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Inactivation of Cyanobacteria by Underwater Shock Wave

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Abstract. A treatment of underwater shock wave was proposed to solve this problems which the harm caused by cyanobacteria blooms. Underwater shock wave technology has the features of energy saving, environmental protection, safe and efficient. The underwater shock wave technology effective performance for the removal of cyanobacteria was investigated. The results obtained from on-site algae water showed that the initial chlorophyll-a content of Taihu Lake wild algae is 216.22 $\mu\text{g/L}$, after applying with the optimum working conditions treatment, the chlorophyll-a of the treated group is only 3.84 $\mu\text{g/L}$ at the ninth day, while the concentration of chlorophyll-a was 209.87 $\mu\text{g/L}$ in control group after 9 days of culture, the average removal rate was 98.22%. The initial algal toxin level in the wild algae in Taihu Lake was 4.23 $\mu\text{g/L}$, after treatment with underwater shock wave, the concentration of algae toxin in the treatment group decrease below the limit of detection (0.1 $\mu\text{g/L}$) after 1 day of algae culture, meanwhile, the control group increased to 4.36 $\mu\text{g/L}$. The contents of TN, TP and COD in the treatment group were lower than the control group with the underwater shock wave treatment. The results indicated that the underwater shock wave cannot only inactivated the wild cyanobacteria, but also can improve water quality.

1. Introduction

Cyanobacteria are the most primitive and oldest algae in prokaryotes. They can adapt to different environments, especially for high temperature and high salt, it has strong adaptability. In recent years, cyanobacteria blooms have been reported in the world (including at least 108 countries) due to eutrophication of water bodies [1]. The annual economic loss caused by cyanobacteria blooms is about 1.5 billion in the United States [2]. The occurrence of cyanobacterial blooms not only causes deterioration of water quality, but also affects the ecological environment. What is more serious is that some types of toxins can affect human health [3].

Underwater shock wave technology, the basic principle is that the power supply is charged for a long time, the electric energy is stored in the capacitor, and released from the electrodes in a short time (millisecond or microsecond), a pulse current of 10^3 - 10^5 A is formed between the electrodes at the moment of discharge, the energy density is as high as 10^8 - 10^9 J/m³, cause high temperature of 10^3 - 10^5 K and high pressure of 10^8 - 10^9 Pa. The high temperature and high pressure environment creates a dense plasma between the discharge channels, forming a plasma channel, and the expansion of the plasma channel generates shock waves [4]. There are a number of studies on shock wave propagation in fluids and so its properties are well documented. Shock wave pressure can be calculated using the Hugoniot equations [5].

$$P = \rho_0 u_s u_p \quad (1)$$

$$u_s = A + B u_p \quad (2)$$

where P is the pressure of a shock wave, ρ_0 is the density of water, u_s is the shock wave velocity, u_p is



the particle velocity, and A is 1.45 km/s (acoustic sound velocity in water), and B is 1.99[6]. Therefore, P can be expressed as a function of measurable u_s as

$$P = \rho_0 u_s (u_s - A) / B. \quad (3)$$

So far, underwater shock wave technology has been widely used in wastewater treatment, food processing, microbial inactivation, biomedical and other fields[7-11].

2. Materials and Methods

2.1 Study Site and Sampling

Cyanobacteria samples were obtained from Lake Taihu. Lake Taihu, which covers an area of 2300 km², is the third-largest shallow freshwater lake in China, and is one of the most severely eutrophic lakes in China. Serious algal blooms have occurred annually during late spring and autumn. Here, the cyanobacteria samples were collected using plastic drums and transported to the laboratory within 4 h. All samples were treated within 24 h.

2.2 Experimental Setup and Procedure

Connect AC mains, AC voltage regulator, 5kV high voltage transformer, 0.5μF/30kV high voltage non-inductive capacitor, 30kV/2A rectifier diode, current limiting resistor, 0-100kV high voltage voltmeter, high voltage switch, needle electrode and high voltage wire are connected to form a closable circuit. After the power is turned on, the current is temporarily stored in the high-voltage non-inductive capacitor through the transformer, the rectifier diode, and the current limiting resistor. When the electrical energy within the capacitor needs to be released, the high-voltage switch is closed to release the electric energy stored in the capacitor to a pair of needle electrodes in the water treatment reaction chamber.

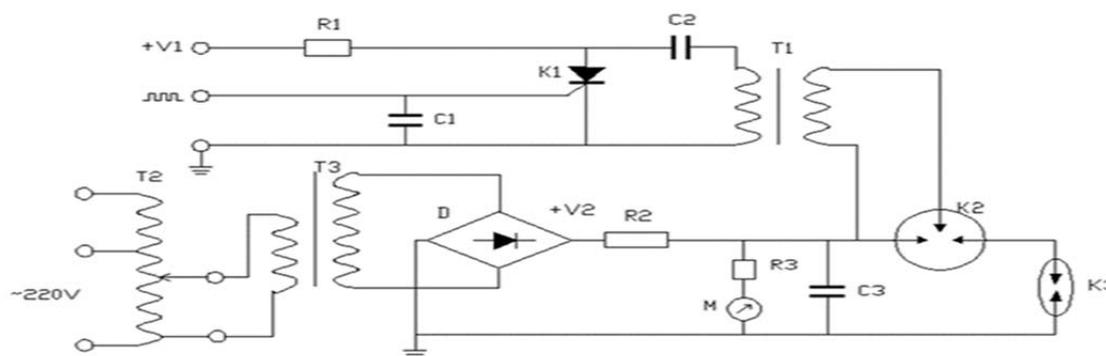


Figure 1. Experimental device

250 ml of algae water obtained from Lake Taihu was poured into the water treatment reaction chamber of the liquid electric device, and discharged 200 times with a discharge voltage of 5kV (The best parameters obtained in the previous experiments). The treated algae water was poured into a 250 ml Erlenmeyer flask at a temperature of $24 \pm 1^\circ\text{C}$, the irradiation time is 12 hours / 12 hours - light / dark cycle with 2000lux light intensity. At the same time, an untreated control group under the same experimental conditions was established, the samples are taken out for analysis at appropriate time intervals. Observing the content of chlorophyll a and the level of algal toxin between the treatment group and the control group. And the changes of total nitrogen, total phosphorus and COD values, initially evaluated the inactivation effect of liquid electric effect on wild algae in Lake Taihu.

3. Results and Discussion

3.1 Variation in Concentrations of Chl-a

Studies have shown that within 24 h after the pulse discharge system inactivates *Microcystis*

aeruginosa, the content of chlorophyll a increases, then decreases with the increase of culture time, and decreases to 0 on the fifth day [12]. The results of this experiment are shown in Fig.2. That the chlorophyll a content immediately after treatment increased to 1.53 times before treatment, about 2989.97 $\mu\text{g} / \text{L}$, and the chlorophyll a content reached the highest at 24 h after treatment, about 3701.01 $\mu\text{g} / \text{L}$. After 24 h, the chlorophyll a content gradually decreased, the average level of chlorophyll a was only 56.46 $\mu\text{g}/\text{L}$ on the 9th day after treatment. Indicating that the underwater shock wave destroyed the photosynthesis system of algae cells, and chlorophyll a is released, when the number of damaged algae cells reaches a certain level, the release of chlorophyll a content reaches the highest, when the culture time continues to extend, chlorophyll a is gradually reduced.

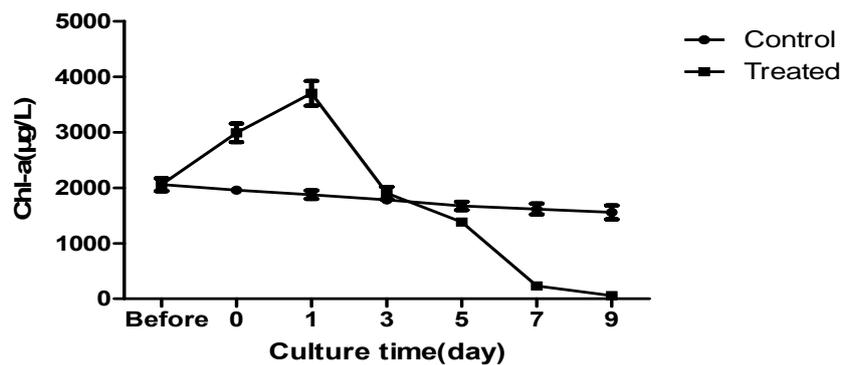


Figure 2. Chl-a content in the control and treatment groups

3.2 Variation in Concentrations of Algal Toxin

The underwater shock wave can cause cell rupture and disintegration to release algal toxins in the algae cells. So the level of algal toxin in the algae solution increases immediately after the treatment, the amount of damaged cells reaches the highest and the level of the content released by the cells reaches the maximum when cultured for one day after the treatment. Studies have shown that high-pressure discharge can remove various organic substances in aqueous solution, such as interface glow discharge can oxidatively degrade microcystins in water [13]. The results of this experiment are shown in Fig.3. That the initial algal toxin level of the algae was 4.12 $\mu\text{g}/\text{L}$, and the concentration of algal toxin in the control group increased slightly after 1 day, which was 4.24 $\mu\text{g}/\text{L}$. In contrast, the level of algal toxin in the experimental group increased significantly to 5.20 $\mu\text{g}/\text{L}$ immediately after treatment, while the concentration of algal toxin in the treatment group decreased below the detection limit (0.1 $\mu\text{g}/\text{L}$) after 1 day of treatment, and then it was undetected. That is, the underwater shock wave technique has a significant degradation effect on the algal toxin in wild algae water of Lake Taihu.

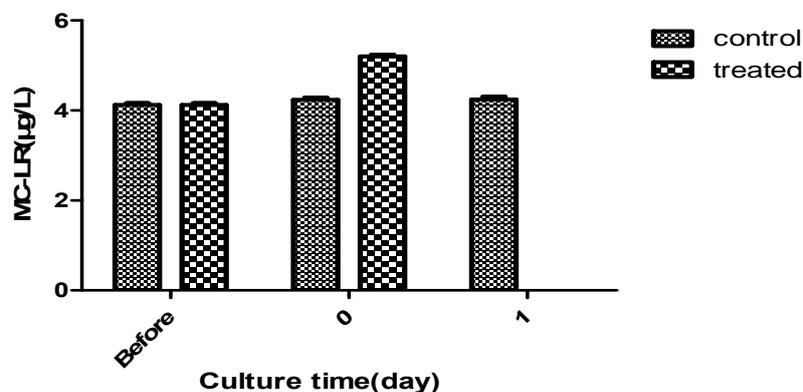


Figure 3. The concentration of algal toxin in the control and treatment groups

3.3 Variation in Concentrations of Total Nitrogen, Total Phosphorus and COD

As shown in Fig. 4, the initial total nitrogen content in the algae water was 3.56 mg/L, and the level of total nitrogen in the control group was 3.69 mg/L after 5 days of culture, which remained basically unchanged. The total nitrogen content of the treatment group increased to 4.89 mg/L immediately after the underwater shock wave treatment, the level of total nitrogen decreased to 1.46 mg/L on the first day after treatment, and the level of total nitrogen is 0.96 mg/L on the 5th day after the culture.

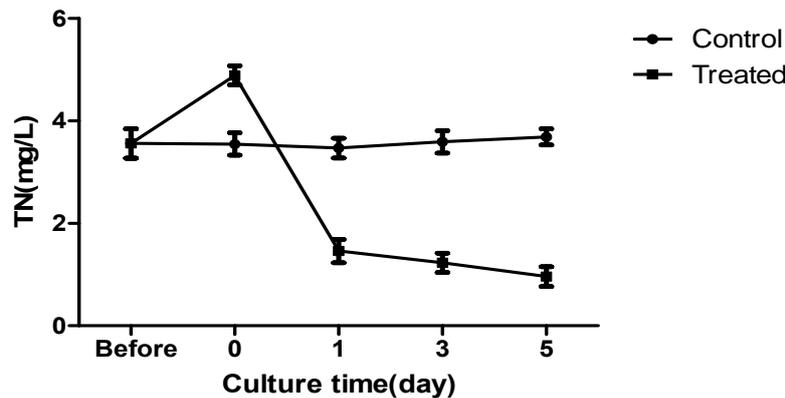


Figure 4. Variation in concentrations of total nitrogen in water

As shown in Fig. 5, the initial total phosphorus content in the algae water was 0.46 mg/L, and the level of total phosphorus in the control group was 0.41 mg/L after 5 days of culture, which remained basically unchanged. The total phosphorus content of the treatment group decreased to 0.28 mg/L immediately after the underwater shock wave treatment, the level of total phosphorus increased to 0.42 mg/L on the first day after treatment, then gradually decreased. And the level of total phosphorus decreased to 0.14 mg/L on the 5th day after the culture.

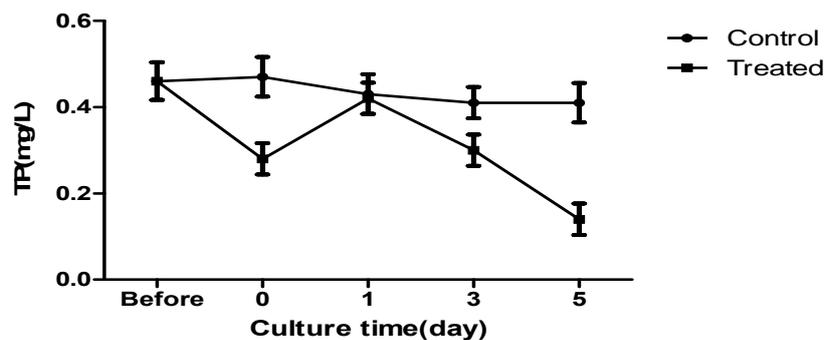


Figure 5. Variation in concentrations of total phosphorus in water.

As shown in Fig.6, the initial COD content in the algae water was 12.87 mg/L, and the level of COD in the control group was 13.52 mg/L after 5 days of culture. The COD content of the treatment group decreased to 8.58 mg/L immediately after the underwater shock wave treatment, the level of COD increased to 11.23 mg/L on the first day after treatment, and the level of COD decreased to 6.59 mg/L on the 5th day after the culture.

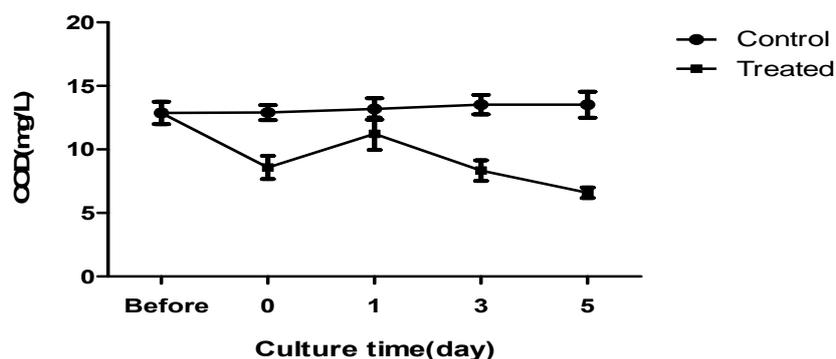


Figure 6. Variation in concentrations of COD in water

The total nitrogen content in the water increased sharply and the total phosphorus also increased after the underwater shock wave treatment. However, the levels of total nitrogen, total phosphorus and COD in the water were lower than those without treatment after treatment for several days. This may be due to the high heat, high pressure, strong electric field, plasma, etc. in the liquid discharge process. The plasma generated in water mainly includes hydrogen atoms, oxygen atoms, free radicals, O_3 , H_2O_2 , etc. in different excited states. Among these particles, $\cdot OH$, $\cdot O$, H_2O_2 , O_3 are essential for the occurrence of chemical reactions, and $\cdot OH$ plays an important role in the inactivation of microorganisms and the degradation of organic matter [14]. At present, plasma generated by high-voltage pulse discharge shock wave technology is widely used to degrade p-chlorophenol, pyridine organics, algae toxins, etc. [15,16].

4. Conclusions

In order to observe the effect of underwater shock wave on inactivation of wild algae in Lake Taihu, the wild algae in Taihu Lake were treated with the best discharge parameters in the experimental study. The results show that the efficiency of inactivation of wild algae in Lake Taihu can reach 96.4% by underwater shock wave, although the level of algal toxin in the water increased immediately after treatment, the algae toxin was degraded after 1 day of static culture. The levels of total nitrogen, total phosphorus and COD in the water were also lower than those without treatment. Therefore, the underwater shock wave technology can be used as an effective environmentally friendly algae-killing method when cyanobacteria blooms.

5. References

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