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Study on the gas-curtain generation characteristics by the multiple gas jets in a liquid-filled tube

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ABSTRACT

To further understand the gas-curtain generation characteristics during the launching process of the underwater guns, a simulated gas-injector with multiple nozzles is designed and the expansion process of these multiple combustion-gas jets is experimentally captured. Experiment results indicate that, with turbulent mixing between the gas jets and the liquid medium, the gas curtain is generated in the observation chamber. Based on the experiment, a three dimensional unsteady model is established to simulate the expansion process of the multiple jets. Numerical result shows, with the injection of the gas jets, pressure declines in the Taylor cavity along the axial direction at the beginning. During the expansion process, the multiple jets contact and interact with each other, and pressure rises in the mixing area. After merging, backflow vortexes interact and converge, and the vortexes move along the axial direction with the expansion of the combustion gas jets.

1. Introduction

Although marine defense technology is developing rapidly, tradition guns have not been widely applied in the underwater defense. This is mainly because the resistance of underwater movement is 800 times of the resistance in the air. The increased resistance induces extremely high pressure in the gun barrel, which may cause exploding accidents. For the sake of safety, the muzzle velocity of the traditional submerged gun launcher is limited to a low level.

The water piercing launcher is a new concept for submerged launched missiles, which employs the concentric canister launch system to expel the combustion gas. As the exhaust gas reaching the exterior of the launcher, it drives the liquid medium away and creates a gas path, which decreases resistance on the moving missile [1]. To understand the mechanism of gas-curtain, Yagla [1,2] experimentally captured the gas-liquid interface of the gas-curtain. And the experiment indicates that both the launching speed and depth of the water piercing launcher are improved. Based on the experiment, a mathematical model of the launching process is established by Weiland [3,4], and the interaction process between the exhaust gas and the liquid medium is numerically discussed.

The generation process of the gas-curtain is related to the interaction between the gas jets and the liquid medium. Researchers have already gained some achievement in this respect. Cheng [5] numerically studied the kinetic characteristics of the high temperature gas jet during the launching process. Linck [6] and Arghode [7] carried out characteristic tests on the interaction between the liquid and the exhausted gas, and the effect of the engine nozzle shape is experimentally discussed. Weiland [8] analyzed the relationship between kinetic characteristics of gas-liquid interface and interface instability in the water entering process of a round jet.

Although the new concept of water piercing launcher has not applied in the underwater gun launcher, it provides a research direction for underwater guns. Based on the concept of water piercing launcher, a new submerged gun launcher is proposed. Unlike the missile launcher, the gas-curtain of the gun launcher is generated in the limited gun tube. In the aspect of gas-liquid interaction in a limited space, QI [9] experimentally and numerically analyzed the expansion process of a single gas jet in a 2-D flat chamber. Vivaldi [10] carried out experiments on the expansion of a single CO_2 gas jet in a cylindrical chamber. To figure out the interaction between the multiple jets, Yu [11] observed the expansion characteristics of the twin jets in a flat chamber. On this base, Xue [12,13] further discussed the influence of structure parameters on the expansion process of the twin jets in cylindrical chambers. Graaf [14] experimentally observed the merging process of the four gas jets in a liquid environment.

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Table 1
Size the three sprayers.

	The diameter of the center nozzle Φ_1/mm	The diameter of the slant nozzles Φ_2/mm	The size of the side wall nozzles/mm
A	1.5	1.5	3 × 1
B	2	1.5	3 × 1
C	2	2	3 × 1

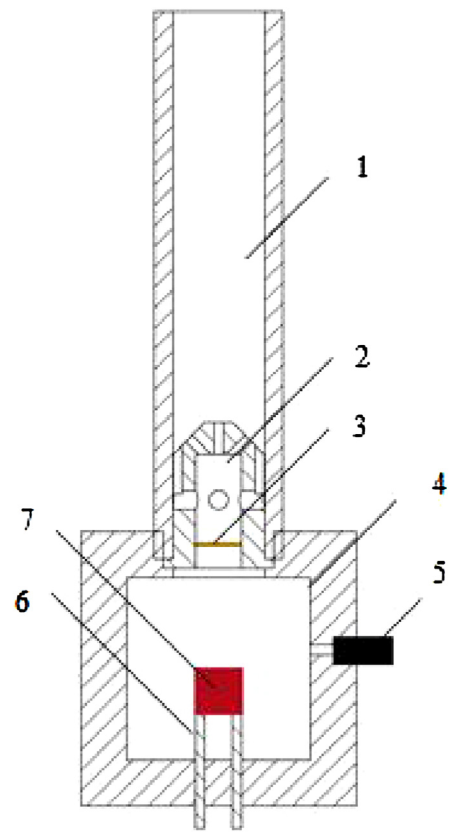

Fig. 1. Structure of the experimental device.
1. Observation chamber, 2. Sprayer, 3. Sealing film, 4. Combustion chamber, 5. Pressure sensor, 6. Ignition electrode, 7. Ignition charge.

In order to understand the gas-curtain generation mechanism of submerge guns, a simulator with multiple nozzles is designed to observe interaction between the multiple gas jets and the expansion process of the gas-curtain. According to the experimental results, numerical simulation is carried out to obtain the varied characteristics of the flow field.

2. Experimental device and principles

Fig. 1 shows the structure of the experimental device, which is composed of a combustor, an observation chamber and a sprayer. The combustor is equipped with an ignition charge, which is fixed on the ignition electrode. The major ingredient of the ignition charge is Nitrocellulose ($C_{12}H_{16}(ONO_2)_3O_3$). For easy observation, the observation chamber, of which the diameter is 20 mm and the length is 1m, is made of transparent organic glass. The sprayer is made of metal and has multiple nozzles in the interior. Fig. 2 shows the distribution of the nozzles on the sprayer surface. As the figure shows, the sprayer consists of 9 nozzles, including 1 round nozzle in the center, 4 round nozzles in the oblique plane and 4 rectangular nozzles in the wall. In order to understand the impact of sprayer structure, contrast experiments are conducted with three different sprayers. And the parameters of the sprayers are shown in Table 1.

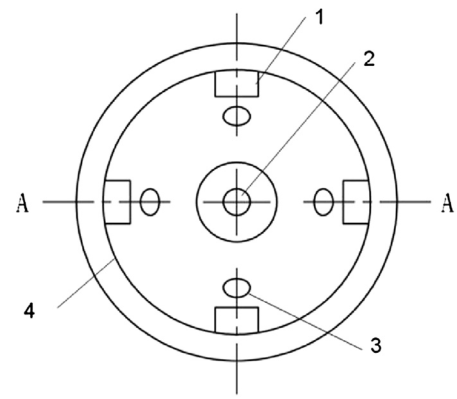

Fig. 2. Projection of the sprayer.
1. Side wall nozzle, 2. Center nozzle, 3. Slant nozzle, 4. Observation chamber.

In the experiment, the ignition charge is ignited by the impulse current generated by the electric ignition system. With the combustion of the powder, combustion gas is accumulated in the combustor and the pressure in the chamber increases rapidly. When the pressure reaches the maximum value that the sealing film can withstand, the film is broken and the combustion gas is injected into the observation chamber. Then turbulent mixing occurs between the multiple jets and the liquid that induces the generation of gas-curtain in the observation chamber.

3. Experimental results

The expansion consequence of the multiple combustion-gas jets in the liquid chamber with sprayer A is shown in Fig. 3, the maximum static pressure measured by the pressure sensor is 1.9 MPa.

As shown in Fig. 3, the combustion gas jets experience a process from independent extending to synergistic development. At the initial stage, the multiple jets are sequentially injected into the liquid chamber. Before $t = 1$ ms, only the oblique jets and the center jet expand in the direction of nozzles. With the expansion of the gas jets, the oblique jets hit the chamber wall, and the expansion changes to the axial direction. At $t = 2$ ms, the combustion gas is ejected from the side wall nozzles. The inconformity of the side wall jets is due to that the inlet of the side wall nozzles is on the wall. When the combustion gas is ejected into the inner chamber of the sprayer, it moves in the axial direction, and radial component of the velocity is much smaller than the axial component. At $t = 3$ ms, the side wall jets merge with the oblique jets that forms 4 side jets on the chamber wall. With the radial expansion of the gas jets, the side jets merge at $t = 4$ ms. Then the side jets merge with the center jet that generates the gas-curtain in the observation chamber. As shown in the figure, after $t = 7.5$ ms, the multiple jets converge into an entirety that expands along the chamber.

Fig. 4 compares the shape of the gas-curtains generated by different sprayers with the same injection pressure of 2.3 MPa. According to the expansion sequences, the axial displacements of the gas-curtains can be obtained, as is shown in Fig. 5. Taking a derivative with the displacement, the instantaneous expansion velocity can be obtained, as shown in Table 2.