A Collaborative Purification Device for Medical Exhaust Gas and Wastewater based on Low Temperature Plasma Technology

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Abstract: With the continuous development of environmental protection and sustainable development strategy, the traditional medical waste gas and wastewater discharge will not only pollute the environment, but also seriously threaten human physical and mental health. It has become an urgent problem to control it scientifically and deal with it reasonably. In this paper, an integrated device for treating medical waste gas and waste water with low temperature plasma is designed, which uses silver-plated graphite fiber as electrode. The device uses plasma to purify medical waste gas and wastewater, no secondary pollution, high efficiency and environmental protection; through the atomization device is set to make waste water and waste gas synergistic purification, improve purification efficiency; the modified graphite fiber electrode is adopted to reduce energy consumption. This research improves the efficiency of waste water and waste gas treatment to fill the current gap in the industry, and contributes to the sustainable development strategy.

1 INTRODUCTION

With the implementation of sustainable development strategy in the world, people pay more and more attention to sustainability. Under the background of global environmental protection, how to scientifically control and reasonably treat the organic waste gas and medical waste water in the medical industry has become an urgent problem (Wei, 2020).

Hospital sewage contains a large number of pathogenic bacteria, viruses and chemical agents (Lin, 2017), which is characterized by space pollution, acute infection and latent infection (Yang, 2017). Medical waste gas is harmful gas produced by combustion of medical waste (Zhang, 2019). Such industrial waste gas contains alcohols, acids and ketones, which will not only pollute the environment, but also seriously threaten human physical and mental health.

At present large hospital medical wastewater treatment mainly using chlorine disinfectants for disinfection, such as NaClO, ClO2, in which NaClO in the process of using residual, easy to react with organic matter in water generated in the process of sterilization effect of chemicals cause cancer, birth defects, there is a certain risk, the need of personnel management. However, the traditional method has its inevitable drawbacks in principle, such as high cost of facility construction, maintenance and management, multi-stage processing and complicated process control.

In the processing of medical waste is the traditional adsorption method, although adsorption method has a very wide range of application and low energy consumption, but if the exhaust gases contain a variety of pollutants, the adsorption efficiency of adsorption method would significantly reduce, and adsorbent regeneration difficulty, easy to poisoning, so led to the organic waste gas treatment lack of quality assurance. So finding a new type of medical waste gas, wastewater treatment technology is imperative. Although there are many differences between this research and our former study (Hua, 2022; Chen, Zhuang, 2021; Gu, 2021; Chen, Zhang, 2021), we still carry out the excellent research about a collaborative purification device for medical exhaust gas and wastewater based on low temperature plasma technology.

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2 DEVICE INNOVATION

With the support of the existing technology, we have designed an integrated device for treating medical waste gas and waste water using low-temperature plasma with graphite fiber coated with silver as electrode. Graphite fiber surface modification technology was used to improve the plasma surface discharge efficiency, and a liquid gasification device was creatively added to the device, which could further improve the common purification effect of waste water and waste gas. And the plasma power and purification rate were studied, and finally successfully produced a set of waste water gasification, low temperature and high efficiency plasma water purification in one of the waste water and waste gas treatment equipment, on the existing basis to improve the purification rate and reduce the energy required, the traditional purification device to improve and upgrade.

(1) Plasma purification

Using plasma purification medical waste gas waste water, no secondary pollution, and efficient environmental protection: compared with the traditional chemical precipitation method, using plasma purification more green environmental protection, in line with the requirements of energy conservation and emissions reduction, oxidation and plasma generated is strong gas efficient of purification of bacteria, viruses and other organisms that have slipped into the medical wastewater and organic chemicals, achieve discharge standards.

(2) Modified graphite fiber electrode

Modified graphite fiber electrode is adopted to reduce energy consumption. Compared with the copper column, the surface of graphite fiber rod is loose and porous, which is beneficial to generate more plasma in dielectric barrier discharge and improve the purification efficiency. Graphite fiber itself is an excellent conductor of electricity, coating its surface with silver can further reduce its resistivity, but also improve its corrosion resistance, prolong the service life. The experimental results show that the low temperature plasma generator using modified graphite fiber as electrode can save 20%~30% power consumption compared with the similar device.

(3) Atomization device

Through atomizing device, waste water and waste gas can be synergistically purified to improve purification efficiency. The medical waste water is mixed with the exhaust gas after pressurized atomization, and the gas-liquid mixture phase enters the static mixing tube at the same time with the air after plasma treatment, and is mixed in the mixing tube and fully reacts. This treatment method can improve the utilization rate of plasma, reduce the power consumption, and accelerate the reaction rate of plasma and pollutants. Through experimental calculation, the reaction rate is the fastest at the interface between plasma and waste water. The cooperative purification method of waste gas and waste water of this device can greatly improve the contact area of plasma air and waste water, accelerate the reaction rate, and thus improve the purification efficiency of the whole machine.

3 PURIFICATION PLANT

The purification device includes gas-liquid mixed structure, plasma generator, mixed reaction structure and condensation separation structure. Fig.1 is a schematic diagram of the overall structure of the device.

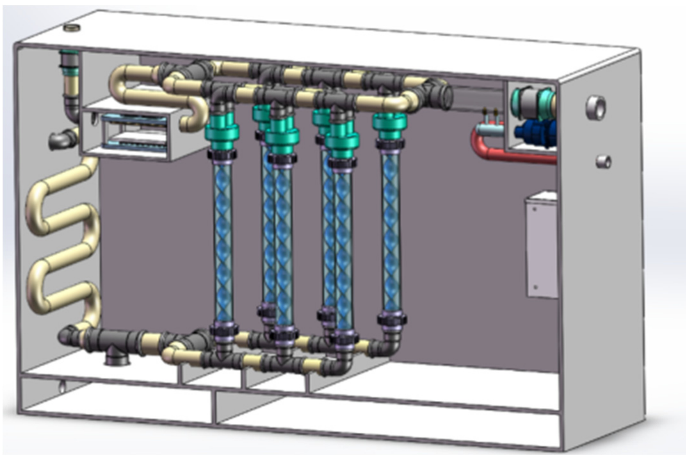


Figure 1: Cruise drone landing platform structure.

(1) Gas-liquid mixed structure

The gas-liquid mixing mechanism comprises a gas input part and a liquid input part. Fig. 2 is a schematic diagram of gas-liquid mixture structure. The gas input part consists of a turbocharger, which rotates to input the exhaust gas; The liquid input part is composed of a water pump and a number of atomizing nozzles arranged on the pipe wall, through which the waste liquid is pumped into the pump, and then the waste liquid is changed into mist through the nozzle, and mixed with the waste gas.

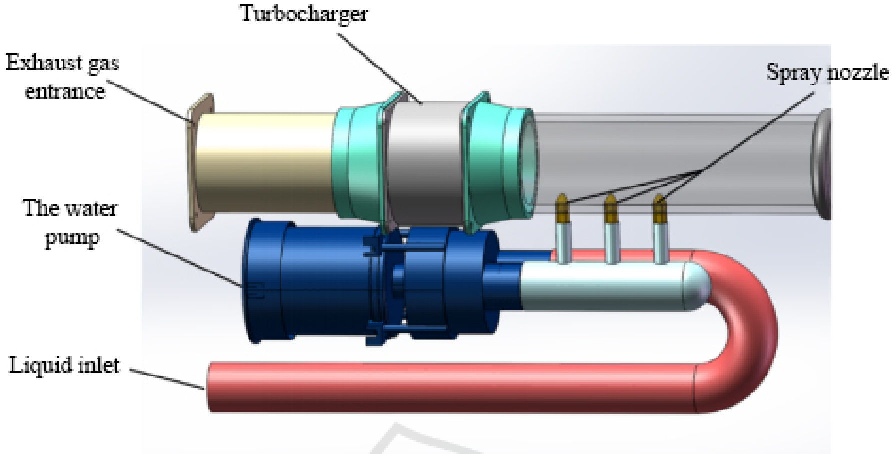


Figure 2: Gas-liquid mixed structure.

(2) Plasma generator

Plasma generator by DBD low temperature plasma generator, turbocharger, desiccant, through the turbocharger will input air, the air through the desiccant to remove moisture, and DBD low temperature plasma generator to produce plasma, input the air generator within the plasma transfer and fresh air to produce new plasma. Fig. 3 is a schematic diagram of plasma generator.

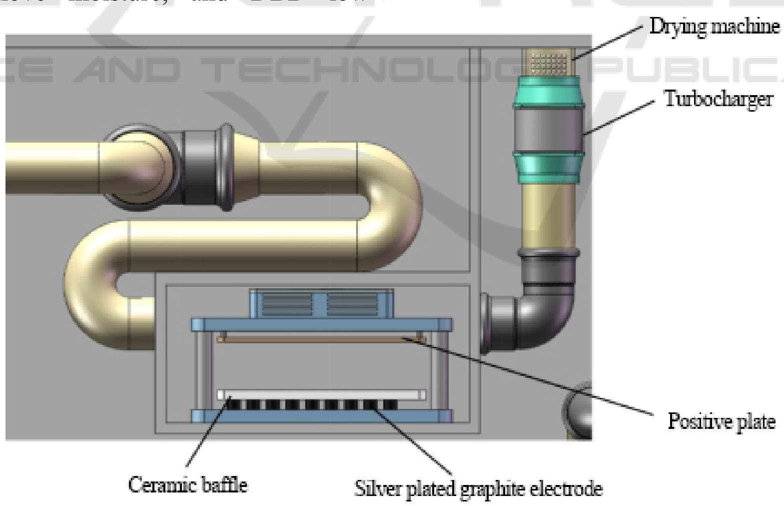


Figure 3: Plasma generator.

(3) Mixed reaction structure

The mixing structure consists of an input tube, several static mixers and an output tube. Fig. 4 is a schematic diagram of mixed reaction structure. Each static mixer tube inlet connection by two inputs, input contains plasma of air and waste gas and waste liquid atomization of mixed gas, the static mixer with multiple mixing unit, overlapping, can instantly at very good mixing effect, including plasma air and steam mixed fully response, the output pipe will count all products in the static mixer.

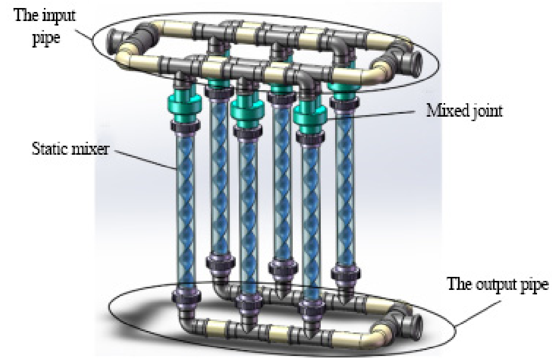


Figure 4: Mixed reaction structure.

(4) condensation separation structure

The condensation separation structure consists of a liquid storage tank and a condensation bend. Fig.5 is a schematic diagram of the condensation separation structure. After treatment, the mixed steam condenses in atomized droplets after passing through the condensing bend and flows into the liquid storage tank, while the gas phase continues to pass through the bend and is finally discharged from the gas outlet. The waste liquid in the liquid storage tank is discharged through the liquid outlet after reaching a certain amount. Sensors are installed on the wall of the liquid storage tank, which can monitor the pollution components in the waste liquid in real time to ensure that the liquid after treatment meets the discharge requirements.

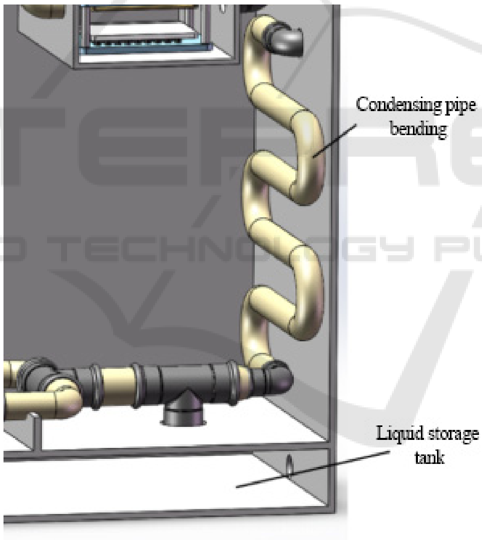
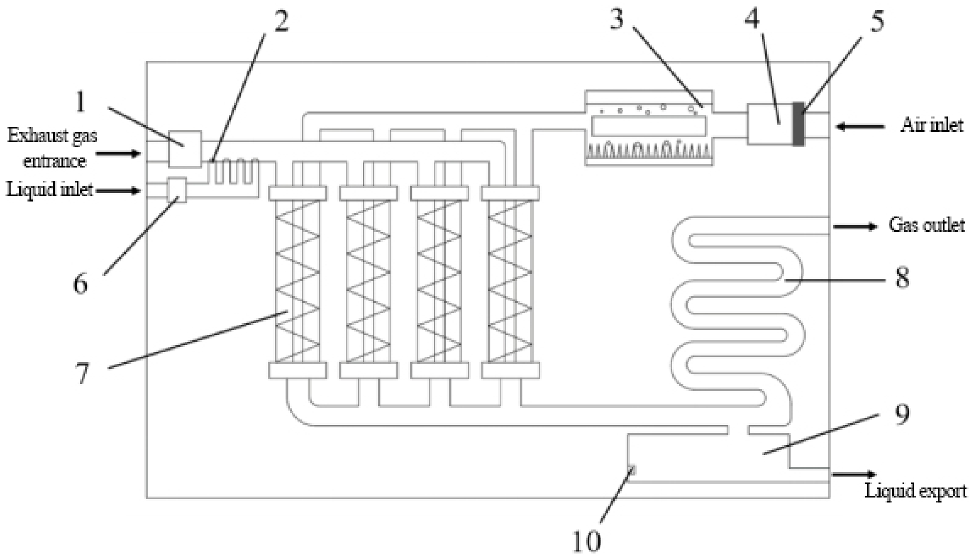


Figure 5: Condensing separation structure.

(5) Purification process of medical waste gas and waste liquid

The working process is as follows: the waste gas generated after the incineration of medical appliances will be removed through activated carbon before entering the device, and the solid residue in the waste liquid will be removed through coarse filtration before entering the device to ensure that the liquid entering the device only contains liquid phase. Medical waste liquid by the liquid inlet through the pump pumping unit, by several nozzle jet again in fog, waste gas from waste gas entrance from the turbocharger suction device, mixed with mist waste liquid in nozzle place, and at the other side of the device, DBD plasma plasma generator, air drawn in by the turbocharger after drying device, mixed with plasma plasma mixture formation, Then, the mixed phase reacts fully with the waste gas liquid in the mixed reaction structure, and finally separates the gas liquid in the condensation separation structure. After treatment, the waste liquid and waste gas are discharged from the liquid outlet and the gas outlet respectively. Fig. 6 is the schematic diagram of the device.



(Note 1: Turbocharger 2: atomizer 3: DBD plasma generator 4: Turbocharger 5: desiccants 6: water pump 7: static mixer 8: condensing bend 9: liquid storage box 10: sensor)

Figure 6: Schematic diagram of device principle.

4 CONTROL MODULE

The control module is used to control each step of the whole device. This module is composed of STM32F103C8T6 single chip microcomputer and connected high-voltage power supply, water pump, turbocharger, voltage matching circuit, temperature and humidity sensor, button, OLED display screen and so on.

Power control circuit is used to realize the control of low voltage, small current controller circuit to power circuit, through the control of high voltage module, water pump, turbocharger, etc., to achieve the control of current, water flow and air.

As shown in Fig.7, the high voltage module, water pump and turbocharger are connected with 12V power supply and controlled by relays SR_1, SR_2, SR_3 and SR_4, which are driven by triodes current amplifier circuit.

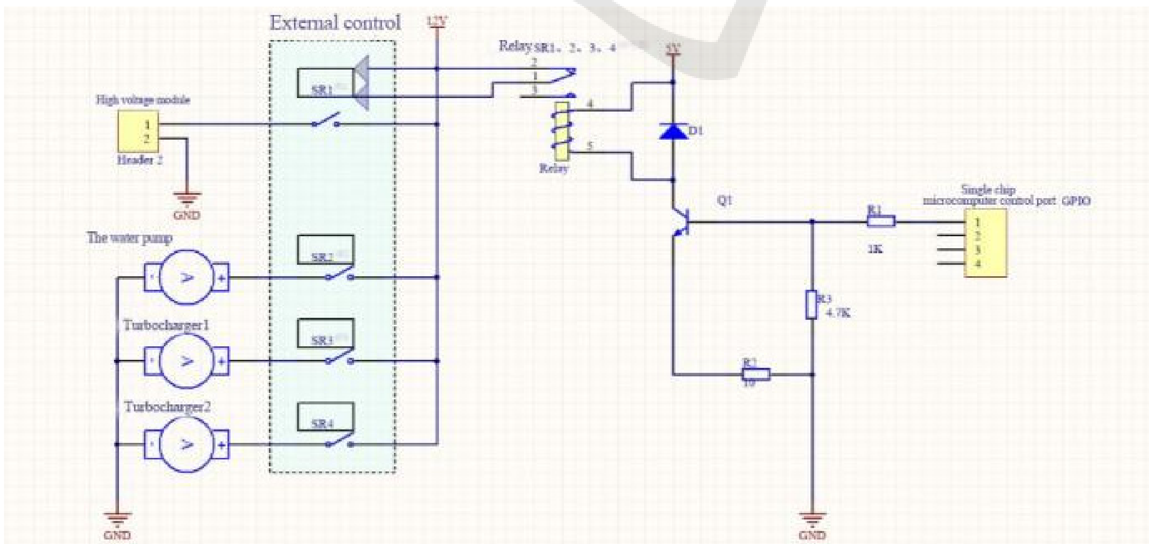


Figure 7: Power control circuit.

When the level of GPIO port corresponding to the single chip is 0, the base level of Q_1 is pulled down, Q_1 is in cut-off state, and the relay is open. When the level of GPIO port corresponding to the single chip is 1, the base level of Q_1 rises, and the control current is generated. Q_1 turns on and the relay pulls in. When the level of the corresponding GPIO port changes from low to high, the relay pops open to produce a high counter electromotive force. At this time, diode D_1 turns on to absorb the current and avoid burning the transistor and MCU.

5 EXPERIMENT AND TEST RESULTS

The experimental materials were silver nitrate and acetone, which were analytically pure. Polypropylene (PP) emulsion (91735), solid content in 30%~33%. Graphite fiber and deionized water are self-made by the laboratory. The resistivity of graphite fiber is about $13.5\times10^{6}\Omega\cdot m$. Epoxy sizing agent is removed with acetone before use.

(1) Experimental process

The preparation of silver-containing slurry, PP emulsion as the main raw material, PP/H2O emulsion prepared for graphite fiber impregnation coating. Then impregnated coating treatment, graphite fiber is fixed on the bracket, put into the slurry containing silver, through repeated impregnation to make the slurry evenly coated on the fiber surface. Graphite fibers were impregnated with PP/H2O emulsion slurry with silver nitrate content of 5%. Finally, the graphite fiber after impregnation coating treatment was placed in high temperature tubular furnace (GSL-1700X) for pyrolysis. The graphite fibers were fixed at both ends on the support, and a certain tension was applied. The temperature was heated to 500℃ at a rate of 10 K/min in nitrogen atmosphere, and the temperature was kept for 10min.

(2) By scanning electron microscope (SEM) test characterization

The fibers were glued to the sample table with conductive adhesive and observed at a constant temperature of 50℃. Fig.8 shows SEM images of graphite fiber GF-1 before and after treatment. As can be seen from the figure, the surface of untreated graphite fiber is very smooth, while many foreign bodies can be observed on the surface of coated and pyrolyzed graphite fiber. In this device, the polymer in the slurry acts as a binder to make the silver nitrate adhere to the surface of the graphite fiber. Silver nitrate is converted to elemental silver by pyrolysis.

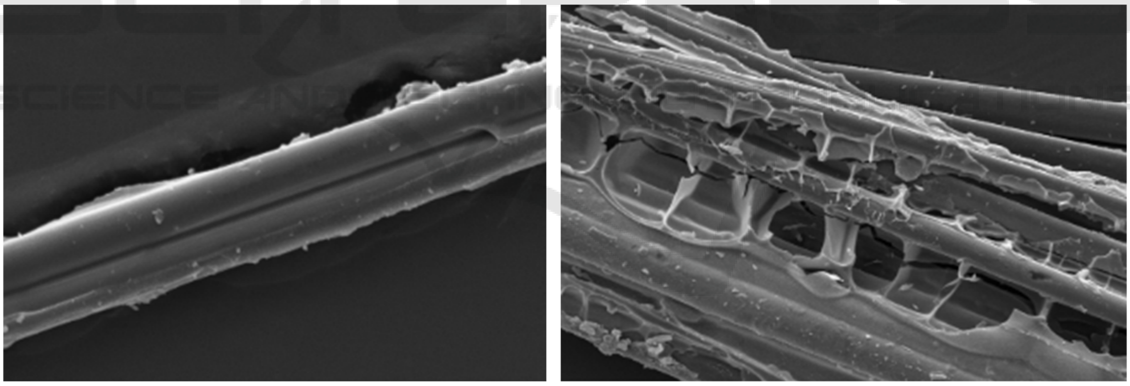


Figure 8: SEM photos before and after treatment (untreated on the left, silver plated on the right).

It can be seen that the silver is mainly distributed evenly on the surface of the graphite fiber coated by PP/H2O emulsion in the form of fine nanoparticles.

(3) Resistivity test

The self-made fiber resistivity tester and DC dual probe method were used to test the resistivity of the fiber sample. The test length was 10cm, and the DC current was adjusted to 0.05a after the power was turned on. The voltage was read and the resistivity was calculated. The calculation formula of resistivity is as follows:

$$\rho = \frac{U}{I} \cdot \frac{Y}{D \cdot L} \times 10^{-7}$$

Where, ρ is the resistivity (ω ·m); U is voltage (V); I is the current (A); Y is fiber linear density (g/1 000 m); D is fiber body density (g/cm3); L is fiber test length (cm).

According to the resistivity test results of untreated and silver-plated graphite fibers, compared with the untreated graphite fiber, the resistivity of the silver-plated graphite fiber decreased. The resistivity of the silver-coated graphite fiber prepared by PP/H2O emulsion coating decreased significantly, and the resistivity of the silver-coated graphite fiber decreased about 40.7% compared with that before treatment.

6 CONCLUSION

(1) The device uses the principle of dielectric barrier discharge (DBD), which produces both low-temperature plasma and a large amount of ozone. At the same time, the discharge effect at the electrode can be reduced, so that the discharge is concentrated on the electrode surface to form a more uniform discharge.

(2) The air containing plasma is mixed with the waste gas liquid mixture in the mixed reaction vessel to form activated water. The water activated by low temperature plasma has certain bactericidal ability and can be used in the treatment of medical wastewater. Moreover, plasma activated water has obvious bactericidal effect on Staphylococcus aureus, Escherichia coli and pseudomonas aeruginosa.

(3) The power consumption of the existing medical wastewater treatment system is 120kwh/d, and the electricity consumption is 84 yuan /d based on 0.7 yuan/KWH, and the daily drug consumption is 78 yuan /d, with a total cost of 162 yuan /d. The power consumption of the low-temperature plasma purification system is 78 yuan /d, and there is no need to add pharmaceutical costs, and the cost is reduced about 61%.

(4) Compared with the existing medical wastewater treatment system, the low-temperature plasma wastewater treatment system has a higher removal rate of pollutants in the medical wastewater, and can basically remove the components of COD, BOD5 and Escherichia coli that are harmful to the environment in the medical wastewater. The removal of BOD5 indirectly reduces the survival rate of microorganisms in wastewater, makes wastewater discharge to meet national standards, and reduces the pollution of wastewater to the environment. At the same time, the device will be mixed with waste water and waste gas at the same time, improve the treatment efficiency of waste water and waste gas, with good social benefits.

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