Research on Anti-biofouling Technology of Ocean Observation Instruments based on Ultraviolet Method

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Abstract: Ocean observation equipment is an important tool for marine survey, development and protection. Because of being placed in sea water for a long time, the research on its anti-biofouling technology is also of great significance. This article discusses the formation principle of biological attachment, and introduces the commonly used methods, according to the classification of active and passive manner, and development status of seawater anti-biofouling technology. Then, according to the characteristics of marine observation instruments, this article in particular introduces and recommends the principles and application cases of the ultraviolet radiation method for anti-biofouling. Ultraviolet anti-biofouling technology can effectively reduce the degree of biological attachment on ocean observation sensors and significantly increase the deployment time of ocean observation instruments. Therefore, it can reduce maintenance costs and improve data quality. It is a very important way for the cabled ocean observation sensor systems to prevent biological attachment.

1 INTRODUCTION

Since the 20th century, countries around the world have paid more and more attention to the impact on humans and animals caused by the changes of marine environment. Marine observation instruments and equipment are important tools for conducting marine surveys and research, ecological observation, scientific development, and marine environmental protection. Therefore, their work characteristics and quality are directly related to the level and benefits of these activities. These ocean observation instruments generally use a large number of optical, acoustic, electrical, chemical, and biological sensors (Yebra et al., 2004). A small amount of adhesion of marine organisms on the surface of the sensitive components of these sensors may cause serious damage to the working performance of the devices (Babin et al., 2008; Onuf, 2006; Lobe & Das, 2010; National Marine Information Center, 2013). As a result, serious hazards such as the failure of the instrument transmission mechanism, signal distortion, performance degradation, shortening of service life and even potential safety hazards may happen and cause huge economic losses. Therefore, preventing marine organisms from attaching is an important guarantee for the long-term operation of marine observation instruments and the acquisition of accurate and reliable data (Yu et al., 2006; Wang et al., 2016).

In summary, the research on methods and technologies for marine observation instruments to prevent biological attachment is of great significance. A stable, reliable, flexible and controllable technology for preventing biological attachment of marine observation instruments with a wide range of applications is essential for protecting marine observation instruments and improving the quality and stability of marine observation data. This article will introduce the anti-biofouling technologies and methods commonly used in marine observation instruments and focus on the principles and applications of the ultraviolet anti-biofouling method used in this project. It is expected to provide some technical guidance and application ideas for those who want to use the ultraviolet method for seawater anti-biofouling technology applications.

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2 DEVELOPMENT STATUS OF SEAWATER ANTI-BIOFOULING TECHNOLOGY

Anti-biofouling technology is a method to prevent organisms from growing and accumulating on the surface of underwater structures. There are many classification methods for anti-biofouling technologies. For example, Lehaitre et al. (2008) divide them into active methods and passive methods. There are many active anti-biofouling strategies, such as physical decontamination technology, interval immersion disinfection technology, partial electrolytic chlorine technology, ultraviolet(UV) light technology, etc. (Shan et al., 2011). Passive methods are the most commonly used methods in traditional industries, mainly using various anti-fouling coating to prevent the attachment of organisms (Lei et al., 2017). At present, the common anti-biofouling technologies applied to marine observation instruments mainly include anti-fouling coatings, mechanical methods (such as electric brushes), electrochemical methods (electrolysis of copper sheets surrounding the sensor), and UV light irradiation (Blanco et al., 2013; Delauney & Compere, 2008).

The anti-fouling coating method is mainly used for shell anti-fouling in the field of marine observation instruments. At present, the commonly used chemical anti-fouling coatings mainly include tin-free self-polishing anti-fouling coatings, fouling release anti-fouling coatings and conductive coating anti-fouling coatings, etc. (Wu et al., 2017). These chemical coatings are more or less toxic, which is not conducive to the health of users and marine environmental protection. Moreover, this method is relatively mature in the application of ships, stations and other large equipment, and most of the applications in ocean observation sensors remain in the research stage (Cao et al., 2020).

YSI's water quality multi-parameter sensor uses a brush system to brush off the attachments on the sensor probe. This method works better when the brush system is normal and the components are precisely matched, but once the bristles are deformed and the gap between the brush head and the sensor probe becomes larger, the effect becomes worse (Shan et al., 2011). In addition, this method has higher requirements on the reliability of the motor rotating seal, and it is more difficult to be applied to the protection of the spherical surface (Wu et al., 2017).

Electrochemical methods are the most widely used ways because they are effective for both micro biofilms and large attachments. This kind of anti-biofouling device generally uses titanium as an electrode, and generates a sterilizing agent to kill attachments through electrolysis. Delauney and Compère selected a salinity sensor, a dissolved oxygen sensor and a fluorometer to verify the technology. Their experiments have shown that the effect of this method is very good (Bixler & Bhushan, 2012), but the sterilant produced during the action of this method will affect the accuracy of part of the data collected by the sensor which may cause instrument measurement errors and reduce the accuracy of the data.

The UV light irradiation method uses specific wavelength UV light to destroy bacteria and other microorganisms, thereby to prevent the adsorption of bacterial biofilm on the surface of marine instruments and the growth of plankton larval cells, and then to eliminate the proliferation of high-grade marine biological cells such as algae and shellfish in the later period. Eventually, the growth and attachment of organisms are completely stagnated (Bueley, 2014). The advantage of the anti-biofouling methods based on UV light irradiation is non-contact, non-chemical and can be applied to a variety of sensor materials and geometries without causing any marine pollution. Therefore, it has wider applicability than the above-mentioned various strategies, and it can significantly increase the deployment time of ocean observation instruments, thereby reducing maintenance costs and improving data quality.

3 PRINCIPLES OF UV ANTI-BIOFOULING TECHNOLOGY

At present, people of this industry generally believe the development of marine biological attachments is divided into five stages (Delauney et al., 2010; Prakash et al., 2015). In the first stage, the attached body immediately adsorbs organic and inorganic molecules on its surface after being immersed in seawater, thereby forming a primary film.In the second stage, microbial cells such as bacteria are transported and fixed on the surface of the primary film.In the third stage, microbial cells such as bacteria begin to produce extracellular polymer networks to form microbial membranes.In the fourth stage, an increasingly complex community composed of simple multicellular organisms, microalgae and sediments began to develop.In the fifth stage, higher marine organisms such as barnacles and mussels gradually attach and grow, forming large-area, high-coverage attachment forms.The development of the above five stages is based on the biofilm formed by bacteria and cell networks. Fundamentally, the main mechanism of these biofilm formation is the proliferation of colonizing cells. UV light exactly prevents the further attachment of marine organisms by destroying the reproduction of such cells.

When short-wave UV light (wavelength 240nm~280nm) irradiates microbial cells such as bacteria, most of the UV radiation in the spectrum is absorbed by the nucleotides in DNA, which leads to the destruction of DNA and the growth,which in turn leads to the growth and regeneration death of microorganisms. The formation of organic film and colonization tissue on the surface of the attached body is further inhibited. Higher-order communities cannot form and develop, so the purpose of preventing biological attachment is achieved.

The performance of the UV anti-biofouling technology depends on the UV radiation fluence, that is, the fluence rate of the irradiated surface with time. To calculate the fluence, the fluence rate need to be obtained firstly. According to Beer Lambert's law, the relationship between the fluence rate of a ray and its propagation distance and the medium it passes through is shown in the following equation (Nabulsi et al., 2012):

$$\mathrm{I} = \mathrm{I}_x e^{-(kx)}, \qquad k = \alpha + \sigma \tag{1}$$

In formula (1), I is the fluence rate. Ix is the initial fluence rate. x is the ray length. α and β are respectively the absorption coefficient and scattering coefficient of a given medium. As we all know, at the intersection of two media, light is both refracted and emitted. The Fresnel equation describes the relationship between the fluence rate of refracted and reflected light and the transmittance and reflectance (Gupta et al., 2019), which is shown below:

$$R_0 = (\frac{n_1 - n_2}{n_1 + n_2})^2$$

$$R = \begin{cases} R_0 + (1 - R_0)(1 - \cos\theta_i)^5, & n_1 \le n_2 \\ R_0 + (1 - R_0)(1 - \cos\theta_t)^5, & n_1 > n_2, \theta_i \le \theta_{crit} \\ 1, & n_1 > n_2, \theta_i > \theta_{crit} \end{cases} \tag{2}$$

$$T = 1 - R$$

where R and T are respectively reflectance and transmittance. θ_i and θ_t are the incident angle and refraction angle. θ_{crit} is the critical angle at which total internal reflection occurs. The calculation method is: $sin\,\theta_{crit} = \frac{n_1}{n_2}$. It can be concluded that when a given light interacts with the interface of two media, the fluence rates of reflected light and transmitted light are respectively the product of incident light fluence rate and the reflectance and transmittance. The equations are as follows (Gupta et al., 2019):

$$\begin{aligned} I_{reflected} &= I * R \\ I_{transmitted} &= I * T \end{aligned} \tag{3}$$

Therefore, when UV rays travel through different media, formulas (1) ~ (3) can be used to calculate the energy density and angle of the light source, which can be used to estimate the fluence rate of the UV lamp irradiation position. Based on this, a fluence rate contour map is generated for each UV LED module, and an air-calibrated model is used to estimate the fluence rate incident on the surface of each sensor placed in seawater.

4 APPLICATIONS OF UV ANTI-BIOFOULING TECHNOLOGY

At present, in the field of ocean observation, company AML launched anti-biofouling products based on the principle of UV light in 2014. It was applied on the Folger Pinnacle scientific platform of the Canadian Ocean Observation Network. The biological attachment at the location of this scientific platform is very serious. After the instrument has been placed on the seabed for 12 months, the unprotected sensor has been heavily attached, including the probe, but the probe of the protected sensor is clean, and the degree of contamination of the remaining part is better than that of the unprotected sensor. The actual situation is shown in Figure 1. As shown, the left and middle sensors are protected, and the right one is unprotected. The detection probes and adjacent structures of left and middle sensors are effectively protected, and only light microorganisms are attached. The detection probe and adjacent structures of unprotected sensor have been covered a large number of medium and high-level attachments. The comparison of test data shows that the turbidity and conductivity data of unprotected sensor gradually deviated from the true value after 1 month, while the protected sensors followed the true value well within 12 months (Wu et al., 2017).

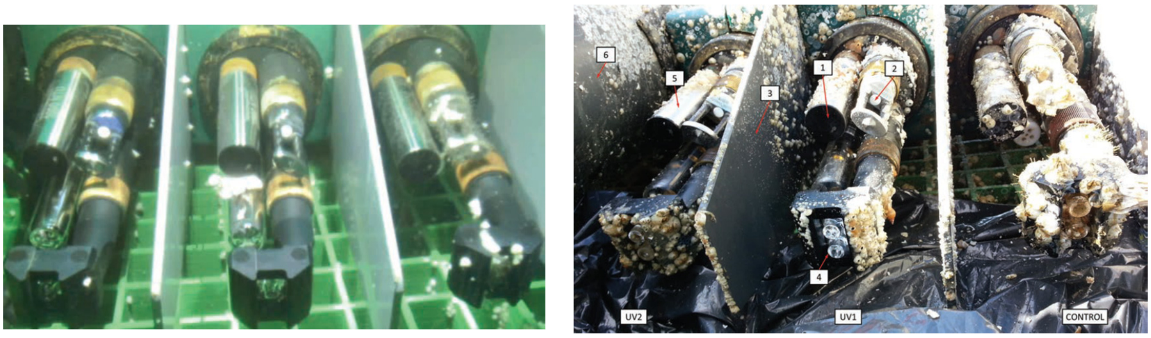

Figure 1: Test results of UV anti-biofouling products from AML.

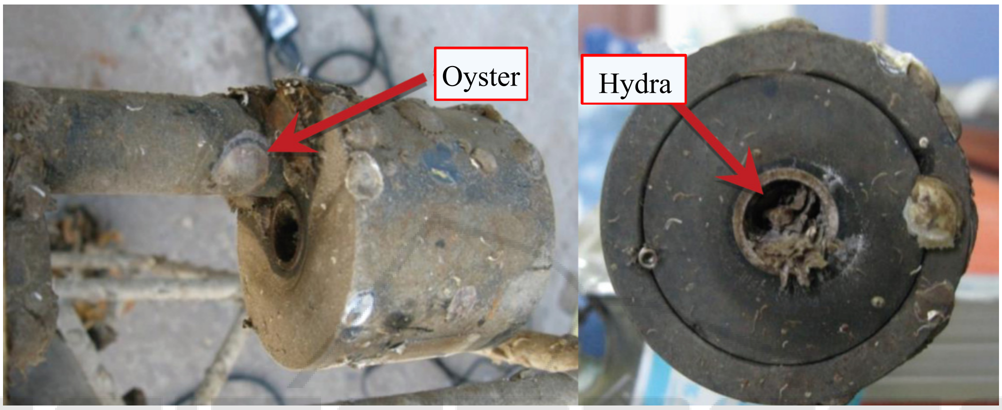

Figure 2: Domestic CTD without anti-biofouling measures.

The National Ocean Technology Center designed and developed a CTD anti-biofouling device based on the principle of UV sterilization, and conducted a comparative test on the coast of the Bohai Sea from June to September in 2017 (Lan et al., 2019). The test equipment includes a Domestic CTD (No.1702#) without any anti-biofouling device, a Domestic CTD (No.1610#) with a UV anti-biofouling device, and a SBE37 CTD with a slow-release anti-biofouling component (No.5500#). The working modes of the three instruments are basically synchronized, and they perform measurement and data storage tasks independently without affecting each other. After nearly 3 months of continuous testing and comparison, it was found that the diversion tube in No.1702# conductivity probe was almost completely blocked by organisms such as oysters and polyps, and normal measurement was no longer possible. which is shown in figure 2. The No.1610# conductivity probe is located in the UV radiation range and there is no sign of marine attachments. which is shown in figure 3. The inner wall of the ceramic draft tube is clean and free of foreign matter, which has a significant effect of preventing biological attachment. There are a large number of marine organisms attached to the exterior of No.5500# conductivity cell protective cover, and the slow-release anti-biofouling component of the conductivity cell has been partially invalidated due to the long deployment time. At the same time, analysis of the collected data found that No.1610# was significantly better than No.1702# in terms of the stability and accuracy of salinity data determination and the amount of instrument drift.

Figure 3: Domestic CTD with UV anti-biofouling device.

5 CONCLUSIONS

In summary, the UV anti-biofouling technology and method can effectively slow down and prevent the biological adhesion on ocean observation sensors. At the same time, compared with other methods, the UV irradiation method can achieve more efficient and targeted fixed-point protection effects on any angle and area, any material and shape, and it can achieve a good anti-biofouling attachment effect on ocean observation sensors and their connecting accessories and frame structures. This method can effectively extend the maintenance cycle and service life of ocean observation instruments, greatly improve the deployment time of sensors and the stability of monitoring data. This method can greatly save human and material resources, and improve the technical capabilities of ocean observation and development.

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