

The Pulsed Arc Electrohydraulic Discharge Treatment Study on Waste Water and Its Application

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ABSTRACT: With the speedy development of modern industry, the technology of wastewater treatment plays an essential role in the research of environmental protection science. The tech of Pulsed Arc Electrohydraulic Discharge (PAED) has been intense researched by virtue of its marked treatment effect, low power consumption and so on. The experiment was conducted in the commercial second class waste water treatment plant by the tech of PAED. The 10 L volume PAED reactor with cross flow eccentric electrode arrangement was used for batch mode. The PAED power supply is 3kJ/pulse with 2 Hz discharge rate. Two different types, one from up-stream and the other from down-stream of bio-treatment pound, with different level of pH, electrical conductivity and E-coli concentration were treated. Three different electrode materials Ti, W and Ti-alloy were tested. There results show that W electrode showed the best performance for the inactivation of E-coli at 1kWh/m³ of cumulative electrical energy in-puts. Fundamental discharge characteristics, pressure wave propagation, optical emission characteristics etc. link with disinfection performance will be discussed in detail.

KEYWORD: Pulsed Arc Electrohydraulic Discharge, Discharge electrode, Wastewater treatment

1 INSTRUCTION

In recent years, with the sustainable development of pulsed power technology, PAED gains tremendous advancement [1-3]. PAED is the technology which utilizes the electro-hydraulic efficiency to generate the pressure wave, UV, the H, O and OH radicals [4]. The aim of killing the microbes can be realized through the physical-chemical reaction of the resultant [5-6]. For instance, the protein film of bacteria can be destroyed by pressure shock wave; the molecular bond of the bacteria's DNA also can be destroyed by photo-decomposing of UV and oxidative cracking of OH radicals [7-9]. Compared with the other tech of water treatment(PCED, PPED), the tech of Pulsed Arc Electrohydraulic Discharge has obvious advantages on the aspect of treatment effect energy efficiency [10].

Generally speaking, the PAED system operates at a frequency from 0.01 to 100 Hz with the peak current above 10kA and the voltages ranging from 2.5kV to 3.5kV. After the breakdown of air switch during the process of PAED, the energy stored in the high voltage pulse capacitor can be released through the certain distance of water arc electrode gap and the

violent discharge phenomenon can be formed [11-12].

Research on the subject of the PAED Physical-chemical effects has been done very systematically and deeply.

N. Karpel Vel Leitner et al. observed that the highest UV intensity can be generated by PAED and the wavelength range is from 380nm to 425nm when the energy of the energy pulse power supply was 0.5kJ/pluse [13]. B. R. Locke et al. obtained the relationship between sterilizing rate and PH, conductivity, treatment time by PAED [14]P Sunka et al.[15] pointed out the effect of electric field intensity on the generation rate of free group when the water arc electrode gap was Needle-Plate.

In the present article, the research on combining the tech of PAED with wastewater treatment was not so much, moreover, its main directions was the relationship between sterilizing rate and PH, conductivity, treatment time by PAED. However, in this article the research was focused on the relations between the E. coli sterilization efficacy of PAED and the water arc electrodes. In addition, this paper also makes an analysis on the resultant after the discharge of PAED occurred.

2 EXPERIMENTAL APPARATUS

The schematic diagram of experimental apparatus is shown in Fig. 1. The experimental apparatus consists of two parts: the pulsed arc power supply and reaction chamber (10L). Among them, the power supply of PAED which consists of a slide transformer (AC 220V), a high voltage transformer, an energy storage capacitor (20 μ f~160 μ f), rectifier, resistor (3k Ω) and a pseudo spark switch can provide a single pulse energy of 3kJ and the range of its charging voltage is from 2.5kV to 3.5 kV. The discharge frequency of this wastewater treatment system is 0.1Hz~100Hz.

The reaction chamber (10L) is a stainless steel drum which has a diameter of 25cm. In the reaction chamber there are four positions which are used to fix the iron electrode. The distance of electrodes can be accurate control of a range from 0.5cm to 1.5cm by stepping motor. The four different positions are used to research on the pressure wave generated by PAED. There are six threaded holes which are located respectively on the outer end and the cylinder wall of reaction chamber. The transparent quartz pyrex window is used to observe the UV generated by PAED.

The measuring part of wastewater treatment system consists of a high voltage probe (Tektronix P6015A) which is used to measure the applied voltage, ammeter shunt (GF-1, top measure current is 30 kA, 0.006879V/A) which is used to measure the discharge current, and the piezoelectric type pressure sensor (CY-YD) which is used to measure the waveforms of the pressure. The voltage signals of the waveforms are sent to the electric amplifier (YE5853B) which can be displayed on the digital oscilloscope (TEK-TDS1012B) and the spectrometer is used to detect the UV generated by PAED.

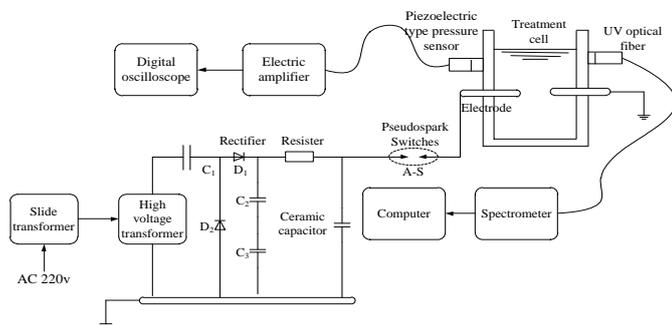


Fig.1. Schematic diagram of PAED and the analyzer system

3 RESULTS AND DISCUSSION

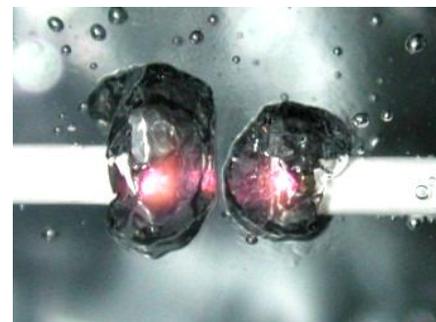
3.1 The breakdown mechanism of Pulsed Arc Electrohydraulic Discharge

After the breakdown of the plasma channel between the electrodes of pseudo spark switches, the pulse

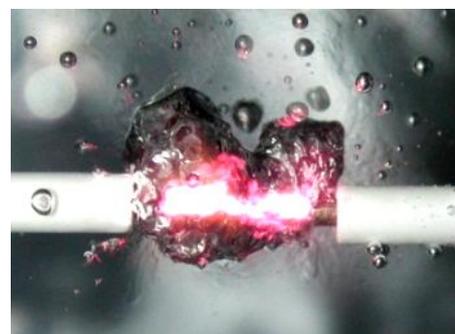
energy stored in the pulse capacitor are released into the plasma channel for a short time (about 100 μ s). Then the peak current will reach dozens of kA, the temperature of the plasma channel will also reach 10⁴K. With the continuous development of the plasma arc column, the water medium can be transformed into the gas. Therefore, the pulse energy has not only gasified the liquid between the two iron electrodes, but also transforms into the air bubble's internal energy and the inflation potential energy [16-18]. With the energy transition between the internal energy and the inflation potential energy, the bubbles start to puff and shrink [19-20]. Finally, the waveforms of the pressure are formed, shown in Fig.3. The plasma channel between the iron electrodes fixed on the reaction chamber is also broken at the same time.



Discharge after formation of bubbles



Expansion



Bridging

Fig.2. Breakdown process of PAED the plasma channel

With the continuous development of plasma channel, the water medium which gets enough energy turns into the air bubble, and the formation of air

bubble also promotes the development of plasma arc column [21]. It is noticed that the discharge voltage between the iron electrodes in the water medium will not reduce to 0V immediately, due to the development process of streamer channels. This kind of phenomenon can be named as the pre-breakdown of PAED. Fig.3 shows the process of pre-breakdown lasting about 3.1ms. With the breakdown of the plasma channel between the pseudo spark switch, the discharge voltage will not reduce to zero. On the contrary, the discharge current will rise to the peak value in 2 μ S. The breakdown voltage of the iron electrodes decreased from 2.5kV to 2.0 kV, because of the energy used to develop the plasma channel. The process of pre-breakdown is closely associated with the conductivity of water medium, PH, BOD and COD.

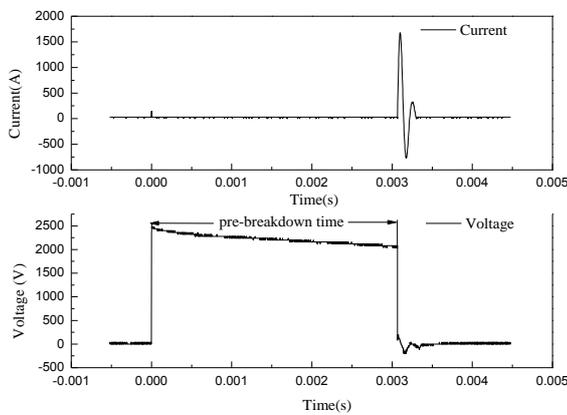


Fig.3. The voltage wave and the current wave of the water arc gap

3.2 Relationship of the electrodes and the electric field intensity of plasma channel

With the continuous development of plasma channel, the inter-collision of plasma, free radicals, and other free electron will be accelerated under the power of electric field. As a result, the iron electrodes and the process of PAED become closely related under the influence of electric field intensity which can be estimated by

$$E_{\max} = \frac{2U}{r \ln(1 + \frac{4d}{r})} \quad (1)$$

In which U is the voltage of the iron electrodes, d is the distance of iron electrodes in the water medium, r is the radius of the iron electrodes. Usually, the electric field intensity is closely related to the distance of iron electrodes and the radius of them. If the voltage keeps invariant, the electric field intensity will reduce along with the increase of the distance of iron electrodes. The analogous results were obtained: along with the increase of radius of the iron

electrodes, the electric field intensity will increase at first then decreases.

Fig.4 shows the simulation waveforms of the electric field intensity in the water medium. By the line of electric force between the region of the positive and the negative electrodes, it is found that the electric field intensity of the electrode border is higher than the other place, which may lead to the generation of electric arc probably locating there.

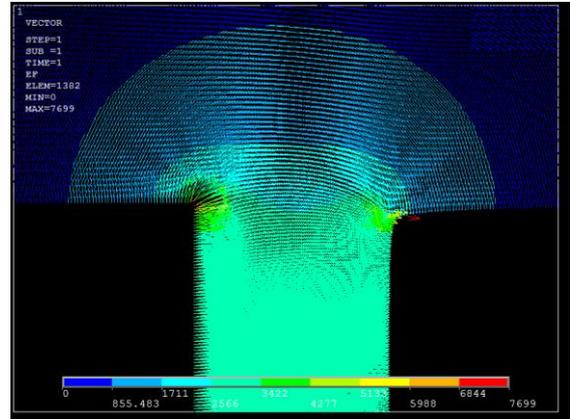


Fig.4. The simulation waveforms of the electric field intensity. The discharge voltage: 3Kv, the distance of iron electrodes: 1mm, the radius of the iron electrodes: 10cm, the pulse energy: 3KJ/pulse.

3.3 Effect of the sterilization efficacy of PAED with different distance of tungsten electrodes

To determine the effect of the sterilization efficacy of PAED with different distance of iron electrodes, pulsed arc electrohydraulic discharge experiments were conducted at an applied. In the reaction chamber (10L), the distance of electrodes changes from 0.5mm to 2.5mm. E. coli is used as a representative to research the effect of wastewater treatment by PAED. In order to detect the number of E. coli, membrane filter method which should take a certain amount of sample (1 μ L~1000 μ L) trained in the M-FC agar for 24hour (45 $^{\circ}$ C) is used. The average amount of bacterial colony which can be estimated by

$$N = \frac{G \times 1000}{L} \quad (2)$$

In which N is the average amount of bacterial colony (CFU/L), G is the average amount of bacterial colony trained on the filter, L is the water volume flowing through the filter (ml).

Fig.5 (a), (b) shows the average amount of bacterial colony trained on the M-FC agar before and after discharge. The charging voltage is 3kV, the distance of iron electrodes is 1mm, the pulse energy is 3kJ/pulse.



Fig.5. (a) The average amount of bacterial colony after discharge for 30min



Fig.5. (b) The average amount of bacterial colony in raw water

Fig.6 shows the effect of arc electrode gap on *E. coli* sterilization by PAED. Under this condition the charging voltage is 3kV and the conductivity of water medium is 0.688 ms/cm. Along with the increase of the distance from 0 to 1.5mm, the *E. coli* sterilization rate by PAED increases from 92% to 99.87%, however, when the distance of arc electrode gap is 2.5mm, the *E. coli* sterilization rate by PAED will decrease to 56%.

The reason is that according to eq.(1), along with the increase of the distance from 0 to 1.5mm, the electric field intensity will increase so that the initial plasma can get more energy for the electrohydraulic effect, and the effect initial plasma density will increase too. So the *E. coli* sterilization rate by PAED will improve. But if the distance increase to 2.5mm, the electric field intensity could not provide enough electric field force for the development of plasma channel, and the corona discharge will happen on the edge of the arc electrode gap. In this case, the pressure wave, UV, the H, O and OH radicals generated by PAED will reduce evidently. So the *E. coli* sterilization rate will decrease on 56%.

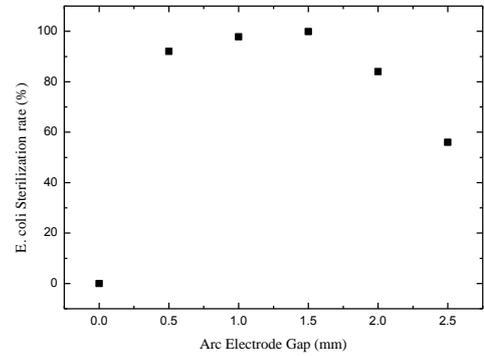


Fig.6. The effect of arc electrode gap on *E. coli* sterilization by PAED. Charging voltage: 3kV, conductivity of water medium: 0.688 ms/cm, the pulse energy: 3KJ/pulse.

3.4 Effect of the sterilization efficacy of PAED with different diameter of tungstenelectrodes

Fig.7 shows the effect of arc electrode gap on *E. coli* sterilization by PAED. Under this condition the charging voltage is 3kV and the conductivity of water medium is 0.688 ms/cm. Along with the increase of the diameter from 6 to 12mm, the *E. coli* sterilization rate by PAED increases from 94% to 99.6%. The reason is that according to eq.(1), along with the increase of the distance from 6 to 12mm, the electric field intensity will increase so that the initial plasma can get more energy for the electrohydraulic effect, and the effect initial plasma density will increase too. So the *E. coli* sterilization rate by PAED will improve to 99.6%.

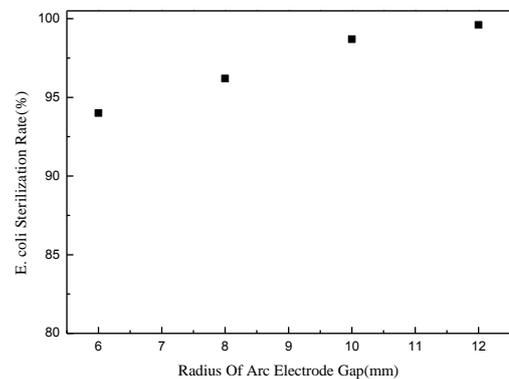


Fig.7. The effect of the radius of arc electrode gap on *E. coli* sterilization by PAED. Charging voltage: 3kV, conductivity of water medium: 0.688 ms/cm, the pulse energy: 3KJ/pulse.

3.5 Effect of the sterilization efficacy of PAED with different types of electrode materials

To determine the effect of the sterilization efficacy of PAED with different types of electrode materials, pulsed arc electrohydraulic discharge experiments were conducted at an applied. Fig.8 shows the effect

of different types of electrode materials (Titanium, Tungsten, Titanium Alloy) on E. coli sterilization by PAED under the condition that a charging voltage reaches 3kV and the conductivity of water medium is 0.688 ms/cm. In this experiment, the Tungsten electrode shows better sterilization effect than that of other types of electrode materials. This is due to the secondary emission coefficient of electrode materials and fusion welding resistance are in close contact with the sterilization efficacy. The criterion for fusion welding resistance can be estimated by

$$K = \rho C T_M \sqrt{\delta} \quad (3)$$

In which, ρ is the density of electrode materials, C is the constant of fusion welding resistance, T_M is melting points of electrode materials, δ is conductivity. It can be noted that the melting points of electrode materials (Titanium, Tungsten, Titanium Alloy) is respectively 1668⁰C, 3410⁰C, 1822⁰C. In addition, Tungsten has the highest secondary emission coefficient among the three types of electrode materials. Therefore, with the continuous development of plasma channel, if secondary emission coefficient is higher than others, the number of high energy particles, free radicals, and other free electron will increase thus resulting in the better effect of PAED.

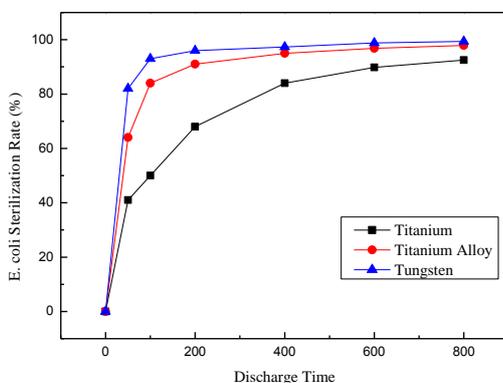


Fig.8. The effect of the types of electrode materials on E. coli sterilization by PAED

4 CONCLUSION

This paper states the effect of electrode in water medium by PAED. The electric field intensity of plasma channel has a close relation to the distance of iron electrodes and the radius of the iron electrodes. Along with the increase of radius of the iron electrodes, the electric field intensity will increase at first then decreases, in the meantime, the electric field intensity will reduce along with the increase of the distance of iron electrodes. With the continuous

development of plasma channel, the process of pre-breakdown is closely associated with the conductivity of water medium, PH, BOD and COD. Further work, effect of the E. coli sterilization efficacy of PAED is closely associated with the distance of electrodes, the diameter of electrodes and the types of electrode materials. The amount of the metal element content in water medium is the least if the Tungsten electrode is used as the electrode materials.

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