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Mock-up test for red-tide removal using artificial float with ceramic membrane

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In Korea, in particular the south coast, the marine industry has been gradually damaged by red tide. The pollution of offshore regions and the death of wild and offshore fish-farm fishes have resulted in significant economic losses to fishermen. The primary approach employed to remove red tide domestically is to spray red clay. However, not only is it hard to find the effect, but phosphorus and a trace quantities of metal in red clay promote the proliferation of red-tide algae. Therefore, the use of red clay is not ideal. In this study, a laboratory-sized mock-up test is performed to predict the efficiency of red-tide removal, water current, and flow velocity in the case where an artificial float with its membrane filled with ceramic carriers is installed around the perimeter of an offshore underwater fish farm. Mock-up devices are classified as circular and scaled-down types. Based on the test with the circular type, the flow velocity had a reduction rate of 78% after the passage of layer 1, and it had increased to 81~82% after the passage of layer 2. The reduction rate of red tide was initially 2000 cell/ml at the time it passed layer 1, and had reduced to between 400 cell/ml and 800 cell/ml after passing layer 2. In the test with the scaled-down type, the reduction pattern of the flow velocity was the same as that of the circular type. In conclusion, the artificial float with a ceramic membrane was effective at removing red tide and reduced the flow velocity between membrane layers to increase the stay time of red tide. It was verified that an actual artificial float could secure a sufficient time to remove red tide by causing the red tide to remain for a longer time between layers to increase the concentration, pumping red-tide microorganisms, and then removing the red tide through a filter press. It is expected that the use of artificial floats will become an effective measure to remove red tide.

Key words: Mock-up test, Ceramic membrane, Ceramic carrier, Red tide, Chattonella.

Introduction

There has been increased damage due to red tide daily. These harmful algal blooms (HABs) not only cause severe economic loss to marine resources, but result in offshore pollution, causing the death of wild and offshore fish-farm fishes [1]. In particular, since the occurrence of mixotrophic dinoflagellate *Cochlodinium polykrikoides* in Korea in 1995, the offshore fish-farm industry has faced losses of approximately USD 95 million [2-4]. Therefore, many treatment methods have been applied to remove underwater organisms, including activated carbon absorption and advanced oxidation processes (AOPs). However, these approaches are not suitable for highly ionic ocean water [5]. To remove red tide in the southern coastal regions of Korea, the primary approach has been to spray red clay. However, phosphorus and trace amounts of metal in red clay actually promote the proliferation of red-tide algae, so it may extend the range of red tide and increase its duration [6]. Accordingly, there is a need to identify a concrete and clear measure to reduce the damage caused by red tide along the southern coast of Korea. In recent years, there has been active research on a plan for removing red tide with the use of a membrane [5].

To prevent the damage caused by red tide, a trial was recently done to install a membrane layer filled with ceramic carriers on the perimeter of an offshore underwater fish farm and to filter and remove red-tide algae [7-9]. According to a previous study, the anti-biofouling effect of the ceramic carriers in the membrane remained for about 3 months, and it was expected to be effective at removing red-tide algae. Because the ceramic carriers are porous, it is would be useful to apply a variety of coating layers for red-tide removal, and therefore it appears to be a viable option for the more effective removal of red tide [10].

Therefore, in order to minimize the damage to offshore underwater fish farm, this study involved conducting a mock-up test to determine the red-tide removal effect, water flow, and flow velocity of an artificial float with membrane layers filled with porous ceramic carriers.

Experimental Method

Mock-up test to find the red-tide removal effect of ceramic carriers

In this study, an offshore fish farm was scaled down in its design and applied to a mock-up test in order to determine the efficiency of removal of red tide. Fig. 1 illustrates the schematic diagram of the devices

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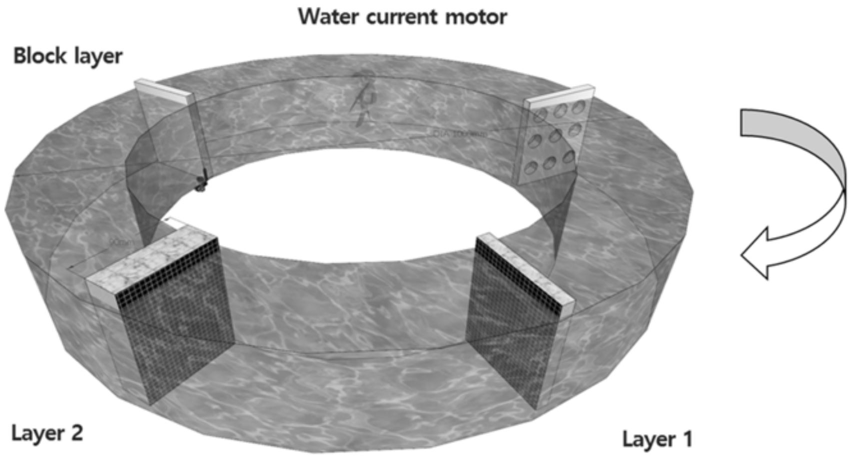
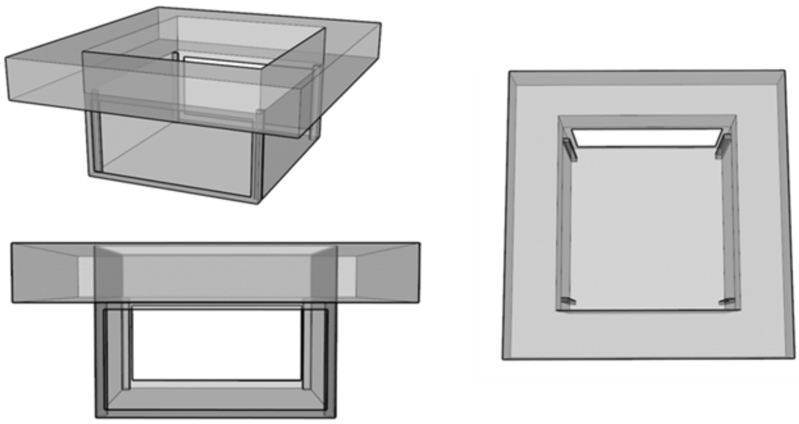


(a)



(b)

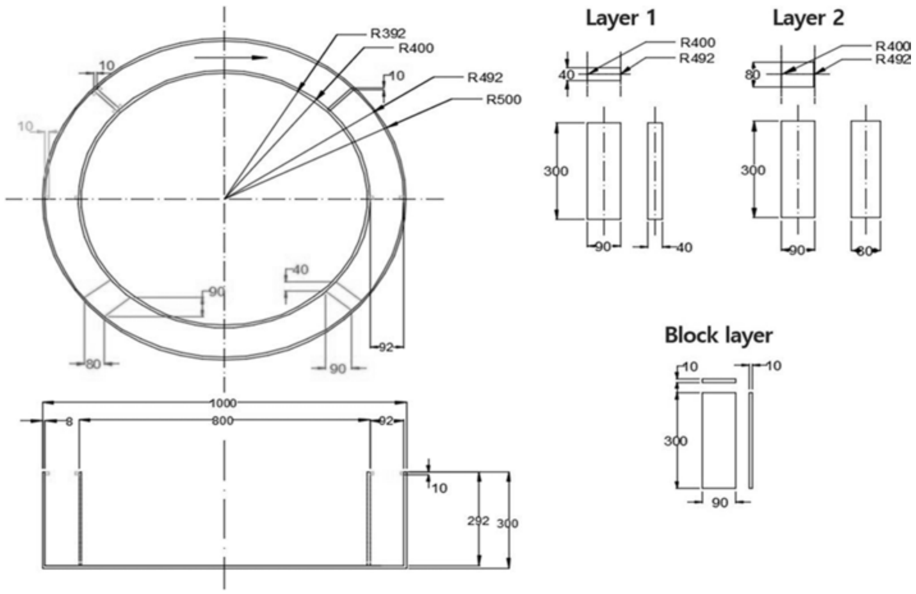
Fig. 1. Schematic of mock-up test devices employed for the removal of red tide: (a) circular type and (b) scaled-down type: perspective view (upper left), side view (lower left), and top view (right).

employed for the mock-up test on an offshore fish farm. In Fig. 1(a), the circular type is used to determine the change in flow velocity influenced by the membrane layers with the ceramic carriers as well as the removal efficiency of red-tide algae. Using the circular type, it is possible to analyze the red-tide removal efficiency of membrane layers 1 and 2. With respect to the water circulation, different values of flow velocity and water current were observed when layers 1 and 2 were installed. As shown in Fig. 1(b), the farm was scaled down but had the same design as that of an actual offshore fish farm, and ink was injected to represent red tide, and enabled the water flow to be traced.

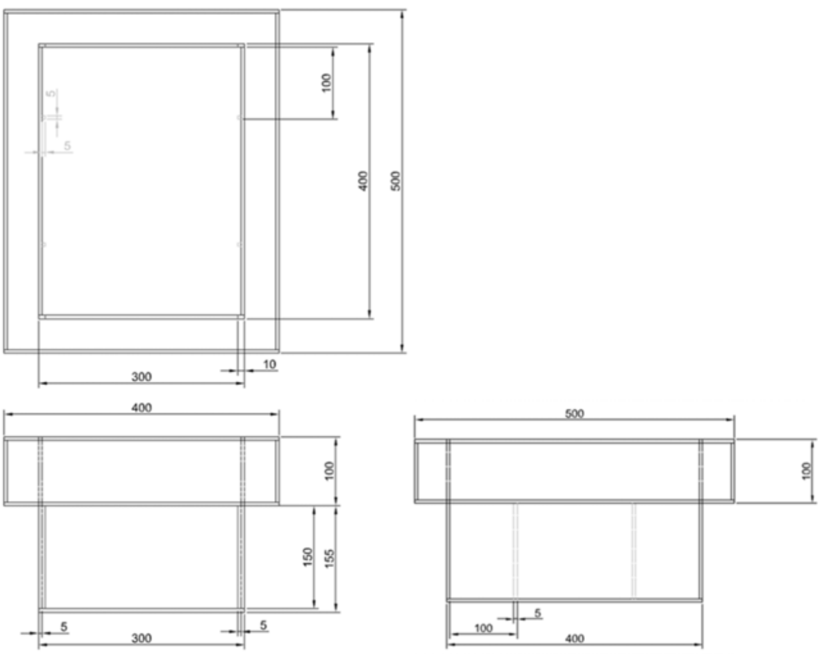
Fig. 2 shows the drawings of the devices for the mock-up test. As shown in Fig. 2(a), a prototype was created in order to find the red-tide removal efficiency of the layers without any scaling downwards from an actual model. Fig. 2(b) shows the actual artificial float that was applied, and which was scaled down to 300-mm wide and 400-mm long, from 6-m wide and 6-m long. In the mock-up test, the number of ceramic carriers that was applied was smaller than that of a real artificial float. Nevertheless, because a suitable number was applied by checking the layers of ceramic carriers and the red-tide algae flow, it was possible to perform this study.

Experimental method using mock-up devices

The mock-up devices utilized to determine the removal efficiency of red-tide algae were created as



(a)



(b)

Fig. 2. Drawings of mock-up test devices employed for the removal of red tide: (a) circular type and (b) scaled-down type.

shown in Fig. 1 and Fig. 2. They were used for the test, as shown in Table 1.

Using two types of mock-up devices, the removal efficiency of red-tide algae and water-flow velocity and current were observed. In the case of the circular-type device, a block layer was applied to create circulation-mode and non-circulation-mode conditions. In the circulation mode, water was circulated in order to observe the changes in flow velocity and water current depending on layers 1 and 2 with ceramic carriers. In the non-circulation mode, Chattonella algae was used as actual red-tide algae; a block layer was installed, and a drainage motor was installed just before the block layer in order for red-tide algae to drain immediately after passing layer 2. The change in the amount of Chattonella algae at the time when red-tide algae

Table 1. Experimental conditions with two types of mock-up test devices.

Mock-up	Experimental	Red tide
Circular type	Removal of red tide (with block layer) Water current with ink (without block layer)	Chattonella algae (red tide)
Scaled-down type	Water current with ink	

Fig. 3. Red tide (Chattonella algae) can be seen in red circle in the scaled-down-type mock-up test device.

passed layers 1 and 2 was measured. In this way, the red-tide algae removal efficiency of the layer with ceramic carriers was examined. In the case of the scaled-down type device, the artificial float was scaled down. For this reason, unlike the circular-type device, it had the test in the water-floating condition without a block layer. Tests conducted with Chattonella red-tide algae indicated that the algae was diluted in all directions by the presence of too much water because there was no block layer, as shown in Fig. 3, and it was impossible to measure the amount. Therefore, the flow pattern of red-tide algae was checked using yellow ink. Layers 1 and 2 had the same length and height, but different thickness values of 45 mm and 80 mm, respectively. Therefore, the change in flow velocity and the difference in the red-tide algae removal effect were compared depending on the thickness.

Red-tide algae and ceramic carriers

Fig. 4 illustrates the ceramic carriers and red tidal current. The ceramic carriers utilized had various sizes. Because it has a porosity of 34.9%, it was expected to remove a lot of red-tide algae. In a previous study, the anti-biofouling effect of ceramic carriers remained for three months, and the test on the red-tide algae removal efficiency for a different type of ceramic carrier revealed a high removal efficiency. Therefore, it was expected to result in a highly efficient removal in the mock-up test. As is the case with Cochlodinium, which is the most harmful algae threatening offshore fish farms, Chattonella algae live off the southern coast of Korea, and it is one of the organisms that cause red

Fig. 4. Ceramic carriers and red tide (Chattonella algae) used for mock-up test.

Table 2. Composition of ceramic carriers.

Component	SiO_2	Al_2O_3	Fe_2O_3	K_2O	CaO	TiO_2
Content (wt%)	63.870	18.144	8.818	3.353	3.166	1.155
Component	MgO	BaO	MnO	Cr_2O_3	ZnO	
Content (wt%)	0.986	0.376	0.089	0.026	0.016	

tide. This study used Chattonella, which has a faster culture speed than Cochlodinium, and which can be cultured easily in order to perform the test.

Table 2 shows the composition of ceramic carriers, which mainly include SiO_2, Al_2O_3, and Fe_2O_3. It was expected that there would be no compositional influence on the removal of red-tide algae.

Results and Discussions

Mock-up test in circular type

In order to check the red-tide removal efficiency, the water current, and flow velocity of membrane layers 1 and 2, the round-shaped mock-up device, which is the most suitable device, was tested first. To determine the flow velocity and water-current pattern, a test was conducted in a circulation mode without a block layer. Fig. 5 presents the initial flow velocity and the change in the flow velocity depending on the type of layer. Regardless of the initial flow velocity, there was a reduction rate of 78% when it passed the 45T layer 1, and the reduction rate was 81~82% when it passed the 80T layer 2. It was determined that the shape and layer structure of the ceramic carriers in the membrane layers led to the creation of turbulent flow after the passage, and therefore resulted in a reduction in the flow velocity. Accordingly, if the flow velocity reduces through the double-membrane layer structure, as in the case of the artificial float, the red-tide algae passing the layers slowly is naturally concentrated; at this time, a pump works in between the layers to enable the red-tide algae to escape, and such a system was used as a filter press to remove red-tide algae, enabling clean red-tide-free water to return to the ocean. Therefore, it is expected that red-tide algae will be removed entirely.

Fig. 6 shows the variation in the amount of red-tide

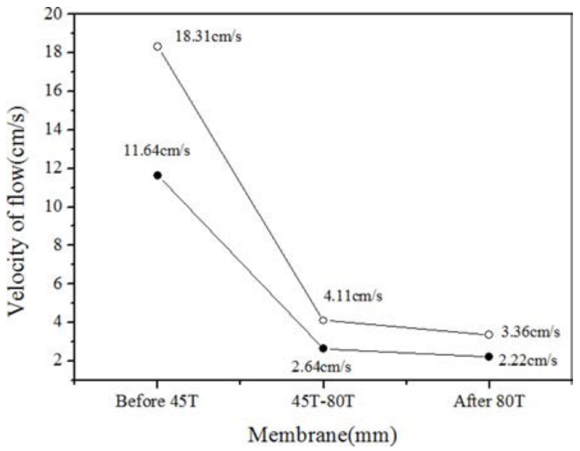


Fig. 5. Velocity of flow before, in-between, and after each membrane layer in the circular-type mock-up test device.

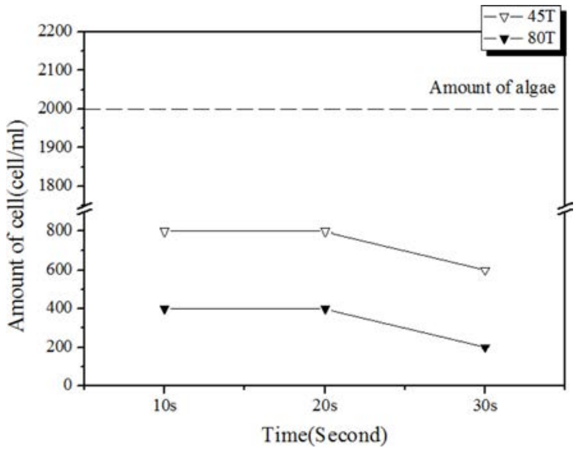


Fig. 6. Number of Chattonella cells with time in non-circulation mode with a block layer in a circular-type mock-up test device.

algae when a block layer is installed in the circular-type mock-up device for the test in non-circulation mode. If the amount of red-tide algae is measured in circulation mode, the red tide that is not removed overlaps with the newly generated red tide after one cycle, and it is therefore difficult to measure the removal efficiency accurately. For this reason, the non-circulation mode was selected. In the non-circulation mode-based test, the water passing the membrane was all drained to be collected separately, and then the red-tide concentration of the drained water was measured. The amount of Chattonella algae was then measured at the initial 2000 cell/ml, 10 s, 20 s, and 30 s after the passage of layers 1 and 2. As a result, the amount greatly reduced to 800 cell/ml 10 s after the passage of the initial 45T layer 1. The result is determined to be drawn, as shown in the previous research, where a large amount of red-tide algae was absorbed by ceramic carriers when they passed ceramic carriers. The reduction rate was higher when they passed the 80T layer 2. This is believed to be because a thicker layer of ceramic carriers was passed and a large

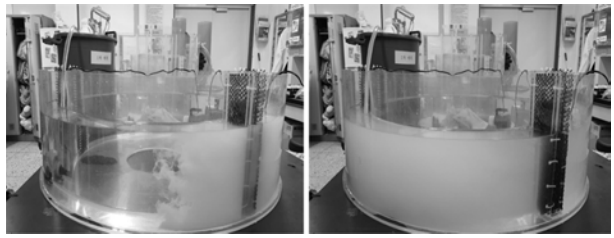


Fig. 7. Flow of yellow ink in a circular test mode without block layer in a circular-type mock-up test device.

amount of red-tide algae was absorbed. In addition, over time, the reduction efficiency increases. The result was natural as the test was conducted in a non-circulation mode.

Fig. 7 shows the mock-up test after the injection of yellow ink, which was used to predict the red-tide algae current pattern in a circulation mode. Ink was found to flow slower (35 s) than in the case without layers 1 and 2 (7 s). The results showed that it was possible to provide a sufficient time for red-tide algae to remain between layers. Nevertheless, it was impossible to observe the reduction effect of the layer passage because of the high concentration of ink and tiny particles.

Mock-up test of scaled-down type

In the scaled-down-type mock-up device, the red-tide current pattern of the artificial float was inferred, and the influence of the scaled-down layer on the flow velocity was analyzed. Fig. 8 shows the variation in flow velocity in the scaled-down mock-up device. The flow velocity decreased in a way similar to that of the circular-type mock-up device. Therefore, it was found that the tendency of the circular-type device was similar to that of the scaled-down-type device, and that the size and layer structure of ceramic carriers had the most significant effect. If ceramic carriers with high porosity are layered in the smallest size compactly, it will be possible to slow the flow velocity most efficiently and remove red-tide algae. To determine the red-tide algae removal efficiency in the scaled-down mock-up device, a test was conducted. As shown in Fig. 3, the scaled-down mock-up device had a lot of water, so the Chattonella algae tended to be diluted. For this reason, although the amount of Chattonella algae was checked immediately after the test, it was impossible to measure the precise amount and determine the red-tide algae removal efficiency. Given the flow-velocity test conducted earlier, it is expected that the scaled-down-type device has the same or similar red-tide algae removal efficiency as the circular-type and scaled-down-type devices show a similar mock-up pattern.

Fig. 9 shows the flow test with yellow ink, which is used to find the current pattern of red-tide algae in the scaled-down mock-up device. As shown in the circular-

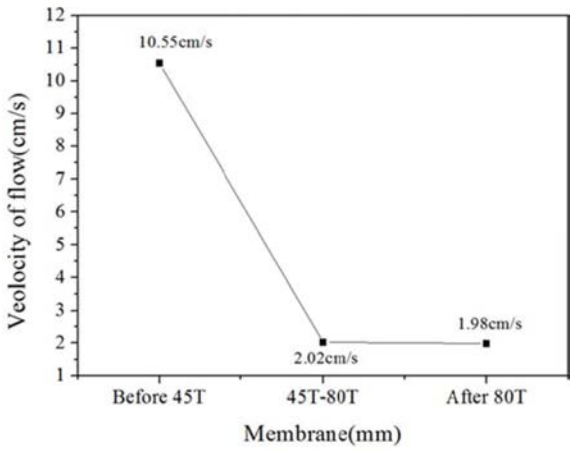


Fig. 8. Velocity of flow before, in-between, and after each membrane layer in the scaled-down mock-up test device.

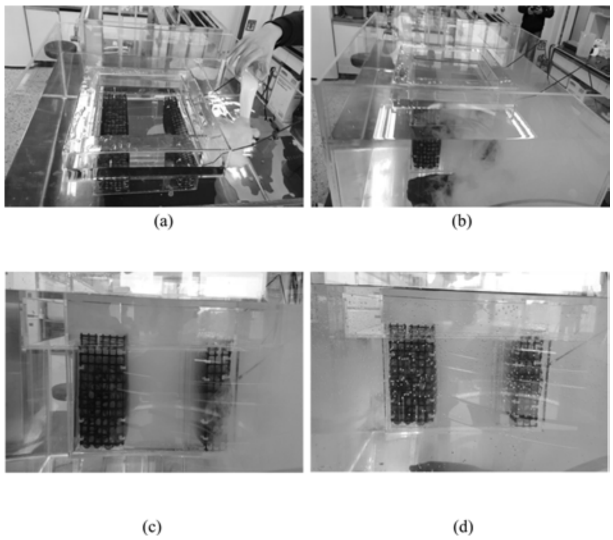


Fig. 9. Flow of yellow ink current in a scaled-down-type mock-up test device. (a) Pouring ink in front of layer 1, (b) 5 s after pouring, (c) 20 s after pouring, and (d) 40 s after pouring.

type device, it was observed that yellow ink slowed in speed in terms of the red-tide algae current in the scaled-down mock-up device. From the results, it was again shown that the two types of mock-up devices had similar results. In Fig. 9(d), yellow ink was still passing beyond layer 2. This is attributed to the absence of a protective shield between the mock-up test device and the tank, and because ink, which is a solution (as opposed to particles), is not absorbed by ceramic carriers. Accordingly, the purpose of this test was to observe the speed with which ink spreads. It was found to make red-tide algae stay longer between layer 1 and layer 2 in terms of reducing the flow velocity of red-tide algae. Therefore, if it is possible to efficiently remove the concentrated red tide between the layers within the additional secured time, it is believed that the proposed method can minimize the damage to offshore fish farms.

Conclusions

In this study, to reduce the extensive red-tide-induced damage to offshore fish farms, a mock-up test was conducted in order to determine the red-tide algae removal efficiency, water current, and flow velocity of the laboratory-sized artificial float that was developed. The mock-up devices were classified as a circular-type and scaled-down-type devices. According to the analysis on the flow velocity of layers 1 and 2 in the circular type, the flow velocity was reduced and the removal efficiency of the red-tide algae was found to have increased after the passage of the layers. It was determined that ceramic carriers in the layers were absorbed into the red-tide algae, thereby decreasing the amount of red-tide algae. For the scaled-down type, the red-tide algae were diluted, making it impossible to verify the reduction efficiency. The flow velocity, and yellow ink flow pattern of the scaled-down-type device were similar to those of the circular-type device. As a result, the scaled-down-type device was expected to remove red-tide algae effectively. In conclusion, the red-tide removal efficiency of the artificial float was verified in the mock-up test, and the efficiency was 60% at the time of passage by layer 1, and 80% after the passage of layer 2. The above figures show the red-tide removal efficiencies after the flow passes through the two layers; however, if red-tide algae remain in layers 1 and 2 for a longer period to increase the concentration of red tide, after which it is removed entirely using the pumping and filter press method, a removal efficiency of at least 99% is attainable.

Based on the mock-up test, it was possible to concentrate red tide to slow the red-tide flow between membrane layers, and to remove the concentrated red tide effectively using the pumping and filter press method. In addition, it was found that the red-tide removal efficiency reached 80% only with the use of the ceramic carrier-based membrane. If an artificial float is actually used in the ocean based on the data in this mock-up test, it is believed that the ceramic membrane-based artificial float will effectively remove red tide, and may become a fundamental measure to prevent red tide.

Acknowledgments

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