz-type

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Abstract—Pulse combustion as an advanced combustion has many advantages, such as high combustion efficiency, low pollution emissions. Due to the complex mechanism of pulse combustion, narrow adjustment range of load, it is difficult to achieve a large-scale application. For this reason, the pulse combustion process is investigated by means of simulation in this paper, and the effects of some parameters on the combustion process are analyzed including the inlet pressure, excess air ratio, decoupling chamber pressure and wall temperature of the combustion chamber. The results indicate that the stable pulse combustion could be produced in the combustor when the temperature of the combustion chamber is from 800k to 1400k. With the excess air coefficient increased, the pulsation frequency gradually decreases. As the excess air coefficient or inlet pressure increases, the pressure in the combustor gradually increases. The combustor performance could be controlled by adjusting the decoupling chamber pressure.

Keywords- numerical simulation;pulse combustion; stability; operational characteristics;adjusting methods

I. INTRODUCTION

Pulse combustion is a periodic combustion process under certain acoustic conditions. The temperature, pressure and flow velocity inside the combustor varies periodically. Pulse combustion technology has attracted more and more attention due to its being low pollution emission, high efficient combustion and heat transfer coefficient. Kazuo [1, 2] et al. developed a double valveless pulse combustor to achieve a valveless pulse combustor. Datt [3, 4] et al. (2009) investigated the nonlinear characteristics of the pulse combustor. The stable pulse combustion can be formed when the wall temperature reaches 1140K; pulsation began to decay when the wall temperature rises to 1160k, forming steady combustion eventually; flameout occurs when the wall temperature is below 1025k. Bloom [5, 6] et al. (2009) established lumped parameter model considering the impact of friction, analyzed the pressure and velocity by means of asymptotic expansion method, and concluded that the presence of friction in tailpipe had a significant influence on pulsation of pressure and velocity. Kilicarslan [7, 8] et al. (2007) analyzed gas-fired pulse combustion. The result indicated that the acoustic pressure could be reduced, and the difference between the inlet pressure and outlet pressure could be increased by increasing the length of the tail pipe at the same frequency.

Until now, there are few theoretical studies on pulse combustion. Understanding the mechanism of pulse combustion is necessary for the pulse combustor design and optimization [9, 10]. Hence, in this study, the pulse combustion mechanism is investigated by simulation and several typical factors are also investigated.

II. MATHEMATICAL MODEL

The large eddy simulation (LES) is introduced for modeling turbulence in this work. The governing equations are described as follows:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i}(\rho \overline{u_i}) = 0 \qquad (1)$$

$$\frac{\partial}{\partial t}(\rho \overline{u_i}) + \frac{\partial}{\partial x_j}(\rho \overline{u_i} \, \overline{u_j}) = \frac{\partial}{\partial x_j}(\mu \frac{\partial \sigma_{ij}}{\partial x_j}) - \frac{\partial \overline{p}}{\partial x_i} - \frac{\partial \tau_{ij}}{\partial x_j} \quad (2)$$

where σ_{ij} is the stress tensor due to molecular viscosity defined by:

$$\sigma_{ij} = [\mu(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i})] - \frac{2}{3}\mu\frac{\partial \overline{u_l}}{\partial x_l}\delta_{ij} \qquad (3)$$

For the pulse combustion process, the species transport equations take the following form:

$$\frac{\partial}{\partial t}(\rho Y_i) + \nabla\bullet(\rho \vec{v} Y_i) = -\nabla\bullet\vec{J_i} + R_i + S_i \qquad (4)$$

Where $\vec{J_i}$ is the diffusion flux of species i, which arises due to concentration gradients:

$$\vec{J_i} = -(\rho D_{i,m} + \frac{\mu_t}{Sc_t})\nabla Y_i \qquad (5)$$

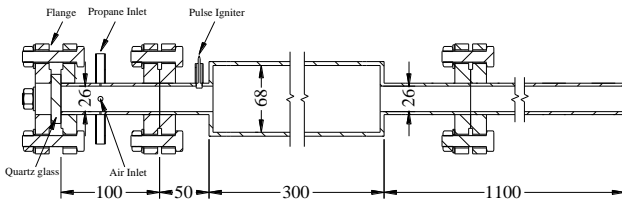## III. RESULTS AND DISCUSSION

Figure 1.   Schematic diagram of pulse combustor system

In this work, the valveless self-excited pulse combustor of the Helmholtz-type is selected as the research objective. The combustible gas is propane. Fig.1 shows the schematic diagram of combustor, which consists of mixing chamber, combustion chamber and tailpipe. Mixing chamber has a 100mm length and 26mm pipe diameter. The length and diameter of the combustion chamber are 300mm and 68mm respectively. The tailpipe has an 1100mm length and 26mm pipe diameter. The diameter of propane and air inlet is 5mm and 1mm, respectively. In order to avoid the noise during operation and stabilize the tail pipe pressure, a decoupling chamber is set up at the end of the tailpipe, which has 800mm length and 500mm diameter.
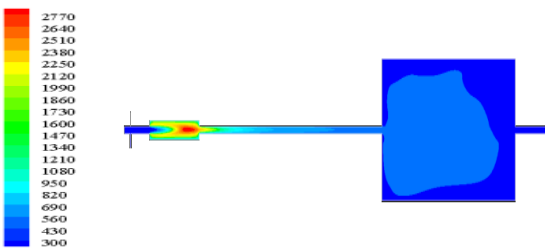

Figure 2.   Contour of temperature in the pulse combustor.

Fig.2 shows the contours of temperature in the system. It can be found that there is a high temperature in the middle and rear of the combustion chamber. The temperature is relatively lower near the inlet and outlet. It implies that the propane mixed with the air in the mixing chamber adequately, the whole pulse combustion process has been substantially completed in the combustion chamber, which is consistent with the experiment phenomenon.

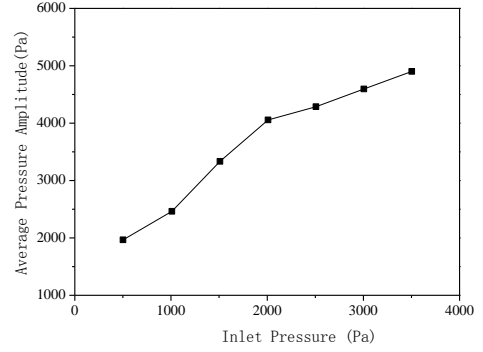### A. Effect of inlet pressure on the averaged pressure amplitude

Figure 3.   Effect of inlet pressure on the averaged pressure amplitude

The effect of inlet pressure on averaged pressure amplitude is evaluated as shown in Fig. 3. It can be found that with the inlet pressure increased, averaged pressure amplitude in the combustion chamber shows a rising trend. An increase in inlet pressure hinders the gas reverse flow after combustion, which reduces heat loss and improves combustion intensity. Hence, when the inlet pressure in below 2000Pa, the trend of the curve is obvious. As the pressure continues to increase, the degree of the growth becomes weak.

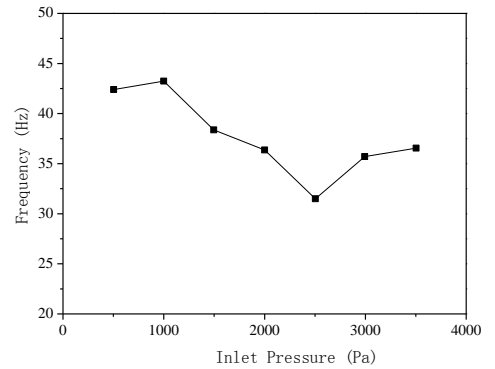### B. Effect of inlet pressure on the frequency

Figure 4.   Effect of inlet pressure on the frequency

Fig.4 shows the variation of frequency with inlet pressure. It can be found that when the inlet pressure is

below 2500K, the frequency decreases with the increasing inlet pressure. Above 2500K, the frequency has a slight increase. However, from the magnitude of the frequency, it can be observed that the difference is not obvious. It implies that the effect of inlet pressure on the frequency is not significant.

C. Effect of wall temperature of the combustion chamber on operation stability
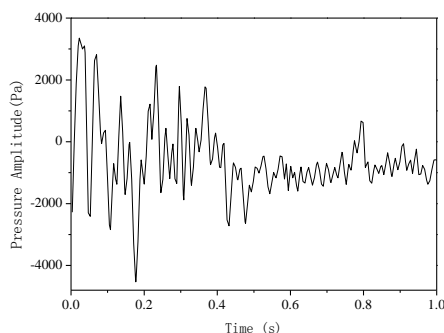

Figure 5.   Effect of wall temperature of the combustion chamber on operation stability

To investigate the effect of wall temperature, the wall temperature in the combustion chamber varies from 800K to 1600K. When the wall temperature is below 1400K, the stable pulse combustion can be achieved. Fig. 6 shows the variation of pressure amplitude with time at the wall temperature of 1600K. In the beginning, the fluctuation of pressure amplitude is obvious. Then the fluctuation becomes weak. It implies that when wall temperature reaches 1600K, the stable pulse combustion can be formed. The reason for this is that a high wall temperature enhances the fuel temperature and promotes the reaction rate. When the fuel amount cannot meet the required amount for combustion, the fluctuation pressure gradually disappears.

D. Effect of the excess air coefficient on pressure amplitude of the combustion chamber
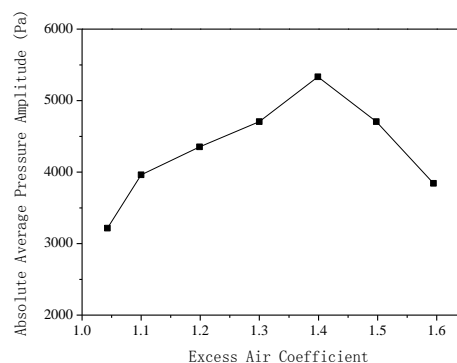

Figure 6.   Effect of the excess air coefficient on pressure amplitude of the combustion chamber

Fig.6 displays the impact of the excess air ratio on the absolute averaged pressure amplitude. It can be found that the pressure amplitude first increases and then decreases with excess air ratio improved. At the excess air ratio of 1.4, the maximum value is reached. It is attributed to that at a low excess air ratio, increasing the excess air ratio means an increase in the inlet pressure, which enhances pressure in the chamber. When excess air ratio reaches a certain level, the fraction of fuel in the mixture gas becomes low, which results in an adequate combustion and reduces absolute averaged pressure amplitude.

E. Effect of decoupling chamber pressure on the pressure of the combustion chamber
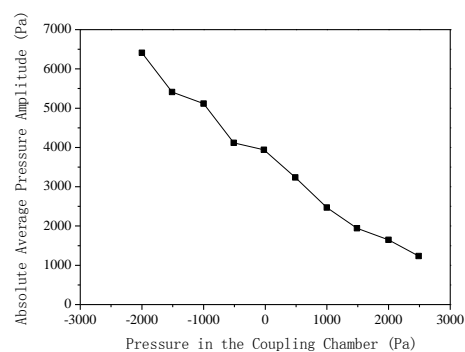

Figure 7.   Effect of decoupling chamber pressure on the pressure of the combustion chamber

The variation of absolute averaged pressure amplitude with decoupling chamber pressure is shown in Fig. 7. When decoupling chamber pressure is below the environmental pressure, pressure amplitude in the combustion chamber decreases with increasing decoupling chamber pressure. It is because increasing decoupling chamber pressure makes an increase of gas temperature and promotes the reaction rate, which leads to the heat accumulation and reduction of the phase difference

between released heat and pressure pulsation. Hence, the pressure is improved. However, a high decoupling chamber pressure decreases the difference between the inlet and outlet pressure, and hinders the pressure.

IV. CONCLUSION

In this work, the pulse combustion process is investigated by simulation. Some factors affecting the performance are analyzed. The results indicate that the pulsation frequency decreases with excess air ratio increased. The pressure is proportional to excess air ratio and inlet pressure.

From the investigation of the effect of wall temperature on the operation stability, the stable pulse combustion can be achieved when the wall temperature in the combustion chamber lies in the range between 800k and 1400k.

ACKNOWLEDGMENT

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