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Experimental study on gas-curtain generation characteristics by multicombustion-gas jets in the cylindrical liquid chamber

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ABSTRACT

The simulator for multicombustion-gas jets injection is designed to study the gas-curtain generation characteristics by multicombustion-gas jets during the underwater gun launch process. The expansion process and interaction process of combustion-gas jets in the liquid are studied under the different injection pressures and nozzle diameters by means of a high-speed camera system, and then the turbulent mixing during the merging are numerically discussed. The experimental results indicate that the gas-curtain is formed by the turbulent mixing process and the turbulent mixing process is enhanced with the injection pressure increasing before gas-curtain forms. In the initial phase, the expansion velocity of the gas-curtain is affected by the center jet and the final expansion velocity is determined by the side jets.

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1. Introduction

The water piercing launcher is a new concept for underwater launching missiles, adopting the unique structure design, which produces a dry gas path underwater with exhaust gas from the engine. Through the gas path, the added mass and resistance during underwater launching can be greatly reduced. Experiment results show that launch speed and depth are both increased by the water piercing launcher (Yagla et al., 2008). There are two launchers for traditional underwater gun, the sealed launcher and submerged launcher. The sealed launcher (Martin et al., 2005), which is widely applied in experimental study, provides the projectile with high muzzle velocity. Employing sealing device, the launcher separates the barrel from the water, which launches the projectile under gaseous environment. However, it will evoke a high requirement on the sealing structure in the later launching process. The submerged launcher (Shi and Chen, 2011), which has simple structure, may cause extremely high pressure during the interior ballistic process. So the speed of submerged launcher is set to a relatively low value. Based on the background of water piercing launcher, the multijets are adopted to generate a gas path in the barrel during submerged launch.

The gas–liquid interaction characteristics during underwater launch have been widely studied, including a water entry process of the engine gas, capturing the gas–liquid interface and stability characteristics of gas–liquid interface. The gas–liquid interface in the piercing launch process was numerically acquired (Yagla et al., 2004). The influence of the launching velocity on the gas-curtain shape and dynamic characteristic of the missile was also numerically discussed (Liu, 2013). Regarding the experimental results, gas–liquid interaction characteristics of the gas-curtain and underwater gas jet interface stability were numerically analyzed (Weiland et al., 2008, 2010). And the Taylor instability of supersonic gas jet with liquid was also discussed (Wang et al., 2001). Modeling tests have been made on underwater engine and the gas jet flied was obtained (Linck et al., 2006). Cheng and Liu (2007) have made analysis on the flow characteristic of liquid and exhausted gas during an underwater launch. The effect of nozzle geometry on gas jet characteristics has also been tested (Arghode et al., 2008).

In the aspect of gas–liquid interaction in the limited space, Qi et al. (2008) studied the two-dimensional expansion process of gas jet in a flat liquid chamber. As research proceeds, the configuration of the single high temperature jet in cylindrical and the step cylindrical liquid chamber has been experimentally (Mang and Yonggang, 2009) and numerically (Mang and Yonggang, 2011) captured. In order to understand the interaction between jets, expansion characteristics of twin combustion-gas jets in the flat (Yonggang et al., 2010) and cylindrical (Xiaochun et al., 2013) liquid chamber have been studied. And the influence of nozzle structural parameters on the jet characteristics has been acquired (Xiaochun et al., 2014).

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2. Experimental setup

In order to understand the generation process of the gas-curtain, namely the dry path, the multijets injection simulator is designed to capture the gas-curtain extension shape. As shown in Fig. 1, the experimental device of multigas jet is composed of the combustor, the sprayer and the cylindrical observation chamber. Combustor is equipped with ignition charge, which consists of fast-burning powder and particle propellants. The fast-burning powder is made up of Nitro-cotton, and the particle propellants are 1/2 single-base powder. The observation chamber is constructed of transparent organic glass tube for easy observation. The diameter of the chamber is 20 mm and the length is 1000 mm. The distribution of the nozzles is shown in Fig. 2. The sprayer consists of 9 nozzles, including 1 center round nozzle, 4 round nozzles in the oblique plane and 4 rectangular nozzles in the side wall. The structural parameters of 3 sprayers used in the experiment are presented in Table 1. As the table shows, on the base of A sprayer, the center nozzle diameter in B sprayer increased to 2 mm. Along the theme of B sprayer, the oblique nozzle diameter in C sprayer is also increased to 2 mm. But the center of the nozzles and the other parameters keep the same. The head of the sprayer is a circular truncated cone. The slant angle is 45°, and diameter in upper surface is 6 mm.

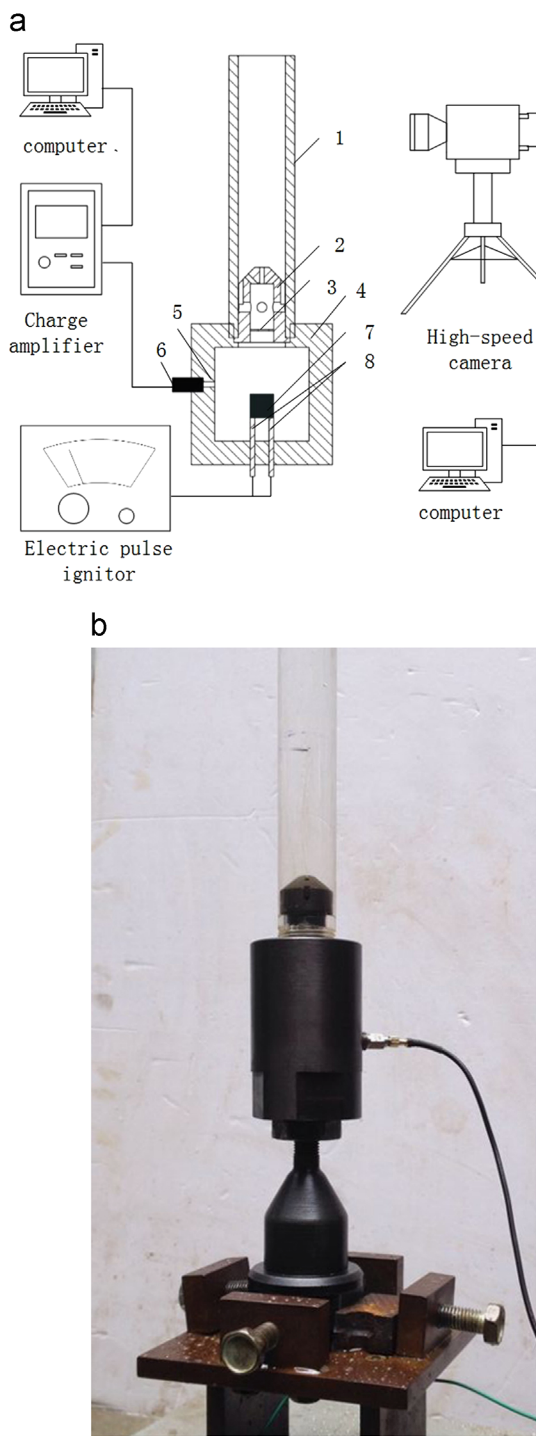

Fig. 1. Structure of experiment device. (a) Diagram of the experiment system. 1. Observation chamber, 2. sprayer, 3. seal film, 4. combustor, 5. pressure hole, 6. pressure sensor, 7. charge and 8. ignition electrodes. (b) Picture of the multigas jets device.

During the experiment, the developing process of multigas jets in the liquid chamber is captured by the high-speed digital camera and injection pressure is measured with pressure sensor. The maximum resolution of the camera is 1024 × 1024 pixels and frequency is 2000 frames/s. To reduce the influence of gravity on the experiment, experimental apparatus is vertically upward placed.

3. Experimental study on expansion characteristics of the multigas jets

The working principle of the experimental device is employing combustion-gas to generate gas-curtain in the liquid chamber. When the current pulse passes through the ignition electrodes, fast-burning powder is ignited immediately and generates high temperature gas. The pressure within the combustor increases dramatically and the particle propellants are ignited. As the pressure grows, the seal film is broken and the gas is injected into the liquid chamber. Then turbulent mixing occurs between multijets and the liquid medium. The expansion processes of the multijets in the liquid are observed with the high-speed digital camera.

Fig. 3 shows the varying curve of combustion pressure p under a typical working condition. As indicated in the figure, the

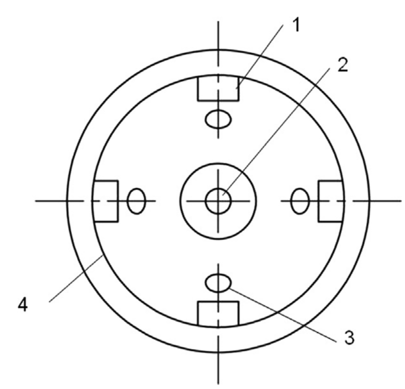

Fig. 2. Top view of the sprayer. 1. Rectangular orifice, 2. center orifice, 3. oblique plane orifice and 4. observation chamber.

Table 1
Parameters of the three sprayers.

Sprayer type	Diameter of the center orifice Φ_1/mm	Diameter of the oblique plane orifices Φ_2/mm	Rectangular orifices/mm
A	1.5	1.5	3 × 1
B	2	1.5	3 × 1
C	2	2	3 × 1

The parameters of 3 sprayers used in the experiment. Φ_1 is the diameter of the center orifice. Φ_2 is the diameter of the oblique plane orifices.

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