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# Study on the removal of algae from lake water and its attendant water quality changes using ultrasound

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ABSTRACT

The use of ultrasound for removing algae under different conditions, in particular under the optimal ultrasonic parameters, and the changes of the sample water quality indicators have been investigated. The results indicate that ultrasonic irradiation could efficiently remove the algae taken from Taihu Lake. Under 20 kHz with 30 W ultrasonic power and 360 s ultrasonic irradiation, the algae removal efficiency reached up to 96% when a low-concentration algae solution was considered. Also, the water quality indicators of the sample were significantly improved after ultrasound treatment, especially for the low-concentration algae solution. The highest removal efficiency of the chlorophyll a (Chl-a), microcystins, total nitrogen, total phosphorus, and chemic oxygen demand at the optimal condition was determined as 26.2, 96, 86, 63, and 60.9% in comparison with the control samples without ultrasound (no US), respectively, and the final value of which were 0.2, 0.01, 0.6, 0.065, and 15.7 mg/L, respectively. The results suggest that ultrasonic irradiation can not only provide an effective method for algae removal but also have a significant improvement for the quality of water.

*Keywords:* Ultrasound; Algae removal; Water quality

## 1. Introduction

Blue-green algae bloom occurs during the summer season in more than half of the lakes and reservoirs in China, which is becoming a serious water quality problem for public and private water supplies. The presence of algae in drinking water causes acute disturbance of taste and odor as well as clogs in the filter system [1]. Besides algae are known to cause many health hazards to humans, including skin rashes, gastrointestinal and respiratory diseases [2], allergic reactions [3], and liver cancer [4]. Another significant concern is that some toxic algae species, such as *Microcystis aeruginosa*, may release microcystins into water [5]. Currently, microcystins are widely researched because of its strong toxicity and vast distribution. According to the WHO's publication guidelines for drinking-water quality, the value for total microcystin-LR is 1 μg/L for safe drinking water [6].

Nowadays, lots of works have been done in restraining the blue-algae bloom at home and abroad.

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A number of approaches to control algae growth are currently available or under investigation, which include minimizing nutrient loading, ecological engineering methods and addition of algaecides [7–9]. However, these methods are often money- or time-consuming or need additional chemicals. Compared with these methods, ultrasound is an environment friendly technology for that it does not require additional chemicals [10–15]. And another important advantage of ultrasound might be that it is sufficient to treat the surface water only and not the whole water body (in contrast to centrifugation). The mechanism of ultrasonic treatment for algae is the mechanical, thermal, and acoustic cavitation effects [16], which could efficiently destruct the key components (e.g. gas vesicle) of the cyanobacteria. As a consequence, the cyanobacteria cells lose buoyancy and sediment to the bottom, we called this phenomenon "removal of algae." According to G.M. Zhang experiment [17], indicating that when *M. aeruginosa* was sonicated using 25 kHz ultrasound (intensity of 0.32 W $cm^{-3}$) for 5 min, the absorbances of both chlorophyll a (Chl-a) and phycocyanin (photosynthetic pigment) were reduced. This research concluded that ultrasound damaged the photosynthetic function in cyanobacteria-inhibiting photosynthesis thus impairing cyanobacterial growth. Also, ultrasonic treatment for algae has features of simple operation and easy introduction of automation, which making the application of ultrasound in water treatment develops rapidly. [18].

Currently, some researches believe that high ultrasonic power can effectively remove algae by mechanical and thermal effects [19–21]. But they ignored that this method is energy-consuming and could even lead some animals to death when compared with low ultrasonic power methods [22]. Furthermore, with the ultrasonic frequency increased, there would be more power required to achieve the same degree of cavitation obtained at lower frequencies because of the shortening in rarefaction phase for the formation of cavitation bubbles [16,22,23]. In order to achieve large-scale cyanobacterial bloom control, the use of ultrasound must be balanced between the frequency employed and the power consumed, and the energy demand must be further minimized. Some studies showed [24–26] that the use of low frequency and low power ultrasonic irradiation to control or remove algae was an efficient and safe way. Therefore, from the perspective of economy and security, low ultrasonic power and low frequency are considered more suitable for treating algae in large and complex water environment, such as Taihu.

The effects of ultrasonic parameters (e.g. power and frequency) on removing algae will be subsequently discussed in this paper, especially the low ultrasonic frequencies and low ultrasonic power. Under these selected parameters, we have investigated the changes of the algae samples and its water quality indicators before and after utilizing ultrasound. All of these experiments were aiming at establishing a fast, efficient and environmental friendly algaecide system in response to algae bloom outbreaks in the future. Additionally, through this study, we provide a theoretical basis to control algae growth from the perspective of the changes of nutrient elements (such as nitrogen and phosphorus) when the algae suspensions are treated by ultrasound.

## 2. Materials and methods

All experiments were carried out for three times in the same condition to obtain the average data.

### 2.1. Materials

The test material was indigenous blue-green algae containing *M. aeruginosa*, which was taken from the Lake of Taihu, China, during the bloom of algae in 2011. The samples were cultured at 28℃ ± 2℃ in Erlenmeyer flasks with BG11 [27] medium at pH 7.0–7.2 (Table 1), Illumination provided was a tube fluorescent light tube (YZ30RR25, Philips, Netherlands) mounted in an incubator (GZP-250, Jinghong Experimental Equipment Co, Ltd, Shanghai), while the light intensity was set to 150 μmol photons/m2/s (12 h dark, 12 h with light). The flasks were manually agitated every three to four times a day. In addition, both of the control samples (no US) and the treated samples (with US) were cultured in this condition. But the samples were not shaken again after the ultrasound treatment.

Fig. 1 shows the sketch of the actual experimental setup. The ultrasonic reactor (ultrasonic generator and ultrasonic probe) was home-made and its frequency can be adjusted from 20 to 1,100 kHz, as well as the power can be adjusted from 0 to 30 W. We used the ultrasound power meter (UPM-DF-1E, Ohmic Co. Ltd., USA) for ultrasound intensity measurement and used the oscilloscope (TDS1000B, Tektronix Co. Ltd., USA) for ultrasound frequency measurement. We used a microscope (CX21, Olympus, Japan) to count the number of algae and used a spectrophotometer (722 N, Precision and Scientific Instrument Co. Ltd., Shanghai) to monitor the optical density of the water sample at 620 nm. We used HPLC (LC-20A, Shimadzu, Kyoto) to determine the extracellular microcystins.

Table 1
Constituent reagents of BG-11 medium

| Reagent | Concentration (mg/L) | Reagent | Concentration (mg/L) |
|---|---|---|---|
| ρ($NaNO_3$) | 1500.00 | ρ($Na_2$-EDTA) | 1.00 |
| ρ(Ammonium ferric citrate) | 6.00 | ρ($Na_2MoO_4{\cdot}2H_2O$) | 0.39 |
| ρ(Citric acid) | 6.00 | ρ($MgSO_4{\cdot}7H_2O$) | 75.00 |
| ρ($K_2HPO_4$) | 40.00 | ρ($MnCl_2{\cdot}4H_2O$) | 1.81 |
| ρ($H_3BO_3$) | 2.86 | ρ($CuSO_4{\cdot}5H_2O$) | 0.08 |
| ρ($ZnSO_4{\cdot}7H_2O$) | 0.22 | ρ($CaCl_2{\cdot}2H_2O$) | 36.00 |
| ρ($Co(NO_3)_2{\cdot}6H_2O$) | 0.05 | ρ($Na_2CO_3$) | 20.00 |

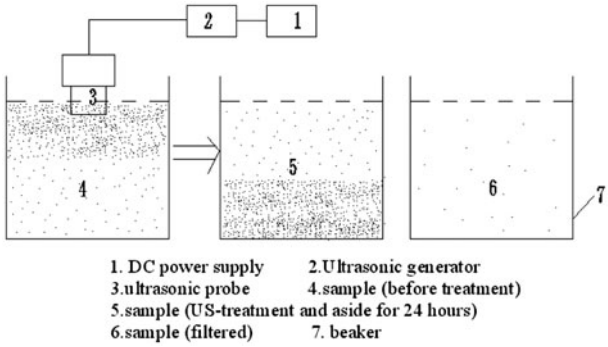


Fig. 1. The sketch of the actual experimental setup.

### 2.2. Methods

#### 2.2.1. Determining the absorbance value of different algae concentrations

The methods involved diluting the indigenous blue-green algae samples (taken from Taihu) and mixing the differently concentrated algae solutions in conical flasks with a magnetic stirrer. The number of algae was counted with the aid of Olympus microscope. The alternative way was to monitor the optical density of the algae solution samples at 620 nm using the spectrophotometer since the M. aeruginosa solution had very strong absorbance at 620 nm (OD620) reported in our previous study [28]. The OD620 value was linear with the counted cell number with R2 of 0.99 within the tested cyanobacteria concentration range. The OD620 of the number of algae cells was corresponds to $5 \times 10^7$ cells/mL. Therefore, the OD620, instead of the cell number, was reported in the study. According to the strength of absorbance, the algae samples were divided into low (0.4 OD620), medium (0.8 OD620), and highly (1.6 OD620) concentrated fractions.

#### 2.2.2. Ultrasound irradiation

The ultrasonic power was set in the range from 10 to 30 W and the irradiation time ranging from 0 to 600 s to treat the three samples. The three differently concentrated algae solutions were taken (cultured in the incubator) and placed in a beaker of 2 L (outside the incubator), respectively. And immediately sampling the algae solution at 3 cm distance from the surface and using the spectrophotometer to measure its absorbance as the initial absorption value. The control groups and treated groups were cultured in the light incubator immediately after being treated. And 24 h later, the algae absorbance was determined as the end absorption value. The algae removal efficiency was calculated by Eq. (1):

$$\eta = \frac{A_i - A_e}{A_i} \times 100\% \quad (1)$$

where $\eta$ is the algae removal efficiency; $A_i$ is the initial absorption value; $A_e$ is the end absorption value.

The distribution of algae was carefully observed. We recorded, and analyzed the data; and then selected the best ultrasonic power and ultrasonic irradiation time according to the algae removal efficiency.

To determine the optimum ultrasonic frequency, the control groups and treatment groups were set up and their initial absorption values were determined. The control group received no treatment and the rest treated with ultrasonic power of 30 W and the ultrasonic irradiation time was 360s. The treated group was divided into eight groups depending on the frequency (20, 60, 100, 300, 500, 700, 900, and 1,100 kHz). The control group and treated groups were cultured in a light incubator immediately after being treated. Every 24 h (continuous take 6 samples) the algae samples were taken from the beaker at 3 cm distance from the surface and the spectrophotometer was use to measure the samples' absorbances as the end absorption values [Eq. (1)]. The data were also recorded and analyzed, and subsequently, the best frequency selected according to the algae removal efficiency.

*2.2.3. Determination of water quality*

The water quality indicators, including extracellular microcystins (MC), total nitrogen (TN), total phosphorus (TP), and chemical oxygen demand ($COD_{Mn}$), were implemented according to the national standards [29]. And the Chl-a was determined according to methods described by MacKinney [30]. And the other water quality indicators were determined as fellows: (1) Take differently concentrated algae solutions and place them in a beaker of 2 L, each differently concentrated algae solution prepared four samples. (2) Additionally, each differently concentrated algae solution take a sample and use the cellulose acetate membrane filter with the pore diameter of 0.45 μm (Wo Hua Filter Co. Ltd., Hangzhou) to filter the suspended algae as the filtered groups. (3) The two samples of each concentration were treated with ultrasound as the treated groups, and the rest was set as control groups (no US). (4) The water quality indicators were determined in three periods: before treatment, immediately after treatment and standing for 24 h after treatment, respectively. The control groups and treatment groups removal efficiency of water quality indicators were calculated by Eq. (2):

$$\varphi = \frac{C_i - C_e}{C_i} \times 100\% \quad (2)$$

where $\varphi$ is the water quality indicators removal efficiency; $C_i$ is the initial concentration of water quality indicators; $C_e$ is the finial concentration of water quality indicators.

## 3. Results and discussion

*3.1. Impact of different algae concentrations and ultrasonic powers on algae removal efficiency*

Three differently concentrated algae solutions were exposed to ultrasonic irradiation at different ultrasonic powers of 10, 20, 30 W with the same frequency of 20 kHz. The results are showed in Fig. 2.

From Fig. 2(a), we can easily know that when the algae concentration was low and treated with 30 W ultrasonic power, the algae removal efficiency was more significant than 10 W. When the ultrasonic irradiation time was 600 s and the ultrasonic intensity was 10 W, the corresponding algae removal efficiency was 62.5%, and when the intensity went to 20 and 30 W, the removal efficiency increased to 92 and 96%, respectively. It suggested the best ultrasonic power was 30 W. In addition, with the US-irradiation time from 360 s increasing to 600 s, the algae removal

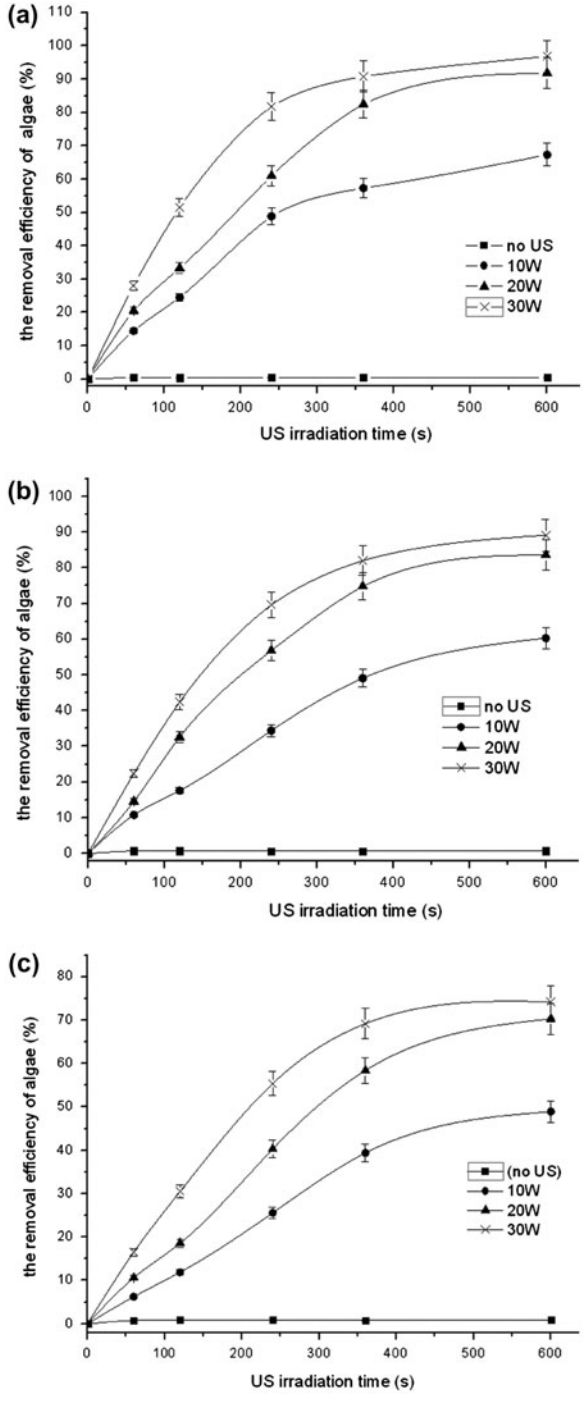


Fig. 2. The impact of ultrasonic power on algae removal efficiency. All of the samples were treated in 2-L beakers, and the algae removal efficiency were determined after standing for 24 h. (a) the changes of removal efficiency of low concentration algae treated by ultrasound; (b) the changes of removal efficiency of medium concentration algae treated by ultrasound; (c) the changes of removal efficiency of high concentration algae treated by ultrasound. (Ultrasonic irradiation time ranges from 0 to 600 s, ultrasonic frequency = 20 kHz).

efficiency from 91 reached 96.8%, with the ultrasonic power at 30 W. It also suggested that the algae removal efficiency was not obviously changed with the irradiation time extension. Therefore, as for the low-concentration algae solution, the best approach of ultrasound treatment was with 30 W ultrasonic power and 360 s ultrasonic irradiation time. As for the medium and high algae concentration solution, we can see from Figs. 2(b) and (c)) the algae removal efficiency changes were almost the same as the low algae concentration solution shown in Fig. 2(a)) The distinction between them are the final removal efficiencies, which were reached at 89.1 and 74.2%, respectively.

According to several researches, with the ultrasonic power increased the algae removal efficiency increased, but when the ultrasonic power and irradiation time reached a certain value the removal efficiency had no significant change [31–33]. This is because when the ultrasound is applied in the algae solution, the ultrasonic wave could cause cavitation bubbles in algae cells. It is the cavitation bubbles that cause the acoustic cavitation effects effective and make the algae cells key component break down, and caused the algae inactivation and finally settlement to the bottom. But at fixed ultrasonic power and irradiation time, the amount of cavitation bubbles produced by ultrasound is limited. Thus, with the algae concentration increased, the efficiency of algae removed by ultrasound decreased [14,16,34–36]. Because of the trend of the curves for the medium and high algae samples were the same as in Fig. 2(a), the optimum parameters were the same as in the former.

### 3.2. Influence of the ultrasonic frequency on algae removal

The ultrasonic power was set at 30 W and radiation time at 360 s. We used different ultrasonic frequency to treat the algae solution taken from thr Taihu Lake, and the density of the algae solution was 1.36 OD620. After being treated, the algae solution samples were cultured with the control groups together in light incubator, and a sample was taken at a frequency of 24 h. The changes of the algae removal efficiency are shown in Fig. 3.

As shown in Fig. 3 and 120 h later, the control group algae mortality rate only reached to 3.5%. Hence, the algae sedimentation within the none-US samples can be neglected. However, when it was treated with ultrasound under 20 kHz frequencies, the removal efficiency was up to 85.6%, but when it came to 1,100 kHz frequencies, the removal efficiency was only 66.5%. It can be seen from Fig. 3 that along with increasing of ultrasonic frequency, the algae removal

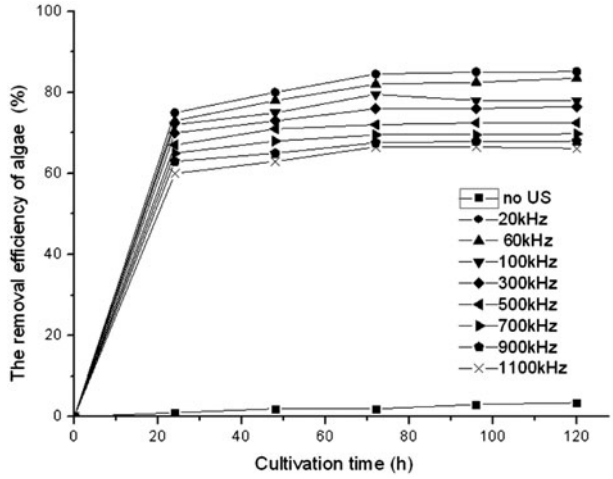


Fig. 3. The impact of ultrasonic frequency on algae removal efficiency (the density of the algae solution was 1.36 OD620, every 24 h determine the value of the removal efficiency after the algae being treated by ultrasound at 30 W and 300 s, the error is 3.2%).

efficiency gradually becomes low. This is because the frequency is one of the most important parameters, which affects the ultrasonic cavitation reaction [21,24,26]. When other parameters were kept at certain conditions, as the frequency increases, the acoustic cavitation process would become difficult to occur. The reason is that as frequency increased the corresponding sonic expansion phase time becomes shorter, and the cavitation nucleus was too late to increase and produce effective cavitation bubbles. Or even cavitation bubbles can be formed, but due to the compression phase time becomes shorter the bubbles may be too late to shrink to collapse, which makes the cavitation effect becomes poor. In addition, from the spread of ultrasonic characteristics we can know that with the increasing of frequency the sound waves attenuation will be increased. So if we want to get the same sonochemistry effect, high-frequency sound waves should consumed more energy [14,24,26,34–36]. Therefore, the frequency of sonochemisty is generally selected between 20 and 50 kHz [35]. Therefore, according to the experimental results and considering environmental and security factors, we choose the 20 kHz as the optimum ultrasonic parameter to remove algae.

### 3.3. Changes of the sample water quality

We used the selected ultrasonic parameters (ultrasonic frequency is 20 kHz and the ultrasonic power is 30 W) to deal with the algae solutions (taken from Taihu) and set the ultrasonic irradiation time as 360 s.

When the algae were removed from the water surface to bottom, analyzing the changes of sample water quality has important guiding significance on removing algae with ultrasound.

### 3.3.1. Changes of Chl-a

It is shown in Fig. 4 that the content of intracellular Chl-a declines to a certain degree after the algae being treated with ultrasound. We can see from the histogram that the Chl-a values of control groups almost have not any change. Contrary, the Chl-a values of treatment groups is degraded under 360 s ultrasonic irradiation. Compared with the medium and high concentrations, the Chl-a content of low algae concentration was reduced by 26.2% after US-treatment. And with the algae concentration increasing the degradation rate of it declined. The medium and high concentration of treatment group's intracellular Chl-a degradation rates were 20.5 and 14.6%.

This is because when the ultrasound is applied in the algae concentration, the ultrasonic wave could cause cavitation bubbles in algae cells. It is the cavitation bubbles that cause the acoustic cavitation effects effective and make the algae cells break down and finally inactivation. But at fixed ultrasonic power and irradiation time, the amount of cavitation bubble produced by ultrasound is limited [14,16,31,34–36]. So, with the algae concentration increasing, the ultrasonic cavitation effects are weakened. Hence, the effect of ultrasound in the degradation of Chl-a function is also weakened. However, after the sample water being treated and standing for 24 h the value of its intracellular Chl-a has a significance changes. The main reason of this phenomenon could be explained as that the algae were inactivated when treated with ultrasound and then precipitated, which make the suspension algae decrease and the intracellular Chl-a decline [12].

### 3.3.2. Changes of MC

The MC, which were generally considered to be caused by the rupture of algal cells in the water [37], can cause animal and human tumor promotion. Therefore, the changes of MC in the sample water should be determined after the algae treated with ultrasound.

In this section, the concentration of algae samples (taken from Taihu) was determined as 1.36 OD620. We set the filtered algae solution as the control group. We can learn from the histogram showed in Fig. 5 that the initial value of microcystins in the sample water was 0.26 mg/l, which seriously exceeded the specified value of the water quality standards. When it was treated with 360 s ultrasonic irradiation, the value of the microcystins declined to 0.06 mg/L, which has almost no changes in the control group (filtered and no US-treatment). In the filtered control samples, the algae toxins in water samples after standing for 24 h decreased by 25.9%. However, when the treatment group comes to the same conditions, the value of microcystins dropped by 96%.

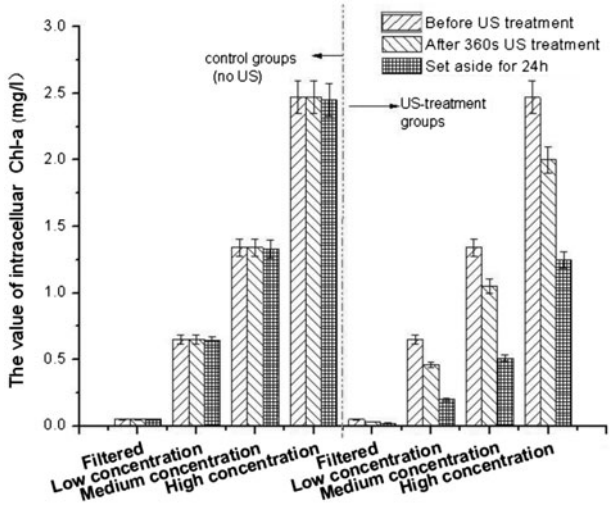


Fig. 4. Different concentrations of algae solution intracellular Chl-a value changes before and after the ultrasonic treatment at the selected ultrasonic parameters. (The left part is the control groups (no US) and the right part is the US-treatment groups).

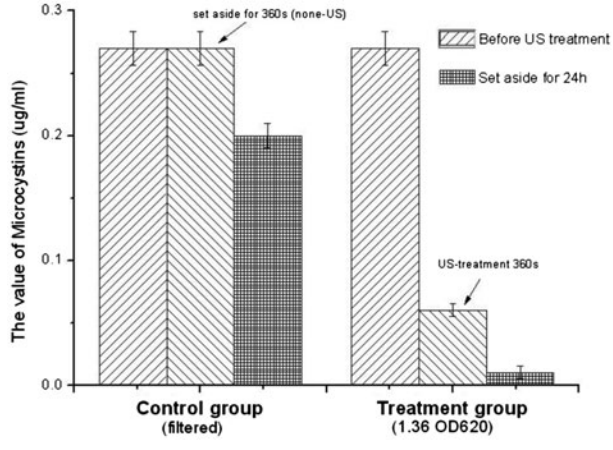


Fig. 5. The value of microcystins in the water sample before and after being treated with ultrasound at the selected ultrasonic parameters. (The left part is the control group (filtered) and the right part is the treatment group (the initial algae cell is 1.36 OD620)).

There are two reasons to explain the phenomenon: on te one hand, under the mechanism of sonochemical reaction the key components of algae on the surface of the sample water was broken up, and losing buoyancy and then settling to the bottom, which caused the microcystins declined sharply. On the other hand, Tsuji et al. indicated that microcystins can be degraded by light [38]. Therefore, when the algae settled at the bottom, the sunlight come to the water surface and causing the contact area increases, which accelerates the degradation of microcystins. In addition, the treatment group exposed to ultrasonic irradiation at 20 kHz with 30 W ultrasonic powers and after 360 s ultrasonic irradiation, we did not detect the microcystins increasing. It suggested that low-frequency and low-power ultrasonic irradiation is an efficient method for degradation of microcystins dissolved in water.

### 3.3.3. Changes of TN and TP

The surplus nutritional elements N and P should be responsible for the algae boom. As it was mentioned previously, the algae solution samples were taken from Taihu, during the bloom of algae in 2011. Therefore, it is important to investigate the changes of TN and TP in the algae solution when the sample was treated with ultrasound.

Three differently concentrated algae solution were exposed to ultrasonic irradiation at 20 kHz with 30 W ultrasonic power. The TN and TP concentration of each treatment sample was measured immediately after treatment and aside for 24 h, and the control samples were also measured at the same time. Fig. 6 shows the TN concentration histogram of all the samples. The concentration of all of the samples was decreased after being treated with ultrasound, which indicated that ultrasound has certain effects to remove the TN in the algae solution. After ultrasound irradiating 360 s in differently concentrated algae solutions: filtered, low, medium and high concentration, with the same ultrasonic frequency of 20 kHz and ultrasonic power of 30 W, the TN were dropped to 45, 41, 36, and 20%, respectively. However, compared with the treatment groups, the concentration of control groups hardly changed. The effects of standing 24 h were obvious contrary compared to immediately treatment 360 s, and the fastest degradation rate was the high concentration group, the final value of TN was 0.8 mg/l, which suggested that the removal efficiency was up to 86%. And the removal efficiency of low algae concentration group was only declined to 70.7%. Hence algae solution at standing for a time after ultrasonic treatment had a better effect on TN removal.

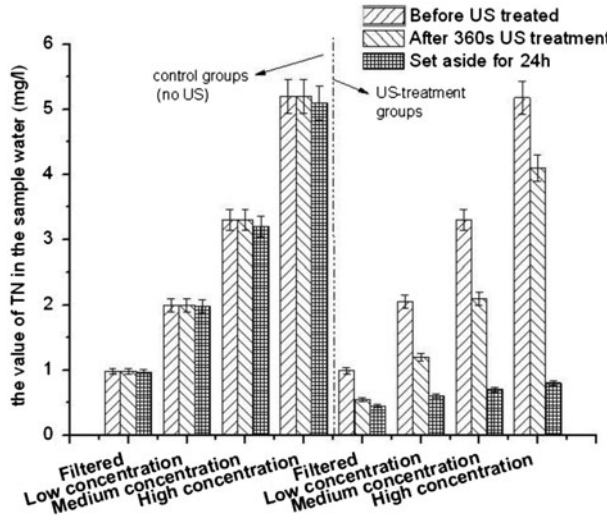


Fig. 6. The changes of TN in different concentrations of algae solution at the selected ultrasonic parameters. (The left part is the control groups (no US) and the right part is the US-treatment groups).

The main mechanism of sonochemical reaction is ultrasonic cavitation. Generally, with the ultrasound irradiating in the water, it would appear tiny hot spot in which could form high temperature and pressure [16,36]. It was under such condition that a part of nitrogen element would in gaseous form to escape from the solution. However, some algae cells would rupture in that extreme environment, thus some intracellular substances released from the algae cell, causing high concentration has low removal efficiency. As it was said above, the algae could settle after ultrasonic treatment, and in this process, the inactivation algae cells would adsorb some substances in the solution to the bottom, leading the value of TN in the sample water decreasing. Moreover, the higher concentration of algae solution the more substance would be adsorbed, including TN [12,14,28]. The Sun et al. [39] work on cyanobacteria death and decomposition also showed that the nitrogen, phosphorus and organic carbon released from the deactivation of algae cells could be adsorbed by the fractured cyanobacteria cells and finally settled to the bottom. Another literature [40] showed that cyanobacteria cells produce a large number of particles or colloids in the process of deactivation or decomposition. And these particles or colloids have a strong adsorption performance for the nutrients. Besides, the algae solution contains lots of microbes, and the released nitrogen and phosphorus directly as their source of nutrients [41]. Thus, after standing for 24 h, the total nitrogen in the algae solution decreased sharply and the high concentration

TN removal efficiency higher than the other groups appeared.

From the histogram shown in Fig. 7, we can see the filtered group treated with ultrasound almost has no change compared with the control group. As to the rest, the value of TP sharply rose after 360 s ultrasonic treatment, but it dropped than its control group after standing 24 h. After ultrasonic irradiating 360 s at different concentration of low, medium, and high intensity, with the same ultrasonic frequency of 20 kHz and ultrasonic power of 30 W, the TP raised by 10, 14, and 18.3%, respectively. However, the effects of standing for 24 h were obvious contrary compared with immediately treatment 360s, the removal efficiency were 63, 51.2, and 45.6%, respectively. And the final values of the TP in the water sample were 0.065, 0.19, and 0.28 mg/L, respectively. This phenomenon was similarly with the changes of the value of TN, except the difference that the phosphorus element could not be volatile by the form of gas.

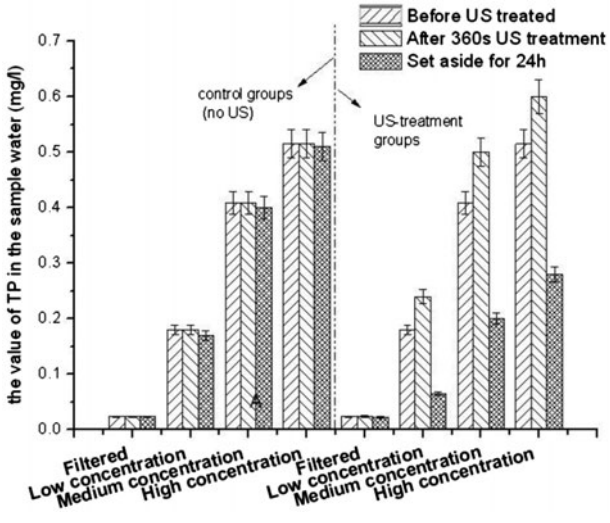


Fig. 7. The changes of TP in different concentrations of algae solution at the selected ultrasonic parameters. (The left part is the control groups (no US) and the right part is the US-treatment groups).

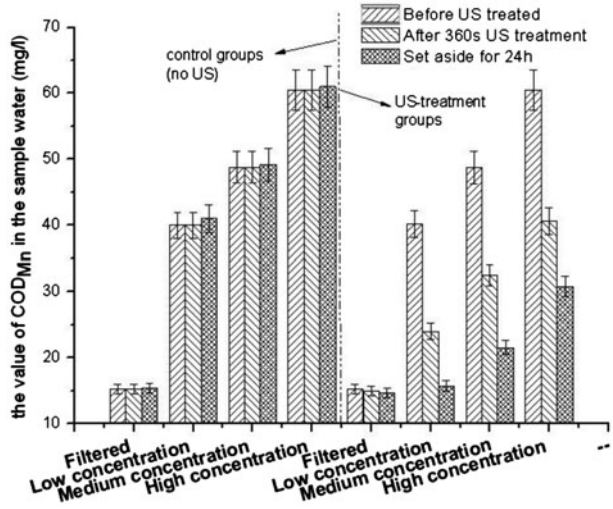


Fig. 8. The changes of $COD_{Mn}$ value before and after treated with ultrasound at the selected ultrasonic parameters. (The left part is the control groups (no US) and the right part is the US-treatment groups).

### 3.3.4. Changes of $COD_{Mn}$

Three different concentrations of algae solution were exposed to ultrasonic irradiation at 20 kHz with 30 W ultrasonic power. The value of $COD_{Mn}$ of each sample was measured immediately after treatment and aside for 24 h cultured in light incubator, respectively. Fig. 8 shows the $COD_{Mn}$ concentration histogram of all the samples. After the samples being processed by ultrasonic 360 s and stood for 24 h, the removal efficiency of low, medium, and high groups of COD were 60.9, 55.7, and 49%, respectively. The value of COD of the filtered group treated with ultrasound almost has no changes compared with the control group, and which is obviously lower than other groups. These experiment results suggest that the COD almost comes from the algae in the sample water. Additionally, as we can see from the histogram, low concentration of the value of COD declines more effectively than higher concentration, and with the sample water being processed by ultrasound with low-frequency and low-power only surplus little algae suspension on the water surface, and when the treated sample stalled a week later, the COD did not increase any more. It indicated that the ultrasound is an effective and environmental method.

After standing the treated sample water for seven days, the settlement algae did not float up to the surface, and the sample quality of which did not change significantly. These results suggest that ultrasound can effectively remove algae and effectively improve the water quality and effectively restrain the growth of algae.

## 4. Conclusion

Ultrasonic irradiation is a promising potentially efficient and environmentally friendly method for removing and inhibiting algae. The absorbance (A) is proportional to the algae cell concentration (C). Three differently algae concentrated solutions (0.4 OD620, 0.8 OD620, 1.6 OD620) were treated by ultrasound,

and the results indicated that ultrasonic irradiation could efficiently prompt the algae cell inactivation and then sedimentation. the best ultrasonic parameters for treating with algae were under 30 W ultrasonic power, 20 kHz ultrasonic frequency and 360 s ultrasonic irradiation, respectively. And the removal efficiency of lower algae concentration could reach up to 96% under the best treatment condition, which is better than the other groups. And the algae removal efficiency increased with the decreased of ultrasonic frequency or the rise of ultrasonic power.

Ultrasound cannot only be considered as a method to remove and inhibit algae; it also can be used to improve the water quality polluted by the algae. The experiments results showed that the highest removal efficiency of the Chl-a, MC, TN, TP, and $COD_{Mn}$ at the optimal condition was determined as 26.2, 96, 86, 63, and 60.9% in comparison with the control samples without ultrasound (no US), respectively, and the final value of which were 0.2, 0.01, 0.6, 0.065, and 15.7 mg/L respectively. Although ultrasonic irradiation possibly only can decompose some of those substances in algae (nutrition, Chl-a, microcytins, etc.), the algae cell is inactivated and then precipitated under the ultrasonic irradiation. Moreover, the nutrient substances (nitrogen, phosphorus, and carbon) in the water can be adsorbed and then removed from the surface water to the bottom with the processing of inactivation algae settlement, which makes the growth of algae lack the essential nutrients. These results suggest that ultrasound can effectively remove algae and effectively improve the water quality and effectively restrain the growth of algae.

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