Experimental study of underwater vehicle’s dissolved gas wake

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Abstract. In order to maintain the internal environment, underwater vehicles continue to emit carbon dioxide. Carbon dioxide dissolves in water to form dissolved carbon dioxide wake characteristics. Based on a self-designed and built experimental bench, a model experiment of dissolved carbon dioxide produced by the underwater vehicle was carried out. The effects of carbon dioxide emission flow and speed of the vehicle on the characteristics of dissolved carbon dioxide wake are analysed. The results showed that, due to the carbon dioxide emissions of the underwater vehicle, the area passed by the underwater vehicle formed a wake containing dissolved carbon dioxide. The dissolved carbon dioxide wake of the underwater vehicle lasts for a long time, that is, in the area far behind the underwater vehicle, the characteristic of dissolved carbon dioxide is still obvious enough to be detected by the detector. In addition, the wake characteristics of dissolved carbon dioxide when the propeller is rotating and when it is not moving are compared. The results show that the mixing action of the propeller has a great influence on the characteristic distribution of dissolved carbon dioxide.

1. Introduction
During the navigation of an underwater vehicle, due to its movement, exhaust gas, and waste water discharge, the physical or chemical characteristics of waters passing through it will be different from the surrounding waters, which is called the wake characteristics of the underwater vehicle. Using these differences, detection devices can be developed to detect corresponding physical or chemical characteristics, thereby indirectly detecting, tracing, tracking and even attacking underwater vehicles. The wake characteristics of underwater vehicles are the basis of underwater homing technology. In the past few decades, research on the wake characteristics of underwater vehicles has attracted more and more attention.

Currently, most researches on the on the wake characteristics of underwater vehicles are the thermal wake, the thermal wake and the bubbly wake, including laboratory tests and computer simulation calculates. In order to maintain the stability of the internal environment, the underwater vehicle needs to continuously discharge exhaust gas. Carbon dioxide is one of the main components of the exhaust gas and is soluble in water, thus forming the characteristics of the dissolved gas wake of the underwater vehicle.

Based on a self-designed and built experimental system, a model experiment of dissolved carbon dioxide produced by the underwater vehicle was carried out. The effects of carbon dioxide emission flow and speed of the vehicle on the characteristics of dissolved carbon dioxide wake are analyzed. In
addition, the wake characteristics of dissolved carbon dioxide when the propeller is rotating and when it is not moving are compared. The results obtained in this paper can be used to guide the countermeasure technology of underwater vehicles.

2. Experimental System And Method

2.1. Experimental System
This experimental research was carried out in the towing pool of Huazhong University of Science and Technology. The experimental system consists of an experimental pool, a towing system, an underwater vehicle model, and a carbon dioxide content test system. The experimental system is shown in Fig.1.

The generated hybrid meshes

The main size of the experimental pool is 175m×6m×5m(length×width×depth), and the water injection depth of the pool during the experiment is 4m. The towing system consists of a trailer above the pool, a track and a power system. During the experiment, the model was fixed to the trailer by connecting rods. In order to reduce the influence of the connecting rods on the experimental results, the connecting rods are designed to be streamlined. Driven by the power system, the trailer drives the model to move.

The experimental model is an underwater vehicle model with a propulsion system and a carbon dioxide emission system. The total length of the underwater vehicle is 1700mm, and the maximum diameter of the model is 150mm. The maximum diameter of the propeller is 30mm.

The propulsion system includes a propeller, a connecting rod, a motor, a power supply and a controller. The power supply supplies power to the motor. The motor rotates and drives the propeller to rotate through the connecting rod. The controller is used to control the rotation speed of the propeller. Among them, the propeller, connecting rod and motor are installed inside the model. The motor communicates with the power supply and controller on the trailer through a cable.

The carbon dioxide emission system includes a carbon dioxide cylinder, a flow control valve, a flow meter, an exhaust pipe and a gas distributor. Under the control of the flow control valve, the carbon dioxide gas to the gas distributor installed in the underwater vehicle model through the exhaust pipe, and the flow in real time. After the carbon dioxide is discharged from the model, under the disturbance and mixing of the model and the propeller, the wake area of the model will form a characteristic of dissolved carbon dioxide wake.

The dissolved carbon dioxide content test system consists of a carbon dioxide content test sensor and a data acquisition computer. The carbon dioxide content test sensor is a film-covered optical sensor produced by AMT GmbH in Germany, used to measure the volume fraction of carbon dioxide in water.
2.2. Experimental Method

The characteristic experiment of the dissolved carbon dioxide wake of the dissolved carbon dioxide wake of the underwater vehicle was carried out in the towing pool. The model exhaust gas is provided by external compressed gas cylinders. Gas distributors are installed symmetrically on the port and starboard sides of the model. The input end of the exhaust pipe is connected to the external compressed gas cylinder, and the output terminal is connected to the gas inlet of the distributor. The exhaust gas flow is controlled by a flow regulating valve, and the gas is discharged into the water through the distributor to form a trail of dissolved carbon dioxide. The model is driven by the trailer, and the propeller is driven by the motor to rotate at the corresponding number of rotations to provide mixing power. The carbon dioxide is dissolved in water to form a dissolved carbon dioxide wake. The dissolved carbon dioxide content sensor measures the change of carbon dioxide content in water with time under water.

In the experiment, the carbon dioxide sensor is fixed in the wake area of the model through a bracket. The sensor is on the upper side of the model, the lateral distance from the model is 300mm, and the vertical distance is 500mm. Under static conditions, the carbon dioxide sensor is located at the center of the exhauster along the longitudinal direction. Under sailing conditions, the sensor is fixed, and the model passes through the side of the sensor.

The specific experimental steps are as follow.

1) Fix the dissolved carbon dioxide content sensor in a suitable position through the bracket;
2) Adjust the navigation depth of the underwater vehicle according to the test conditions;
3) Collect and record the characteristic data of dissolved carbon dioxide in the pool background;
4) Open the compressed gas cylinder, and adjust the exhaust flow and propeller speed. The model collects and records the dissolved carbon dioxide content data through the dissolved carbon dioxide content sensor under the set working conditions;
5) Record test time and test conditions and other parameters;
6) Stop the exhaust, cutoff the drive power of the propeller, and continue to measure the changes in dissolved carbon dioxide content;
7) When the carbon dioxide content in the measurement area no longer changes, stop the measurement and save the measurement database to repeat the above steps to start the next working condition measurement.

3. Experimental results and analysis

3.1. Data analysis of the static condition

Fig. 2 shows the model’s emission of carbon dioxide at a flow rate of 8L/min under the static condition, and the exhaust is stopped after 600 seconds, the change curve of the dissolved carbon dioxide content at a fixed pool is measured with time.

It can be seen from Fig.2 that the background dissolved carbon dioxide content of the experimental pool is 645ppm. With the emission of the carbon dioxide gas, the dissolved carbon dioxide content at the beginning of the measurement point gradually increased from initial 645ppm to a maximum value of 2460 ppm at 1270s, after which the dissolved carbon dioxide content gradually decreased. Under the above condition, the characteristic duration of carbon dioxide in water exceeds 8000s.
3.2. The influence of speed on the wake of dissolved carbon dioxide

Fig. 3 shows that under sailing conditions, the model emission of carbon dioxide flow is 8L/min, and the model sailing speed is 0.5m/s, 1.0m/s, 1.5m/s respectively, the change curve of the dissolved carbon dioxide content at a fixed pool is measured with time.

It can be seen from Fig.3 that after the model passes the measuring point, the dissolved carbon dioxide content at the measuring point presents a process that first increases and then gradually decreases until it disappears. When the speed of the model increases from 0.5m/s to 1.5m/s, the maximum dissolved carbon dioxide content at the measuring point decreases from 700ppm to 688ppm, and the duration of the dissolved carbon dioxide feature has been reduced from 5400s to 4180s. The test results show that as the speed of the model increases, the diffusion of dissolved carbon dioxide in the water is faster. It is specifically manifested as the decrease of the maximum value of dissolved carbon dioxide content at the measuring point and the decrease of the characteristic duration of dissolved carbon dioxide.

3.3. The influence of the carbon dioxide emission on the wake of dissolved carbon dioxide

Fig. 4 shows that under sailing conditions, the model emission of carbon dioxide flow is 2L/min, 4L/min, 8L/min respectively, and the model sailing speed is 0.3m/s, the change curve of the dissolved carbon dioxide content at a fixed pool is measured with time.
It can be seen from Figure 4 that after the model passes the measuring point, the dissolved carbon dioxide content at the measuring point presents a process that first increases and then gradually decreases until it disappears. When the carbon dioxide emission of the model increases from 2L/min to 8L/min, the maximum dissolved carbon dioxide content at the measuring point increases from 690ppm to 824ppm, and the duration of the dissolved carbon dioxide feature has been increased from 3900s to 6400s. The test results show that as the carbon dioxide emission of the model increases, the content of dissolved carbon dioxide in the water increases. It is specifically manifested as the increase of the maximum value of dissolved carbon dioxide content at the measuring point and the characteristic duration of dissolved carbon dioxide.

**Fig. 4** The effect of propeller mixing on test results

### 3.4. The comparison of with propeller and without propeller

In order to analyze the influence of the propeller mixing effect on the characteristics of the dissolved carbon dioxide wake, Fig.5 shows the experimental model with a speed of 1.5 m/s, an exhaust flow of 8 L/min, and the propeller rotates at 938rpm and 0rpm respectively, the change curve of the dissolved carbon dioxide content at a fixed pool is measured with time. It can be seen from Figure 4 that due to the mixing effect of the propeller, the distribution of the model’s characteristics of dissolved carbon dioxide changes significantly.

**Fig. 5** The effect of propeller mixing on test results
4. Conclusion
In this paper, the characteristics of dissolved carbon dioxide wakes of underwater vehicles due to gas emissions have been developed. The experimental results show that under the influence of dissolution and diffusion effects, the characteristics of dissolved carbon dioxide wakes of underwater vehicles show a process of first increasing, then gradually decreasing, and finally slowly disappearing. As the speed of underwater vehicles decreases or the flow of carbon dioxide of carbon dioxide emissions increases, the content of dissolved carbon dioxide in the wake increases. In addition, the characteristics of the wake of dissolved carbon dioxide are very different for the two cases of propeller rotating and propeller not moving.

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