

# A Brief Talk of the Disinfection Process for Reclaimed Water

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**Abstract.** In recent years, with the reclaimed water being more and more widely used, people begin to pay more and more attention to the security of it. Because the reclaimed water comes from the sewage, which has been deeply treated, its quality is quite complex and it may contain many bacteria, viruses and poisonous that are harm to people. When it's reused, it is inevitable that the reclaimed water may come into contact with people's body, which has exposure risk. In order to reduce the risk of exposure, ensure the security of the quality of the reclaimed water, the disinfection becomes the most critical factors in dealing with the reclaimed water in the process. In the paper, the current disinfection techniques were discussed and compared in the aspects of technical features, the effects of disinfection and economy. And a brief summary of the new disinfection technology that was widely studied was made.

## 1 Preface

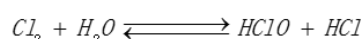
With the rapid development of the world economy, the shortage of water resources has attracted people's attention. Reuse of reclaimed water has become an effective way to solve this problem. In the process of reuse of reclaimed water, the safety of reclaimed water quality is the most noteworthy factor, disinfection is the last link in the reclaimed water treatment process, which plays a key role in ensuring the safety of reclaimed water quality.

Reclaimed water disinfection methods can be basically divided into three categories: 1. Chemical disinfection, Including chlorine, chlorine dioxide and ozone disinfection; 2. Physical disinfection, including ultraviolet disinfection, micro-electrolysis disinfection, and ultrasonic disinfection; 3. Combined disinfection methods, such as UV-chlorine disinfection [1].

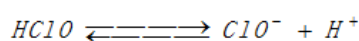
## 2 Chemical disinfection

### 2.1 Chlorine disinfection

Chlorine (Cl<sub>2</sub>) soluble in water (When 20°C and 98kPa, Solubility 7160mg/L). When chlorine dissolves in clean water, The following two reactions occur almost instantaneously:



The reaction rate of this reaction is:  $K_{25^\circ\text{C}} = 6.5 \times 10^{-14}$  (cm<sup>3</sup>/molecules) [2],



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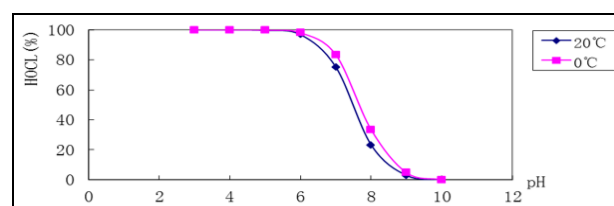
The equilibrium constant of the dissociation reaction is:  $K_i = \frac{[\text{OCl}^-][\text{H}^+]}{[\text{HOCl}]}$ , See Table 1 for the dissociation constant of hypochlorous acid at different temperatures.

**Table 1.** Hypochlorous acid dissociation equilibrium constant

Temperature (°C)	0	5	10	15	20	25
$K_i \times 10^{-8}$	2.0	2.3	2.6	3.0	3.3	3.7

Hypochlorous acid plays a major role in chlorine disinfection HOCl. HOCl is a small neutral molecule, It can spread to the surface of negatively charged bacteria, And penetrate into the inside of the bacteria through the cell wall of the bacteria. When the HOCl molecule reaches the inside of the bacteria, it can oxidize and destroy the enzyme system of bacteria and cause bacteria to die [3]. Although hypochlorite (OCl<sup>-</sup>) also has the ability to kill bacteria, but because it is negatively charged, it is difficult to access the same negatively charged bacteria surface, and its sterilization ability is much worse than that of HOCl [4].

According to Table 1, the percentage of HOCl in water at different pH values and temperatures can be calculated and figure 1 can be drawn.



**Figure 1.** The ratio of HOCl and OCl<sup>-</sup> in the water at different pH values and water

It is not difficult to see from Figure 1, At a certain temperature, when the pH value is higher, ClO<sup>-</sup> is more, when pH>9.0, OCl<sup>-</sup> approaches 100%; When the pH value is low, there is more HOCl. When the pH value is less than 6, HOCl approaches 100%. Then combined with the disinfection mechanism of chlorine, the following conclusions can be drawn, the pH value has a more obvious effect on the disinfection effect of chlorine. When the pH value is low, the content of HOCl is higher, and the sterilization effect is good. When the pH value is low and high, the content of HOCl is lower and the sterilization effect is not obvious.

### 2.2 Chlorine dioxide disinfection

Chlorine dioxide is a highly oxidizing and highly effective disinfectant, and its theoretical oxidation capacity is 2.6 times that of free chlorine [5]. Chlorine dioxide has a strong bactericidal effect and can kill various microorganisms including bacterial spores[6]. There have been many studies on the mechanism of chlorine dioxide disinfection, which can basically be summarized in the following aspects:1. Inhibit the process of cell synthesis of protein[7-9]; 2. It selectively interacts with certain amino acids in proteins[10], changes the permeability of the cell membrane and causes the leakage of certain key substances in the cell[11-12]; 3. Strong oxidative decomposition ability leads to breakage of amino acid chains, which makes proteins lose their function, thereby causing the death of microorganisms[7], destruction of ATPase and lipid peroxidation, etc. [13].

For the mechanism of chlorine dioxide, Xiaoyu Zhang et al. conducted a series of studies using Escherichia coli and obtained the following 4 pictures (2 to 5).

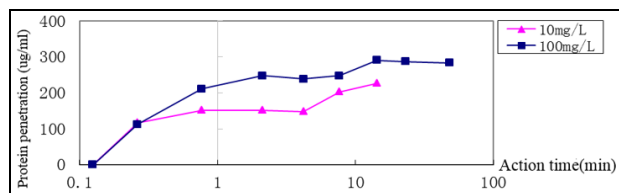


Figure 2. Protein leakage of Escherichia coli after the action of chlorine dioxide

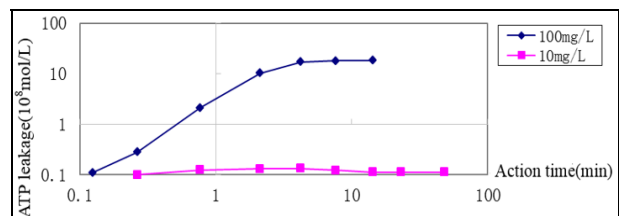


Figure 3. ATP leakage of Escherichia coli after the action of chlorine dioxide

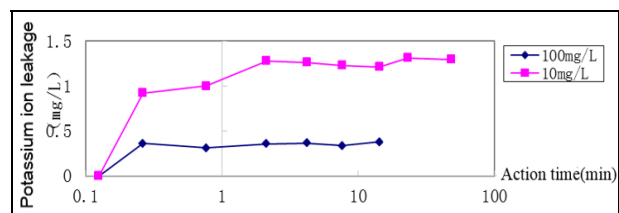


Figure 4. The leakage of potassium ions from Escherichia coli after the action of chlorine dioxide

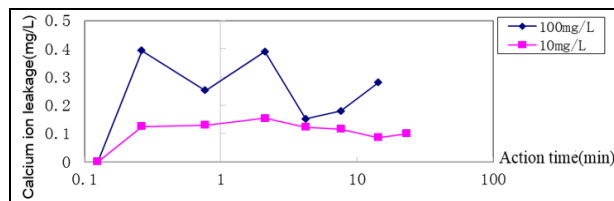


Figure 5. The leakage of calcium ions from Escherichia coli after the action of chlorine dioxide

It is not difficult to see from the figure that chlorine dioxide has the effect of changing the permeability of the cell membrane, and the higher the concentration, the more obvious the effect. Although the leakage of potassium ions in Figure 4 is obviously different from the others, this is because potassium ions are actively transported during cell transport, that is, carrier proteins are required. From this perspective, it can be inferred that chlorine dioxide has inhibitory proteins. The role of synthesis and destruction of proteins.

Chlorine dioxide is a highly effective disinfectant, which can exert a strong bactericidal effect in a small amount. Ming Zhu et al. added a certain amount of chlorine dioxide to the water sample to monitor the remaining chlorine dioxide and the number of coliforms in the water sample at 0, 10, 20, 30, 45, and 60 minutes of the contact reaction, and obtained the following data[14].

Table 2. When the initial dosage of chlorine dioxide is 1.60mg, the number of remaining chlorine dioxide and coliforms changes over time

Time (min)	Concentration (mg·L <sup>-1</sup> )	Number of coliforms	Number of repeated trials
0	1.60	1700	3
10	1.02	1	
20	0.9	1	
30	0.74	1	
45	0.46	1	
60	0.27	1	

Table 3. When the initial dosage of chlorine dioxide is 1.40mg, the number of remaining chlorine dioxide and coliforms changes over time

Time (min)	Concentration (mg·L <sup>-1</sup> )	Number of coliforms	Number of repeated trials
0	1.40	1700	5
10	0.67	2	
20	0.36	2	
30	0.25	1	
45	0.14	1	
60	0.04	1	

It can be seen from Table 2 and Table 3 that when the dosage of chlorine dioxide reaches 1.60 mg/L, the number of coliforms in the water sample has been completely inactivated after 10 minutes of reaction. The high efficiency of chlorine dioxide disinfection is evident.

### 2.3 Ozone disinfection

Ozone, is an allotrope of oxygen, colorless, slightly odorous gas, Very strong oxidizing, under acidic conditions, its oxidation-reduction potential is +2.07V, second only to fluorine at +2.87V, and it is the second strong oxidant<sup>[15]</sup>. It has a strong disinfection and sterilization effect with few disinfection by-products. It is called "green disinfectant" and is widely used in the disinfection of drinking water, swimming pools, etc<sup>[16]-[19]</sup>.

The sterilization mechanism of ozone is a biochemical oxidation reaction<sup>[20]</sup>. It is generally believed that there are two ways to sterilize ozone in water: one is that ozone directly acts on the cell wall of bacteria, destroying it and causing cell death; the other is that ozone releases free radical oxygen with strong oxidizing ability when it is decomposed in water<sup>[21]</sup>. Ozone can oxidize and decompose glucose oxidase, which is necessary for oxidizing glucose in bacteria, and directly interact with bacteria and viruses to destroy their organelles and ribonucleic acid, and decompose large molecular polymers such as DNA, RNA, protein, lipids, and polysaccharides. Bacteria's material metabolism, growth and reproduction process are destroyed<sup>[22]</sup>. In addition, ozone can also penetrate the cell membrane tissue, invade the cell membrane and act on the outer membrane lipoproteins and internal lipopolysaccharides, causing the permeability of the cells to be aberrated, leading to the lysis and death of the cells. In addition, the genetic genes, parasites, parasitic virus particles, bacteriophages, mycoplasma and pyrogens (endotoxins) in the dead bacteria are dissolved and denatured to death. In terms of the principle of the effect of aseptic technology on microorganisms, ozone sterilization belongs to the bacteriolytic level, and can achieve "complete and permanent elimination of all microorganisms in the object"<sup>[20]</sup>.

### 2.4 Comparison of three chemical disinfection methods

Table 4 is obtained by comparing the three disinfection methods<sup>[23-27]</sup>.

**Table 4.** Comparison of three chemical disinfection methods

Disinfection method	Advantage	Disadvantage	Limitation	Economy
chlorine	Low cost, convenient application, simple operation, accurate dosage	High DBP production, strong corrosiveness, long-term use leads to bacterial resistance	The sterilization efficiency is greatly affected by the organic matter and pH in the water	The cost per ton of water is 0.003 yuan-0.0045 yuan

carbon dioxide	High sterilization efficiency, wide application range of pH, low possibility of producing DBP; less corrosive than chlorine and ozone	Unstable and explosive. When the water contains iodide ions, the amount of iodate produced is high, chlorite and aluminate are produced, and it has no effect on some viruses.	Suitable for small and medium-sized water treatment	Treatment cost is about 0.03 yuan per ton of water
ozone	High broad-spectrum antibacterial properties, killing bacteria, viruses and spores; short contact time, less DBP production; can increase the flocculation and sedimentation performance of sewage	Toxic, unstable and corrosive if inhaled	Affected by water quality, it is difficult to realize on-line adjustment when applied to occasions with high requirements on water	The initial investment cost is high, and the operating cost is about 0.1 yuan per ton of water

## 3 Physical disinfection

### 3.1 UV disinfection

Ultraviolet sterilization is a photochemical reaction process caused by ultraviolet photon radiation. This sterilization method can effectively remove bacterial propagules, spores, protozoa, viruses and organic pollutants in water<sup>[3]</sup>.

The mechanism of ultraviolet disinfection is a very long and complicated process. It is generally believed that microorganisms are irradiated by ultraviolet rays and absorb the energy of ultraviolet rays. The essence is the absorption of ultraviolet energy by nucleic acids. Nucleic acid is divided into RNA and DNA, which are the basic material and life foundation of all living organisms<sup>[3]</sup>. After the microbe's DNA absorbs ultraviolet light, it forms a thymine dimer and mutates, and its replication and transcription blockade are hindered, thereby hindering the synthesis of protein ribozymes in the microbe<sup>[28]</sup>; In addition, strong oxidizing free radicals are generated by photoionization energy, thereby destroying other structures of microorganisms and leading to their death<sup>[3]</sup>.

### 3.2 Micro-electrolysis disinfection

Due to the limited level of research at present, people still do not have a unified understanding of the sterilization and disinfection mechanism of microelectrolysis. In summary, there are three points of view: First, in the electrolysis process, the chlorine produced by the electrolysis of chloride ions in the water has a bactericidal effect<sup>[29-30]</sup>; Second, the power plant's effects include electrical breakdown of the cell membrane, which can cause the bacteria to eventually hydrolyze and die by significantly changing the growth environment of the bacteria, or through the electron transfer between the bacterial cell and the click, causing the bacterial cell's respiratory system to become imbalanced and lead to the death of the bacteria; Third, some high-activity, low-life free radicals generated during the electrolysis process, such as oxygen anion radicals, hydroxyl radicals, hypochlorous acid anion radicals and chlorine dioxide anion radicals, are very strong. Bactericidal effect<sup>[31-32]</sup>.

### 3.3 Ultrasonic disinfection

The so-called ultrasonic disinfection is a disinfection method that uses sound waves with a frequency of more than 20kHz to kill microorganisms in the water. The principle is that by applying an ultrasonic field in the water, the liquid produces clusters of bubbles-"cavitation bubbles". When these bubbles are subjected to ultrasound, they will undergo bubble growth, contraction, re-growth, and re-shrinkage processes, and after repeated periodic oscillations, they will eventually burst at a high speed. In the process of its periodic oscillation or collapse, it will produce short-term local high temperature (about 5000K) and high pressure (about 100MPa), heating and cooling rates greater than 1000K/s, and generate a strong electric field, which triggers mechanics, heat, chemistry and biology Academic effect<sup>[33]</sup>.

### 3.4 Comparison of three physical disinfection methods

Table 5 is obtained by comparing the three disinfection methods<sup>[34-38]</sup>.

Table 5. Comparison of three physical disinfection methods

Disinfection method	Advantage	Disadvantage	Limitation	Economy
Ultraviolet rays	Safe, fast, no water pollution, fast disinfection speed, easy operation, no by-products	Without continuous sterilization ability, microbes will undergo light resurrection phenomenon	Affected greatly by suspended solids in water, chroma, hardness, and iron content	Low investment and operating costs

Microelectrolysis	Simple operation and simple equipment	Large energy consumption, uncertain products	Affected by the concentration of chloride ions in the water	Low cost, but higher operating cost
Ultrasound	Simple method, fast speed, high efficiency, easy to adjust	The actual operation is not ideal and the energy consumption is large	Limited to the area close to the ultrasonic emission	High operating cost

## 4 Combined disinfection method

Judging from the current operation of water plants, it is difficult to control the total number of coliforms in the reclaimed water within 3/L with a single disinfection method, and various chemical disinfection methods will produce certain by-products, while physical methods have no by-products. The production of products, but the cost is high and there is no continuous disinfection ability, then the combination of two or more disinfection processes can theoretically not only improve the effect of killing microorganisms, but also reduce the generation of bacterial resistance and reduce the concentration of disinfection. Shorten the disinfection time, while ensuring economy<sup>[1]</sup>. The four typical combined disinfection processes listed in this article are: ozone and ultrasonic combined disinfection, ozone and chlorine combined disinfection, ozone combined with ultraviolet disinfection, and ultraviolet combined with chlorine disinfection.

### 4.1 Ozone and ultrasonic disinfection

The cavitation produced by ultrasonic waves at a certain frequency can break microbial cells and kill some microbes. The combined use of ultrasonic or hydrodynamic cavitation and ozone can reduce ozone consumption, thereby reducing the amount of ozone disinfection by-products, while reducing energy consumption. The combination of the two has a better disinfection effect than using ozone and ultrasonic cavitation alone<sup>[39-40]</sup>.

### 4.2 Ozone and chlorine combined disinfection

Adding a small amount of chlorine or ammonium chloride after ozone disinfection can stabilize the water quality of the pipe network. Ozone oxidation can lead to changes in the types of typical by-products and changes in the amount of follow-up chlorination process. At the same time, ozone oxidation can effectively reduce the genotoxicity of the effluent. Subsequent chlorination and continuous disinfection have less impact on the genotoxicity<sup>[41]</sup>.

### 4.3 Ozone and ultraviolet combined disinfection

Ozone is consumed in sewage disinfection. Catalytic oxidation can be used to increase the oxidation efficiency of ozone to reduce the amount of ozone used. Catalytic oxidation belongs to the category of advanced oxidation, and the oxidation ability of ozone is improved under the action of a catalyst. Ozone/ultraviolet, ozone/hydrogen peroxide combined process belongs to ozone catalytic oxidation process. In addition, certain metals and metal oxides also have the effect of catalyzing ozone<sup>[42]</sup>. BSOH et al. found that the sterilization effect of using ozone-ultraviolet combined method to disinfect reused sewage is better than that of using ozone or ultraviolet alone<sup>[43]</sup>. This is mainly because ultraviolet catalysis causes ozone to produce a large amount of •OH in the water, which enhances its oxidation. The ability and sterilization effect are improved.

### 4.4 UV and chlorine combined disinfection

Combination of ultraviolet and chlorine disinfection is an efficient, economical, thorough and long-lasting disinfection method. On the one hand, it can make up for the disadvantage that a single chlorine disinfection cannot kill cryptosporidium, flagellum and other protozoa, and it can make up for the shortcomings of single ultraviolet disinfection that has no continuous disinfection effect, and can well prevent the occurrence of bacterial photoresurrection; On the one hand, it can also reduce the amount of chlorine used, reduce the generation of disinfection by-products in the water, and reduce the biological toxicity of the water<sup>[44]</sup>. XiuJuan Wang et al. found through experiments that a small dose of ultraviolet radiation supplemented with a small dose of chlorine for disinfection treatment can play the role of a large dose of ultraviolet alone or a large dose of chlorine alone<sup>[45]</sup>.

## 5 Prospects for the research direction of reclaimed water disinfection technology

First, for mature disinfection methods, it is necessary to research and develop more efficient and energy-saving equipment to reduce disinfection costs; second, to research and develop more efficient and environmentally friendly disinfectants to replace disinfectants that are prone to secondary pollution; third, Continue to strengthen the research on the disinfection mechanism, and find effective methods to improve the disinfection effect; fourth, strengthen the kinetic research to improve the ability to predict and control the disinfection process<sup>[1]</sup>.

## 6 Conclusion

In the near future, with the development of science and technology, the reclaimed water treatment process will

be more diversified, the investment will be lower, and the treatment process will be more energy-saving and environmentally friendly.

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