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An Ozone Reactor Design with Various Electrode Configurations

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Abstract

Environmental pollution is increasing, including water pollution due to industrial and household. To overcome this, there are three main concerns, namely the policy and environmental management, environmental awareness of society, and utilization of appropriate technologies to overcome pollution. This study is an attempt to overcome the problems of environmental pollution by designing, creating, and applying appropriate technology to make Ozone reactor with high-voltage corona discharge plasma technology. There are some methods of electrod configuration, namely wire-cylinder, spiral-cylinder, wire-cylinder with Dielectric Barrier Discharge (DBD), and spiral-cylinder with DBD. Corona discharge occurs between high-voltage electrod of each configuration ionize Oxygen flowed in the reactor, thus generating plasma and forming Ozone. The test of four Ozone reactors have been done by wastewater treatment in the form of soft drink samples, obtain the fading colors of wastewater, which is increasingly fade over many cycles of waste treatment process conducted in Ozon reactor. Based on comparison of four of Ozone reactor, it is obtained waste water treatment more maximal on reactor Ozone configuration of spiral-cylinder electrod with DBD.

Keywords*: Ozone reactor, electrods configuration, corona discharge, wastewater*

1. Introduction

Environmental pollution has become increasingly complex. To overcome the pollution there are three things of major concern, namely the policy and environmental management, environmental awareness of all elements of society, and the last is the proper use of technology in overcoming various kinds of pollution. During this time, there was lack of serious attention about pollution processing technology in Indonesia, though there were few problems that will be produced from the use of technology. By the growing of industry in Indonesia time to time, selection and use of appropiate technologies to overcome pollution problems should be applied immediately.

In an industrial production process is generally used various materials of various kinds. Water pollution in the industrial, agricultural, urban and other households, containing heavy metals Cd, Cu, Hg, Zn, and also contains various organic compounds, like dioxins, phenols, benzene, PCBs, and DDT.

Currently, wastewater treatment system is not enough to be used to reduce water pollution. To overcome the problem of water pollution that may cause danger of environmental degradation and the formation of Oxygen in water, efforts will be made through the utilization of plasma technology.

Plasma can be produced through the process of high-voltage corona discharge utilization with a configuration of electrods in a plasma reactor chamber. Corona discharge may generate from multiple electrod configutaions such as needle-plane electrod, wire-cylinder electrod, spiral-cyliner electrod and dielectric barrier discharge. Corona discharge occurs between the electrod configurations, and then will ionize the Oxygen that flowed in the reactor, and produce plasma and Ozone. Number of plasma generated can be influenced by the high voltage source, and also the type, shape, and distance from high-voltage electrods used in the Ozone reactor. In this research, the development of the Ozone reactor design through the comparison of electrod configurations that are used as well as development tools, high voltage pulse generator of high frequency is used as a source of Ozone reactor. By developing a high voltage pulse generator using flyback converter, will obtain a higher voltage pulse. In addition, by adjusting the configuration of electrods on Ozone reactor will be able to obtain a higher corona discharge, so that more plasma and Ozone is generated. This number of plasma and Ozone formed in the same time can be applied in wastewater purification processes.

2. Research Method

In this study, Ozone reactor is designed in four-electrod configuration, namely Ozone reactor configured with wire-cylinder electrod, spiral-cylinder electrod, wire-cylinder electrod with a Dielectric Barrier Discharge (DBD), and the spiral-cylinder with Dielectric Barrier Discharge (DBD). Fourth Ozone reactor is designed for use with high voltage impulse source up to 20 kV. High voltage impulse generator used is a high voltage generator that uses a flyback converter, where the output voltage is high voltage high frequency impulses that can set its value between 0-20 kV.

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2.1. Ozone Reactor with Wire-Cylinder Electrod Configuration

Corona discharge plasma reactor with wire-cylinder electrod configuration consists of two main parts, namely wire as positive electrod and a cylindrical tube as negative electrod (ground). This plasma reactor chamber is shaped a tube, which has two lid on the right tube and the left tube that are made of acrylic material.

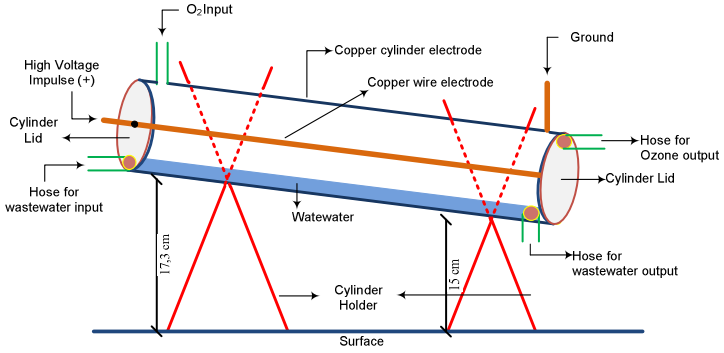


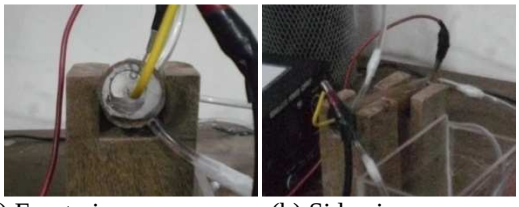
Figure 1. Design of ozone reactor with wire-cylinder electrod configuration

Positive electrod is shaped by a straight wire made of copper wire 1.9 mm in diameter with a length of 15.5 cm. Positive electrod wire is positioned in the middle of the cylinder tube and directly connected with the source of high voltage impulse.

Negative electrod (ground) used a cylindrical pipe made of tubular copper 15.5 cm long and 27 mm in diameter and thickness of the tube 1 mm. On the outside of tubes made of wire connections as the negative terminal of the reactor to be connected directly with ground from the source of high voltage impulse generator.

On the body of negative electrod, namely the cylinder body is made four-point hole with a hose connected to the input and output of the reactor, namely two inlet for Oxygen input and the wastewater input, and two outlet for Ozone output and the wastewater output. Between the electrod wire and electrods are given the distance between cylinders of 12.5 mm as the corona discharge, Oxygen flow and the flow of wastewaste in the reactors.

In use as a corona discharge plasma reactor wastewaste processor, the configuration of wire-cylinder electrod geometry is positioned oblique with slope angle of 10°, with the help of the buffer tube holder with 2 legs that have different heights, the first leg at 17.3 cm and the second leg at a 15-cm buffer. The existence of the buffer tube holder is intended to regulate the flow of wastewater that goes into corona discharge plasma reactor to flow in the reactor to exit through the outlet results of wastewater output.



(a) Front view (b) Side view

Figure 2. Ozone reactor with wire-cylinder configuration

2.2. Ozone Reactor with Spiral-Cylinder Electrod Configuration

Similar to the corona discharge plasma reactor with wire-cylinder electrod configuration, the configuration of spiral-cylinder electrod geometry consists of two main parts, namely a spiral-shaped positive electrod and negative electrod (ground) a cylindrical tube. The plasma reactor chamber of spiral-cylinder configuration is shaped tube that has a lid on the right and left of tube that are made of acrylic material.

Spiral-shaped positive electrod made of 1.9 mm diameter copper wire that was twisted to a spiral-shaped with a diameter of 5.81 mm and 15.5 cm long spiral electrod. Spiral electrod is positioned in the middle of the cylinder tube and directly connected with the source of high voltage impulse.

Negative electrod (ground) used a cylindrical pipe made of tubular copper 15.5 cm long and 27 mm in diameter and thickness of the tube 1 mm. On the outside of tubes made of wire connections as the negative terminal of the reactor to be connected directly with ground from the source of high voltage impulse generator.

On the negative electrod body, namely the cylinder body is made four-point hole with a hose connected to the input and output of the reactor, namely two inlet for Oxygen input and the input of wastewater will be processed

the reactor, and two outlet are for Ozone output and output wastewater processing result reactor. Among the spiral electrod and electrod spacing between the cylinders is given by 10.6 mm as the corona discharge, Oxygen flow and the flow of wastewater in the reactors.

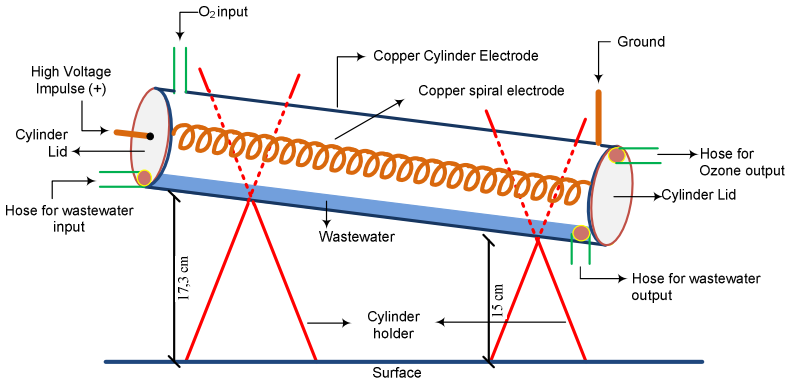


Figure 3. Design of ozone reactor with spiral-cylinder electrod configuration

As with the previous reactor, in its use as wastewater treatment, corona discharge plasma reactor of spiral-cylinder electrod configuration is positioned oblique with slope angle of 10°, with the help of the buffer tube holder with 2 legs that have different heights, the first leg at 17.3 cm and the second leg at a 15-cm buffer.

(a) Front view (b) Side view

Figure 4. Ozone reactor with spiral-cylinder configuration

2.3. Ozone Reactor with Spiral-Cylinder Electrod Configuration and a Dielectric Barrier Discharge (DBD)

Corona discharge plasma reactor with wire-cylinder electrod configuration with DBD consists of three main parts, namely a wire-shaped positive electrod, negative electrod (ground) a cylindrical tube, and the dielectric material that serves as a barrier discharge between the positive electrod to negative electrod. The plasma reactor chamber is shaped tube that has a lid on the right and left which are made of acrylic material.

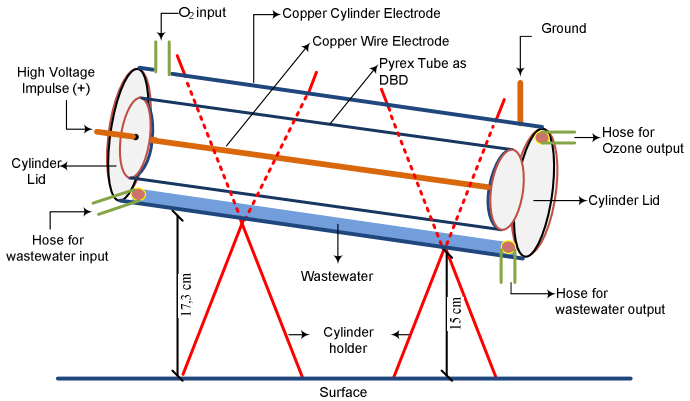


Figure 5. Design of ozone reactor with wire-cylinder and DBD electrod configuration

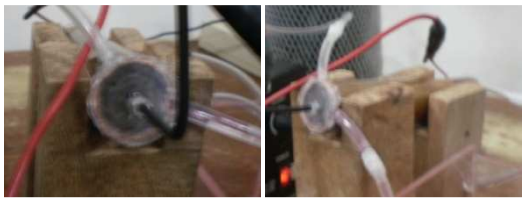
Straight wire shaped positive electrod made of copper wire 1.9 mm in diameter with a length of 15.5 cm. Negative electrod (ground) used a cylindrical pipe made of tubular copper 15.5 cm long and 27 mm in diameter and

thickness of the tube 1 mm. On the outside of tubes made of wire connections as the negative terminal of the reactor to be connected directly with ground from the source of high voltage impulse generator.

Between the wire electrod and cylindrical electrods positioned in the form of a dielectric material made from Pyrex glass tube with a length of 15.5 cm and a diameter of 16 mm tube. Pyrex tube functions as a barrier to prevent breakdown between the positive electrod and negative electrod wire-cylinder. Therefore, the dielectric layer covering the surface of glass pyrex made positive electrod facing the negative electrod.

On the negative electrod body, namely the cylinder body is made four-point hole with a hose connected to the input and output of the reactor, namely two inlet for Oxygen input and the wastewater input, and two outlet for Ozone output and the output wastewater. Between the wire electrod and cylinder electrods are given the distance of 12.5 mm as the corona discharge, Oxygen flow and the flow of wastewater in the reactors.

In its use as a wastewater treatment, corona discharge plasma reactor with configuration of wire-cylinder electrod with the DBD is positioned tilted 10°, with the help of the buffer tube holder with 2 legs that have different heights, the first leg at 17.3 cm and the second leg at a 15-cm buffer.



(a) Front view (b) Side view

Figure 6. Ozone reactor with DBD wire-cylinder configuration

2.4. Ozone Reactor with Spiral-Cylinder Configuration and a Dielectric Barrier Discharge (DBD)

The configuration of DBD spiral-cylinder electrod consists of three main parts, namely a spiral as positive electrod, a cylindrical tube as negative electrod (ground), and the dielectric material serves as a barrier discharge between the positive electrods to negative electrod. The plasma reactor chamber configuration is shaped tube that has a lid on the right and left is made of acrylic material.

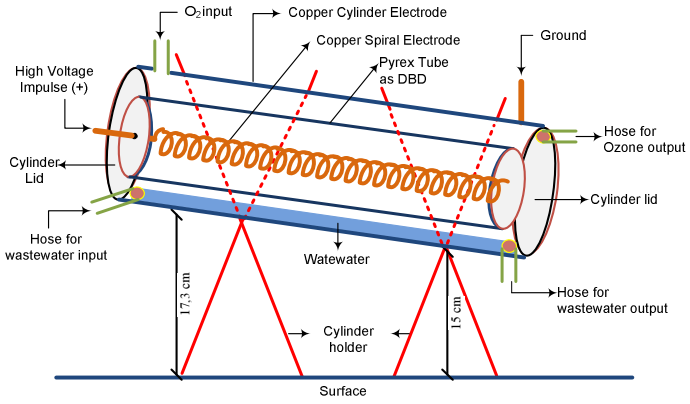


Figure 7. Design of ozone reactor with spiral-cylinder and DBD electrod configuration

Spiral as positive electrod made of 1.9 mm diameter copper wire that was twisted to a spiral-shaped with a diameter of 5.1 mm and 15.5 cm long spiral electrod. Spiral electrod is positioned in the middle of the cylinder tube and directly connected with the source of high voltage impulse.

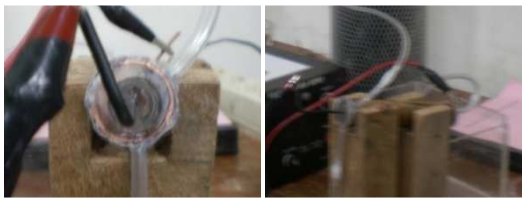
Negative electrod (ground) used a cylindrical pipe made of tubular copper 15.5 cm long and 27 mm in diameter and thickness of the tube 1 mm. On the outside of tubes made of wire connections as the negative terminal of the reactor to be connected directly with ground from the source of high voltage impulse generator.

Among the spiral electrod with cylindrical electrod positioned a dielectric material in the form of a tube made from Pyrex glass with a length of 15.5 cm and a diameter of 16 mm tube. Pyrex tube functions as a barrier (barrier) to prevent breakdown between the positive electrod and negative electrod wire cylinder. Therefore, the dielectric layer covering the surface of glass pyrex made positive electrod facing the negative electrod.

On the negative electrod body, namely the cylinder body is made four-point hole with a hose connected to the input and output of the reactor, namely two inlet for Oxygen input and the wastewater input, and two outlet for

Ozone output and the output wastewater. Between the spiral electrod and cylinder electrods are given the distance of 10.6 mm as the corona discharge, Oxygen flow and the flow of wastewater in the reactors.

In its use as a wastewater treatment, corona discharge plasma reactor with configuration of spiral-cylinder electrod with the DBD is positioned tilted 10°, with the help of the buffer tube holder with 2 legs, the first leg at 17.3 cm and the second leg at a 15-cm buffer.



(a) Front view (b) Side view

Figure 8. Ozone reactor with DBD spiral-cylinder configuration

3. Results and Analysis

Testing and analysis equipment includes the measurement of high voltage and the application for processing wastewater of soft drink industry with corona discharge plasma technology.

The plasma reactor testing is done by examining the process of fading color in the wastewater as detection Ozone formation in the plasma reactor. Tests carried out by processing the color fading samples of wastewater in each reactor Ozone. Wastewater samples used in this test is a sample of a red soft drink liquid with a ratio of 1:10, in example 100 ml of red soft drink mixed with 1000 ml of water. Samples of wastewater flowed into the Ozone reactor is processed together with the supply of pure Oxygen. Here is wastewater processing conditions in the Ozone reactor test:

- Impulse voltage input = 15 kV
- Stream rate of wastewater input = 20 ml/min
- Flow rate of Oxygen input = 1 L/min

3.1. Testing of Ozone Reactor with Wire-Cylinder Electrod Configuration

Here's the process of testing plasma reactor with wire-cylinder configuration is done using the source voltage from high voltage impulse generator. Based on the process of testing a wire-cylinder Ozone reactor is in the process of color fading of wastewater, taken 10-cycle process, where each cycle has an average duration of process 1 hour 10 minutes. Here are the comparison results of wastewater process on Ozone reactor with wire-cylinder electrod configuration.

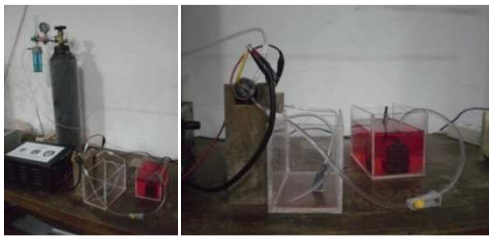
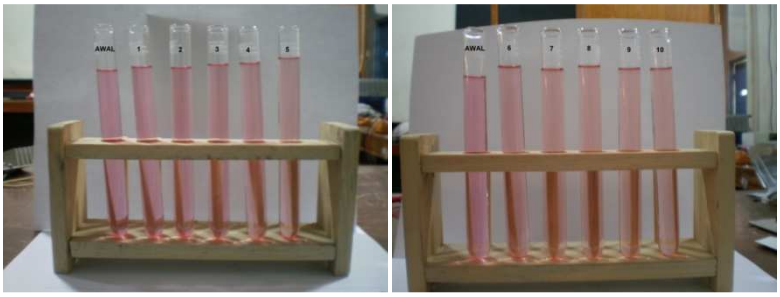


Figure 9. Test of Ozone reactor with wire-cylinder electrod configuration.



(a) (b)

Figure 10. Result of wastewater process on Ozone reactor with wire-cylinder configuration: (a) initial wastewater before process up to the result of fifth cycle of process; (b) the result of sixth cycle up to tenth cycle of process

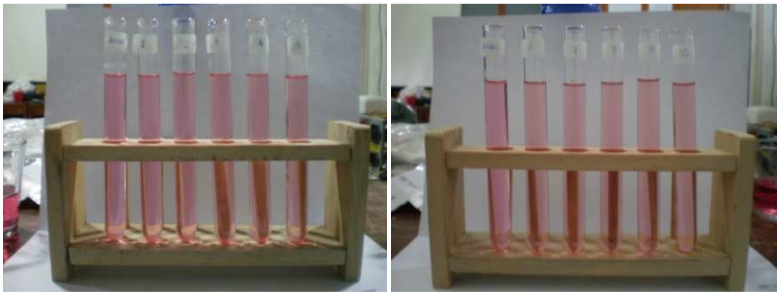
Based on the observation results of wastewater through a process of color fading by Ozone generated at the high-voltage Ozone reactor with wire-cylinder configuration, it can be seen that the longer the process of wastewater treatment, the more faded the color of the wastewater is provided. From Figure 10 can be seen the existence of gradations of color fading from cycle to cycle, that the more processing cycles performed in wastewater treatment, then will be more color fading in wastewater.

3.2. Testing of Ozone Reactor with Spiral-Cylinder Electrod Configuration

Here's the process of testing plasma reactor with spiral-cylinder configuration is done using the source voltage from high voltage impulse generator:

Figure11. Test of Ozone reactor with spiral-cylinder electrod configuration

From the process of testing a spiral-cylinder Ozone reactor is in the process of color fading of wastewater, taken 0-cycle process, where each cycle has an average duration of process 47 minutes. Here are the comparison results of wastewater process on Ozone reactor with spiral-cylinder electrod configuration:



(a) (b)

Figure12. Result of wastewater process on Ozone reactor with spiral-cylinder configuration: (a) initial wastewater before process up to the result of fifth cycle of process; (b) the result of sixth cycle up to tenth cycle of process

Based on the observation results of wastewater through a process of color fading by Ozone generated at the high-voltage Ozone reactor with spiral-cylinder configuration, it can be seen that the longer the process of wastewater treatment, the more faded the color of the wastewater is provided. From Figure 12 can be seen the existence of gradations of color fading from cycle to cycle, that the more processing cycles performed in wastewater treatment, then will be more color fading in wastewater.

3.3. Testing of Ozone Reactor with Wire-Cylinder and a Dielectric Barrier Discharge Electrod Configuration

Here's the process of testing plasma reactor with DBD wire-cylinder configuration is done using the source voltage from high voltage impulse generator:

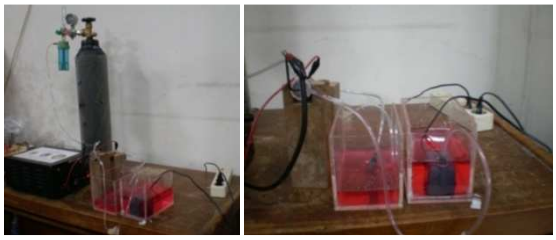
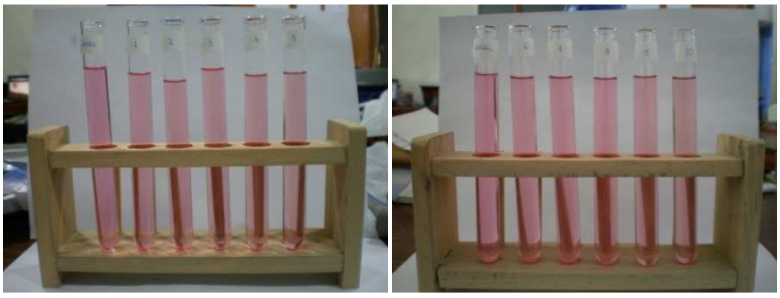


Figure13. Test of Ozone reactor with DBD wire-cylinder electrod configuration

Based on the process of testing a DBD wire-cylinder Ozone reactor is in the process of color fading of wastewater, taken 10-cycle process, where each cycle has an average duration of process 1 hour. Here are the comparison results of wastewater process on Ozone reactor with DBD wire-cylinder electrod configuration:



(a) (b)

Figure14. Result of wastewater process on Ozone reactor with DBD wire-cylinder configuration: (a) initial wastewater before process up to the result of fifth cycle of process; (b) the result of sixth cycle up to tenth cycle of process

From the observation results of wastewater through a process of color fading by Ozone generated at the high-voltage Ozone reactor with DBD wire-cylinder configuration, it can be seen that the longer the process of wastewater treatment, the more faded the color of the wastewater is provided. From Figure 14 can be seen the existence of gradations of color fading from cycle to cycle, that the more processing cycles performed in wastewater treatment, then will be more color fading in wastewater.

3.4. Testing of Ozone Reactor with Spiral-Cylinder and a Dielectric Barrier Discharge Electrod Configuration

The process of testing plasma reactor with DBD spiral-cylinder configuration was done using the source voltage from high voltage impulse generator.

Based on the process of testing a DBD spiral-cylinder Ozone reactor is in the process of color fading of wastewater, taken 10-cycle process, where each cycle has an average duration of process 43 minutes. Here are the comparison results of wastewater process on Ozone reactor with DBD spiral-cylinder electrod configuration.

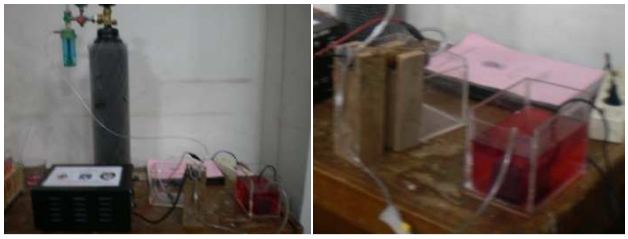
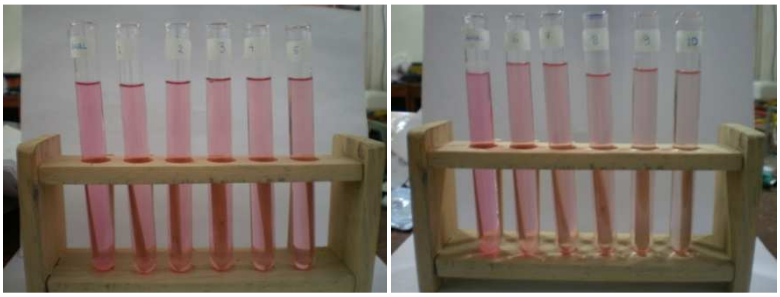


Figure15. Test of Ozone reactor with DBD spiral-cylinder electrod configuration



(a) (b)

Figure16. Result of wastewater process on Ozone reactor with DBD spiral-cylinder configuration: (a) initial wastewater before process up to the result of fifth cycle of process; (b) the result of sixth cycle up to tenth cycle of process

Based on the observation results of wastewater through a process of color fading by Ozone generated at the high-voltage Ozone reactor with DBD spiral-cylinder configuration, it can be seen that the longer the process of wastewater treatment, the more faded the color of the wastewater is provided. From Figure 16 can be seen the existence of gradations of color fading from cycle to cycle, that the more processing cycles performed in wastewater treatment, then will be more color fading in wastewater.

3.5. Comparison of Test Result on Ozone Reactor

Based on the test result of four Ozone reactors in their form of electrod configuration, can be obtained a comparison of the result by comparing each wastewater treatment result after the tenth cycle of the testing process. The following results were obtained.

Figure 17.Comparison result of the tenth cycle of wastewater treatment process in each high-voltage Ozone reactor (left to the right): (a) initial wastewater before the treatment process; (b) Ozone reactor with wire-cylinder configuration; (c) Ozone reactor with spiral-cylinder configuration; (d) Ozone reactor with DBD wire-cylinder configuration; (e) Ozone reactor with DBD spiral-cylinder configuration

From the results of 10-cycles given to the wastewater treatment of soft drinks samples in each of the high-voltage Ozone reactor, can be seen that the results of the Ozone reactor configured with a Dielectric Barrier Discharge (DBD) and spiral-cylinder electrods, has more color faded than the other three reactors. This shows that the Ozone produced in the reactor configured with a DBD spiral-cylinder is more than the wire-cylinder reactor, the wire-cylinder with DBD reactor, or even more than the spiral-cylinder reactor without DBD.

The more number of Ozone imposed on a fluid, and then agree with their characteristics, Ozone is more rapid in fading the liquid color. Likewise on the wastewater is processed in the Ozone reactor configured with DBD spiral-cylinder electrod, the colors fade in wastewater color is clearer, thus indicating more Ozone imposed on the wastewater.

4. Conclusion

Ozone reactor with the plasma technology has been made in the form of four electrod configurations: wire-cylinder electrod configuration, spiral-cylinder electrod configuration, wire-cylinder electrod configuration with DBD, and spiral-cylinder electrod with DBD. Each configuration has been applied to industrial wastewater treatment. Based on the design, testing, and analysis that were done, the test result of wastewater after the treatment using Ozone reactor is physical changes on the wastewater, which is obtained the fading color in the wastewater that is more clearly compared with the color of initial wastewater. Comparison of four configurations is producing different level of fading color in the wastewater. Ozone reactor that produces maximum fading color level on the wastewater result is Ozone reactor configured with Dielectric Barrier Discharge (DBD) and spiral-cylinder electrod

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Galuh Susilowati was born in Jakarta, Ocotber 9, 1989. She received the Bachelor degree from Department of Electrical Engineering, Diponegoro University in 2011. Currently she has been researching on high voltage, plasma discharge, corona discharge and its application on water waste.

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