Algae inhibition experiment and load characteristics of the algae solution

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Abstract: It is necessary to inhibit microbial growth in an industrial cooling water system. This paper has developed a Monopolar/Bipolar polarity high voltage pulser with load adaptability for an algal experimental study. The load characteristics of the Chlorella pyrenoidosa solution were examined, and it was found that the solution load is resistive. The resistance is related to the plate area, concentration, and temperature of the solution. Furthermore, the pulser’s treatment actually inhibits the algae cell growth. This article also explores the influence of various parameters of electric pulses on the algal effect. After the experiment, the optimum pulse parameters were determined to be an electric field intensity of 750 V/cm, a pulse width per second of 120μs, and monopolar polarity.

1. Introduction
Due to the large reproduction of bacteria, numerous microbes are present in industrial circulating cooling water, and as a result, many problems occur, such as pipe blockage and severe corrosion [1]. Among the methods of bacteriostasis and algal inhibition, the applicable scope of biological methods is primarily limited for a particular microorganism, and the chemical methods can easily corrode the equipment and cause secondary pollution [2]. Therefore, the physical methods of electromagnetic pulse processing technology have become a popular research topic [3].

However, there is a lack of experimental data about the load characteristics of the algae solution. There are many contrary opinions about the different effects of monopolar and bipolar pulses [4]-[6]. There is also little information about the major impact parameter and the most superior treatment parameter among electric field intensity, pulse width, etc.

This paper aims at identifying the optimum combination of electric parameters for the best algae inhibition effectiveness within the parameter scope of the pulse generator, and the load properties of the algal solution are analyzed.
2. Experimental devices

2.1. Power supply design

This paper developed a novel monopolar/bipolar polarity high-voltage pulser based on the 9-stage Marx pulse generator and H-bridge. Load $Z_L$ is the algae fluid. The main structure is shown in Figure 1. In order to change the pulse width and frequency, the Pulse Width Modulation (PWM) of the Digital Signal Processor (DSP) is adjusted. The DSP can make the output DC voltage continuous and adjustable by communicating with the high-voltage DC source using the serial port. In addition, it can also yield monopolar or bipolar polarity by controlling the switch of the H Bridge. The hardware platform for the High Voltage Pulser is shown in Figure 2.

![Figure 1. Polarity Tunable High Voltage Pulser’s system structure diagram.](image1)

![Figure 2. Hardware platform for the High Voltage Pulser.](image2)

2.2. Treatment chamber

In this paper, a small rectangular chamber is designed with an interior volume of 50 mm*80 mm*100 mm (ignoring the electrode size). We repeatedly compared both the advantages and disadvantages of a copper electrode, platinum electrode, and graphite electrode. Taking into consideration the high price of platinum electrodes and the electrolytic effect of copper electrode, we selected the graphite electrode, which is shown in Figure 3.

![Figure 3. The experimental treatment chamber.](image3)

3. Load characteristics of the algal solution

The study employs the *Chlorella pyrenoidosa* algae as the experimental subject. Three identical micro-algal solutions with different concentration were made and were named as $x$ solution, $y$ solution, and $z$ solution ($x=4.76y$, $x>y$). The parameters for the pulser were set as the following: bipolar pulse, a pulse frequency of 1 kpps, and a pulse width of 6 μs. The waveforms of measured load under $x$ concentration with a graphite electrode chamber or copper electrode chamber are shown in Figure 4a and 4b.
It was found that the algal solution load is highly resistive. Furthermore, the load characteristics exhibit no difference under the two systems, and the other parameters, including the liquor concentration, are also the same.

In summary, we produced a list of the equivalent resistance of the algae solution, which was connected to the concentration, temperature, and plate area, as shown in Table 1.

| Concentration /x=4.76y | Temperature /°C | Volume/mL |
|------------------------|-----------------|-----------|
| x                      | y               | 23.5      | 66        | 60        | 130       |
| Equivalent             | resistance      | 552       | 604       | 550       | 275       | 768.7     | 314.5     |

The results showed that the load characteristic of the algae solution was resistance. With increasing temperature and concentration, the equivalent resistance of the algae fluid is reduced. Additionally in this process chamber, as the plate area of the algae solution is increased, its equivalent resistance is also reduced.

4. The algae inhibition experiment

4.1. Experimental methodologies
We divided the pulse electric field intensity and pulse width per second (multiplied by the number of pulse per second and the single pulse width) into three levels, and employed the monopole or bipolar pulse condition. Then, in this paper, we conducted several pre-experiments in order to determine the proper values of three electric parameters, shown in Table 2. The distance between the electrode plates is 40mm so that the pulse voltage can directly reflect the electric field intensity.
Table 2. The electrical parameters

| Parameters             | Level 1 | Level 2 | Level 3 |
|------------------------|---------|---------|---------|
| Voltage (kV)           | 1       | 2       | 3       |
| Pulse width per second (μs) | 180     | 120     | 60      |
| Polarity               | Bipolar | Monopolar |

Therefore, there are 18 experimental groups with different parameters, as shown in Table 3. In the table, Bipolar-2 kV-180 μs indicates a bipolar pulser, the voltage is 3 kV, the pulse width time per second is 180 μs, and so on.

Table 3. The pulser parameter group.

| Group | Pulser Parameters | Group | Pulser Parameters | Group | Pulser Parameters |
|-------|-------------------|-------|-------------------|-------|-------------------|
| 1     | Bipolar-3 kV-180 μs | 7     | Bipolar-3 kV-60 μs | 13    | Monopolar-3kV-120μs |
| 2     | Bipolar-2 kV-180 μs | 8     | Bipolar-2 kV-60 μs | 14    | Monopolar-2kV-120μs |
| 3     | Bipolar-1 kV-180 μs | 9     | Bipolar-1 kV-60 μs | 15    | Monopolar-1kV-120μs |
| 4     | Bipolar-3 kV-120 μs | 10    | Monopolar-3kV-180μs | 16    | Monopolar-3kV-60μs |
| 5     | Bipolar-2 kV-120 μs | 11    | Monopolar-2kV-180μs | 17    | Monopolar-2kV-60μs |
| 6     | Bipolar-1 kV-120 μs | 12    | Monopolar-1kV-180μs | 18    | Monopolar-1kV-60μs |

4.2. Experimental procedure

- The algal solution was divided into 19 groups, one blank group, and 18 treatment groups. Then, different pulse parameters were used to treat the algal solution for 5 minutes.
- Each time we finished one experimental group, the algal solutions were then put into the thermostatic water tank for growth. All experiments were finished in the first day. As for the blank group, the measuring time, concentration value, and temperature were recorded when the algal solution had been shaken up, sampled, and diluted five times.
- From the second day to the seventh day, we tested the concentration value and temperature of the algal solution in all of the experimental groups. The detection was done every 24 hours after the first detection time. The experiment platform is shown in Figure 5.
4.3. Results and discussion

After a week, we obtained the growth rate of the algal cells according to formula (1), by which we evaluated the inhibition of algal cell growth by high-voltage pulse. The lower the value, the better the suppressing effect is.

\[ P = \frac{C_n - C_i}{C_i} \]  

(1)

In formula (1), \( P \) refers to the growth rate of the algal cells, \( C_n \) is the concentration of the algae cells of one group in the nth day, and \( C_i \) is the concentration that was measured before the experiment. The growth rates that were recorded over seven continuous days are shown in Table 4.

| Group | Initial value (%) | Training 24 hours | Training 48 hours | Training 72 hours | Training 96 hours | Training 120 hours | Training 144 hours |
|-------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| 1     | -2.13             | -3.04             | 15.19             | 33.12             | 25.22             | 38.28             | 44.06             | 1.51          | 9.66       | 17.52 | 45.90 | 45.00 | 43.19 | 51.34 |
| 2     | 4.63              | 3.39              | 27.46             | 39.18             | 45.97             | 56.15             | 67.87             | 4.42          | 5.90      | 9.73  | 25.95 | 33.32 | 48.06 | 63.40 |
| 3     | -3.77             | 0.58              | 19.12             | 30.13             | 29.55             | 38.54             | 55.05             | 2.09          | 8.35      | 7.16  | 41.48 | 49.23 | 54.61 | 79.07 |
| 4     | -2.65             | 0.59              | 15.88             | 17.93             | 28.22             | 37.93             | 36.46             | -1.48         | 4.45      | 7.71  | 23.73 | 30.85 | 39.45 | 34.41 |
| 5     | -5.54             | -5.54             | 14.28             | 18.65             | 26.52             | 40.80             | 41.09             | 4.66          | 7.58      | 5.54  | 29.43 | 37.30 | 43.72 | 73.73 |
| 6     | -1.83             | 3.96              | 22.86             | 34.13             | 31.69             | 42.06             | 58.82             | 15            | -0.87     | 9.30  | 16.27 | 30.22 | 35.16 | 27.90 | 59.28 |
| 7     | 0.61              | 0.31              | 15.94             | 34.96             | 30.66             | 44.46             | 43.54             | 16            | 2.55      | 1.28  | 8.94  | 22.67 | 30.98 | 24.91 | 36.73 |
| 8     | -5.57             | 4.40              | 10.55             | 22.87             | 26.38             | 44.56             | 42.80             | 17            | 1.62      | 9.74  | 24.99 | 38.30 | 44.46 | 59.07 | 71.72 |
| 9     | 0.63              | 10.44             | 20.88             | 37.33             | 37.64             | 59.47             | 72.44             | 18            | -0.60     | 4.19  | 12.87 | 23.64 | 32.32 | 34.72 | 45.79 |
| Blank | 13.17             | 20.05             | 34.72             | 52.37             | 55.67             | 68.24             |                     |               |           |       |       |       |       |       |

According to the data, group 13 has the best inhibitory effect. Next, we used a single variable method to analyze the data; that is, two random variables in Table 4 were kept unchanged, and the third variable was changed. By analyzing the first variable (voltage), we found that all groups produce good inhibitory effects with 3kV voltage. Thus, it may be concluded that when the voltage is 3kV, the main factor of inhibition is voltage. By analyzing the second variable (pulse width time per second), we found that the pulse width time has a negative influence on the algae growth, and it has nothing to
do with polarity when the voltage is 3 kV. The inhibition effect is 120>60180. As for the third variable (polarity of pulse), monopole has a greater effect than bipolar when the parameters are 3kV-120.

In summary, the best inhibitory effect takes place when the pulser parameters are monopole-3 kV-120. In this condition, the growth rate of the algal cells is 34.41%, which is a 33.83% decrease compared to 68.24% in the blank group. When the electric field intensity is 750 V/cm, the high-voltage pulser has a common inhibitory effect. The influence of pulse width per second follows the following rule: 120, and the monopole effect is superior to that of bipolar. However, when the electric field intensity is too low, there is no obvious regularity to determine how all parameters affect the growth of the algal cells.

5 Conclusions

- This paper applied a graphite electrode to replace the copper electrode in an algae removal with high-voltage pulser experiment, which can avoid the electrolytic effect of the copper electrode.
- This paper found that the Chlorella pyrenoidosa load manifests resistor characteristics. Its equivalent resistance is closely related to the plate area, temperature, and concentration of the algae solution.
- The data proved that the pulse voltage or electric field intensity was the major impact parameter of algae inhibition. The optimal parameters that may lead to the best inhibitory effect were monopole-3 kV-120.

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