ANALYSIS OF THREE-STATE REACTOR IN THE INDUSTRIAL WASTEWATER TREATMENT SYSTEM BASED ON PULSED DISCHARGE PLASMA *

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Abstract

The effective treatment of the industrial wastewater is very significant to the protection of our environment. The system of wastewater treatment based on pulsed discharge plasma provides a new way for the disposal of industrial wastewater. However, the traditional reactor cannot meet the demand of degradation rate and the treatment efficiency. In order to improve the degradation rate and disposal efficiency of the wastewater, a solid-liquid-gas (SLG) three-state reactor for the high voltage pulsed discharge plasma system is put forward, and then the working principle of the reactor is introduced. Furthermore, a simulation model of the reactor is built. After that the electric field distribution of the SLG reactor is analyzed by numerical simulation. The contrast between the traditional reactor and the SLG reactor is carried out. Furthermore, the effect of the voltage and the diameter of the solid ball in the reactor are analyzed. It can be seen from the results of the analysis that the SLG reactor of the wastewater treatment system based on the high voltage pulsed discharge plasma has better effect than two-state reactors. The conclusion that the discharge voltage has great effect on the disposal efficiency can also be drawn. Meanwhile, the diameter of the solid packing can affect the distribution of the electric field. The research results are very important to the application of the SLG reactor in the wastewater treatment system.

I. INTRODUCTION

The development of the industry may bring much wastewater. For instance, in some textile mills or chemical plants, some organic wastewater is generated in the manufacture activities [1-2]. This wastewater is a great threat to the environment. If it is discharged without treatment, it may cause serious pollution. Thus, according to the requirement of the government and the environment ministry, all industries with wastewater should take measures to dispose it before it is discharged. At present, there are many methods as to the treatment of the wastewater, such as adsorption method with activated carbon, biological treatment with micro organism, and etc [2]. However, these methods cannot meet the demand of the treatment efficiency and the degradation rate at the same time. As the development of the technology for the high voltage pulsed discharge plasma, its application feasibility of the plasma in the treatment of wastewater has been proved by many researchers, and some important results have been obtained [3-5]. However, the treatment efficiency still needs improvement. In order to improve the disposal efficiency, a new kind of reactor, that is a solid-liquid-gas (SLG) three-state reactor for the high voltage pulse discharge plasma system, is put forward and analyzed in this paper.

II. WORKING PRINCIPLE OF THE WASTEWATER TREATMENT SYSTEM

A typical treatment system of wastewater based on the high voltage pulsed discharge plasma is shown in Fig. 1, which consists of charging device, wastewater reactor, controller, storage capacitors, monitor inspection of the water quality, and etc.

Actually, the mechanism of the wastewater treatment based on the plasma is much intricate. However, the basic working principle of the wastewater treatment system is as follows: Firstly, the wastewater is pumped in to the wastewater reactor, and then the storage capacitors are charged to high voltage by the charging device. The controller sends a trigger signal to the trigger switch, and then the switch is turned on. The storage capacitors with high voltage begin to discharge through the water and the electrodes in the reactor. Then the high electric field is generated between the electrodes. If the electric field is large enough, the medium such as the water between the anode and the cathode may be broken down and generate plasma. Accompany with the reaction, the water molecule is decomposed into different ions, such as -OH, O_3, and

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etc, which have strong oxidizing property. Except that there are ultraviolet radiation and high energy electrons during the reaction [6].

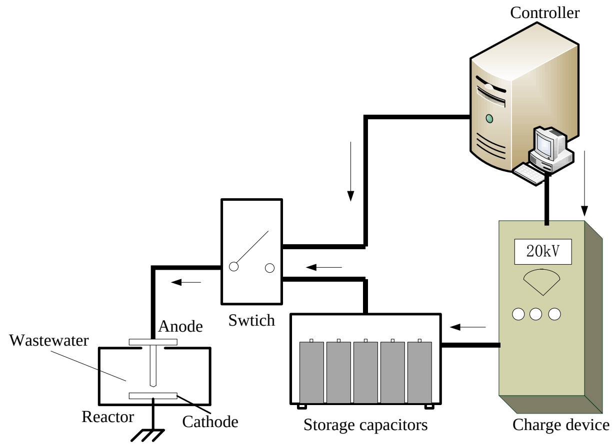

Figure 1. Typical structure of the wastewater treatment system based on high voltage pulsed discharge plasma

Therefore, the organic matters in the wastewater are oxidized by these ions with strong oxidizing property, or its chemical bond is destroyed by the ultraviolet radiation and electrons. At last the organic matters are degraded and changed into innocuous substance, and then the wastewater is disposed. Meanwhile, the content of organic matters in the wastewater is reduced. Generally, if the concentration range of the organic matters in the wastewater meets with the requirement of the discharge standard for industrial wastewater, the treatment of the wastewater is finished and can be discharged directly.

III. DESIGN OF THE SLG REACTOR

Among all the component of the wastewater treatment system, the reactor is the most important as it can affect the degradation rate and the disposal efficiency. Thus, the structure of the reactor is studied by many researchers. It can be seen from the Fig.1 that the electrodes of the reactor is the needle-plate mode, which is always called electro-hydraulic discharge. As the electric field is only put between the needle and the plate, only the wastewater near the electrodes can be degraded effectively. Therefore, its disposal efficiency is not high enough. Furthermore, the needle electrode is easily damaged by rusty and high voltage, so it is usually needed to replace. Thus, the cost for the treatment of the wastewater is much expensive [7-8].

A. Structure of Barrel Type Electrode

For the sake of efficiency, cost and lifetime, the reactor with needle-plate mode is not widely used in the treatment of industrial wastewater. On the contrary, the reactor with barrel type electrodes is superior to the reactor with needle-plate type electrode. The structure of the reactor with barrel type electrode is illustrated in Fig.2.

It can be seen from the Fig.2 that the reactor is a barrel type with cathode and anode. Generally, the anode of the reactor is a metal stick made of copper, and the cathode of the reactor is a copper net which is distributed all the inner surface of the reactor [9]. Furthermore, the container of the reactor is usually made of synthesis glass.

Contrast to the reactor in Fig.1, the contact surface of the electrode and the wastewater is larger in the barrel type reactor. Thus, it can degrade more wastewater at the same time, which is beneficial to the improvement of the disposal efficiency.

As the distribution of the electric field is not even in the reactor, the degradation rate of the wastewater at different place of the reactor is not the same, which will affect the disposal efficiency after all. Thus, in order to improve the efficiency, an air pump is added and the air is ventilated into the wastewater, which is shown in Fig.2.

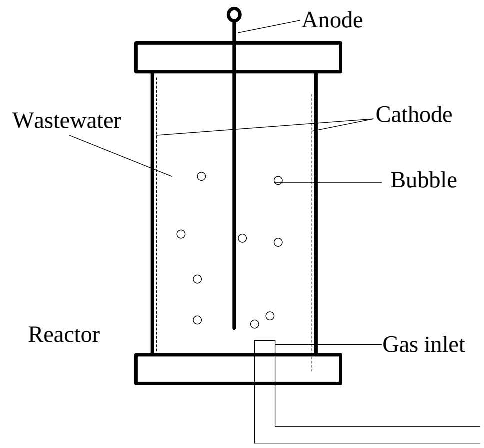

Figure 2. Principle diagram of reactor with barrel type electrode

During the treatment of the wastewater, the harmful organic matters in the wastewater will keep to move with the effect of the gas ventilated by the air pump, which can make the concentration range of the organic matters in the wastewater distribute more even. Meanwhile, the treatment efficiency of the system may be improved.

B. Structure of the SRG Three-state Reactor

Though the barrel type reactor in the Fig.2 is superior to the needle-plate reactor, it is also needed to improve. As the strength of electric field is reduced gradually from the anode to the cathode, the energy for the treatment of wastewater is also reduced, which is not beneficial to the treatment efficiency of the system.

In order to get the distribution characteristics of electric field in the barrel type reactor, a numerical simulation model based on the Maxwell 2D SV is established. In the simulation model, the radius of the anode and the cathode is 2 mm and 12 mm, respectively. The voltage on the anode and cathode is 40 kV and 0 V, respectively. After that the electric field of the reactor between the anode and the cathode is calculated, the simulation result is shown in Fig.3.

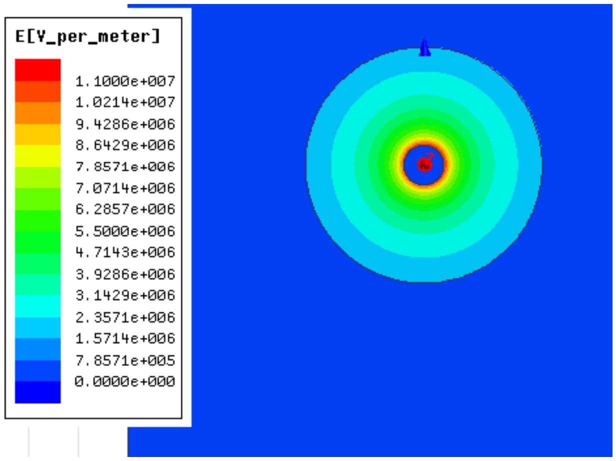

Figure 3. Distribution of electric field for the barrel type reactor

It can be seen from the Fig.3 that the distribution characteristics of the electric field is the same as the analysis above. The maximum value of the electric field is about 1.1×10^{7} V/m, which is shown near the anode. The minimum value of the electric field is about 2×10^{6} V/m, which is just near the cathode.

Therefore, in order to further improve the disposal efficiency of the system, a SLG three-state reactor is put forward, which is shown in Fig.4.

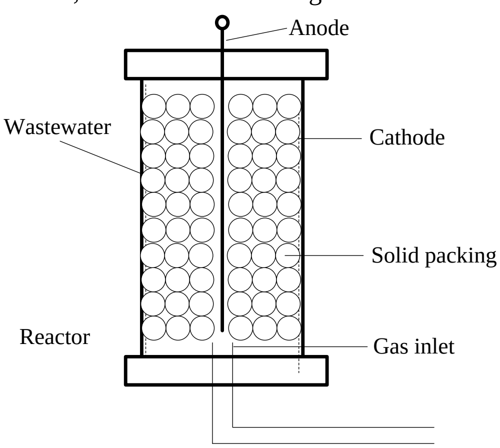

Figure 4. Structure of the SLG three-state reactor

It can be seen from the Fig.4 that the SLG three-state reactor is also a barrel type reactor, but a lot of solid matters are added into the barrel. With the effect of the solid packing, the electric field between the anode and the cathode will be changed, and the disposal efficiency maybe improved.

C. Electric Field Distribution of SLG Three State Reactor

In order to analyze the distribution of the electric field for the SLG three-state reactor, a simulation model of the reactor is established by the Maxwell 2D SV. As the reactor is a symmetric structure, we choose the cross section of the reactor to analyze. The radius of the anode and the cathode is 2 mm and 12 mm, respectively. The voltage between the anode and the cathode is 40 kV. Furthermore, the solid packing in the reactor consists of common glass balls, whose radius is 2.5 mm. After the settings, the simulation model is calculated, and the results are shown in Fig.5.

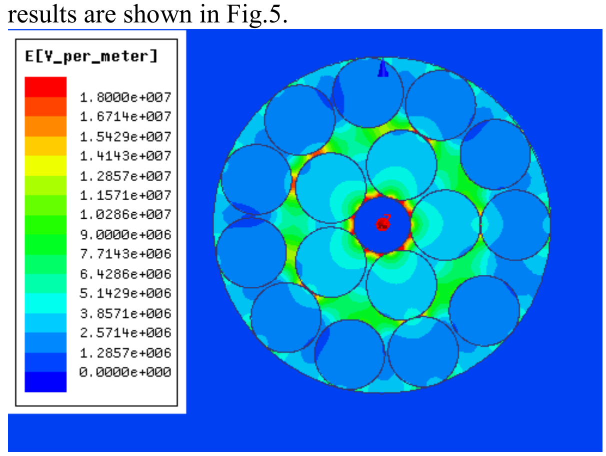

Figure 5. Distribution of electric field for the SLG reactor

It can be seen from Fig.5 that the maximum value of the electric field is over 1.8×10^{7} V/m, which is larger than the value of the electric field in the Fig.3. However, compared to the distribution of the electric field for the liquid-gas reactor in Fig.3, the distribution of the electric field for the SLG three-state reactor is not even. The existence of the glass balls changes the distribution of the electric field. In Fig.3, the maximum value of the electric field is obtained near the anode, and then begins to decrease from the anode to the cathode little by little. However, in the Fig.5，the value of the electric field is not only much strong near the anode, but also between the gaps of the glass balls. It means that the strength of the electric field in the reactor has been improved besides the place near the anode. Thus, the wastewater in the reactor will be disposed effectively under the working of the high electric field. In other words, the treatment efficiency and the degradation rate of the wastewater will be improved,

IV. ANALYSIS OF THE SLG REACTOR AT DIFFERENT PARAMETERS

In order to design the SLG three-state reactor, the characteristics of the reactor at different parameters are analyzed by numerical simulation.

A. Characteristics of the Electric Field at Different Voltage

Firstly, the distribution characteristics of electric field at different voltage are analyzed. The parameters of the reactor are the same as there are in the Section C, the radius of the anode and the cathode is 2 mm and 12 mm, respectively. However, the voltage between the anode and the cathode is 25 kV. The distribution characteristic of the electric field is illustrated in Fig.6.

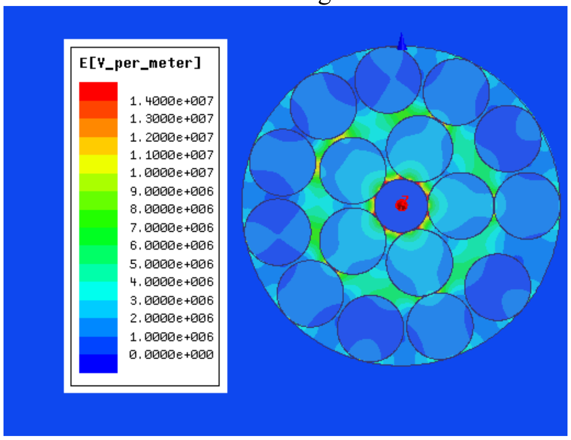

Figure 6. Distribution of electric field for the SLG reactor when the voltage is 25 kV

It can be seen from the Fig.6 that the distribution characteristics of electric field is as same as the results shown in Fig.5. The maximum value of electric field is still near the anode, which is about 1.4×10^{7} V/m. Furthermore, the strength of the electric field between the glass balls is still strong, which is about 1×10^{7}V/m. Meanwhile, it can be seen from the results that as the decreasing of the voltage, the strength of the electric field will be reduced. However, though the voltage is much lower than it in the Fig.3, the strength of the electric field in the SLG three-state reactor shown in Fig.6 is bigger. It means that if we want to obtain the same strength of the electric field, the working voltage of the SLG three-state reactor is much lower, which is beneficial to the choice of the high voltage components and the charging devices.

In order to verify the analysis results above, the simulation model is calculated when the voltage is 10 kV, and the distribution characteristics of electric field is shown in Fig.7.

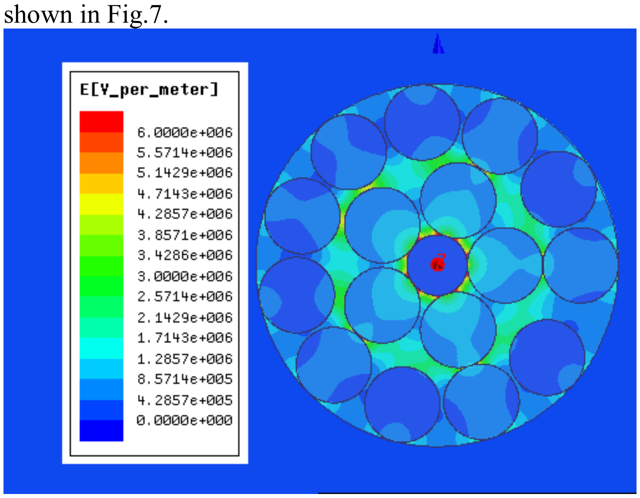

Figure 7. Distribution of electric field for the SLG reactor when the voltage is 10 kV

From the Fig. 7, it can find that the maximum value of the electric field is about 6×10^{6} V/m, and the strength of electric field between the glass balls is about 3×10^{6}V/m. It also can be seen from the results that the decrease rate of the electric field in the SLG three-state reactor is smaller than it in the traditional barrel type reactor.

B. Characteristics of the Electric Field with Different Radius of the Glass Balls

From the analysis above, it can find that the glass balls in the reactor can change the distribution of the electric field. Furthermore, the dimension of the glass balls may also affect the distribution characteristics of the electric field in the reactor. Thus, a simulation model of the reactor is built to analyze the distribution characteristics of the electric field with glass balls at different radius. The voltage between the anode and the cathode is 40 kV, and the radius of the glass ball is 3 mm. Furthermore, other parameters are as same as them in Fig.3. The results of the simulation are shown in Fig.8.

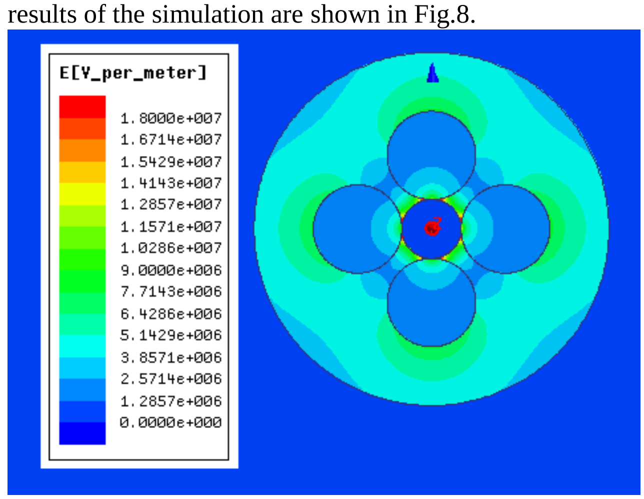

Figure 8. Distribution of electric field for the SLG reactor when the voltage is 40 kV and the radius of glass ball is 3mm

The Fig.8 is the distribution of electric field for the SLG reactor when the radius of glass ball is 3 mm. It can be seen from the Fig.8 that the number of the glass ball is reduced for the sake of the increasing of radius. The maximum value of the electric field is about 1.7×10^{7} V/m. However, the strength of electric field for the most area in the reactor is about 4×10^{6} V/m. It means that the decrease rate of the electric filed is larger than it in Fig.7. Therefore, the smaller glass balls are beneficial to the distribution of the electric field. However, it should take the volume of reactor into consideration when we choose the glass balls as it can take up some space of the reactor.

V. SUMMARY

Reactor is very important to the degradation rate and the disposal efficiency of the wastewater treatment system based on high voltage pulsed discharge plasma. Aiming to the deficiency of the needle-plate type reactor and the traditional barrel type reactor, it put forward a new kind of SLG three-state reactor. From the analysis above, it can draw the conclusion that the solid packing in the reactor can change the distribution of the electric field and improve the strength of the electric field at different areas of the reactor. Thus, it can improve the treatment efficiency and the degradation rate of the wastewater. Furthermore, the requirement of the voltage is brought down by the SLG three-state reactor. Meanwhile, the design and the application of the treatment system based on high voltage pulsed discharge plasma is easier. Besides, the radius of the glass balls can affect the distribution of the electric field. Generally, the small radius of glass ball is more beneficial to the distribution of the electric field.

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