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Analysis on an Oxidation-Reduction Reaction of Photocatalytic Plasma Complex Module

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Abstract

Purpose: This study is about photocatalytic technology and plasma oxidation-reduction technology. To the main cause of exposure to odor pollution, two deodorization techniques were applied to develop a module with higher removal efficiency and ozone reduction effect. **Research design, data and methodology:** A composite module was constructed by arranging two types of dry deodorization equipment (catalyst, adsorbent) in one module. This method was designed to increase the responsiveness to the components of complex odors and the environment. standard, unity, two types of oxidizing photo-catalyst technology and plasma dry deodorization device installed in one module to increase the potential by reduction to 76% of ozone, 100%, and 82%. **Results:** The complex odor disposal efficiency was 92%. Ammonia was processed with 50% hydrogen sulfide and 100% hydrogen sulfide, and ozone was 0.01ppm, achieving a target value of 0.07ppm or less. The combined odor showed a disposal efficiency of 93%, ammonia was 82% and hydrogen sulfide was 100% processed, and ozone achieved a target value of 0.07 ppm or less. **Conclusions:** Ozone removal efficiency was 76% by increasing Oxidation-Reduction Reaction(ORR). The H2S removal efficiency of the deodorizer was higher than that of the biofilter system currently used in sewage disposal plants.

Keywords : Complex odor, Ozon, Oxidation-Reduction reaction, Photocatalyst,Complex module device

JEL Classification Codes : Q47, Q53, Q55, Q56

1. Introduction

Odor perception for a specific odor may vary depending on individual characteristics such as age, gender, health status, etc., and social and cultural differences such as region and standard of living.

The olfactory response to the same substance may differ depending on the degree of pleasure and discomfort for each individual, and differences may occur depending on the frequency of smelling the same person. Exposure to odor substances may cause physiological effects on the respiratory, circulatory and digestive systems, sleep disturbance, headache and vomiting, and allergy symptoms. Representative substances of odor include hydrogen sulfide and methylmercaptan generated from livestock facilities, sewage facilities, feed manufacturing facilities, and pulp manufacturing facilities, as shown in Table 1.

Table 1: Odor substances by major sources

Facilities \ Substances		H_2S	CH_4S	C_2H_6S	CH_3SSCH_3	NH_3	$(CH_3)_3N$	CH_3CHO
Livestock farming	Pork industry	●	●	◎	◎	◎		
	Beef industry	●	●	◎	◎	◎		
	Poultry industry	●	●	◎	◎	●	●	
Manufacturing plant	Textile factory	◎				◎		
Service industry	Waste disposal plant	●	◎	◎	○	◎		◎
	Sewage disposal plant	●	●	◎	○	◎		
	Manure disposal plant	●	●	●	◎	●		
Trash dumpster		◎	◎	○	○	◎	◎	◎

Note: ●: Cause of bad odor, ◎: Substances detected during measurement, ○: Substances that can be detected

Photocatalytic technology was first known by the "Honda-Fujishima Effect". Professor Fujishima of Japan discovered for the first time that bubbles were generated in a titanium dioxide (TiO2) electrode irradiated with light in a solution. Through this, it was confirmed that oxygen was generated in the TiO2 electrode and hydrogen was generated in the other platinum (Pt) electrode. This research result became known when it was published in Nature in 1972.

2. Literature Review

The theoretical voltage required to generate oxygen and hydrogen in water splitting through electrochemical methods is 1.23V. However, it is known that the voltage required for the actual reaction is 1.5V or more. However, by irradiating the TiO2 electrode with ultraviolet (UV) light, water could be decomposed at a lower voltage than the existing value. Currently, research to promote photocatalytic reaction and increase efficiency by using only light without applied voltage is emerging as a global issue. A representative material currently used industrially is the already mentioned TiO2. When light is applied to TiO2, electrons are in an excited state and holes are formed.

The generated electrons with strong reducing power and oxygen with strong oxidizing power react with water to generate active oxygen (oxygen radical), which starts the decomposition of water, thus decomposing carbon dioxide. The photocatalytic reaction occurs by giving light energy equivalent to the band gap to the metal oxide semiconductor, and the electrons excited to the conductor in the valence band and the holes (h+) in the missing site react with the surrounding material.

When used for air purification, active species oxidize and decompose odor molecules with oxygen plants abundantly present around semiconductors and Hydroxyl Radical (·OH) generated by the reaction of holes. The reaction mechanism of the photocatalyst is shown in Figure 1. The strong oxidizing power of the titanium oxide photocatalyst can be obtained by exposing it to light energy equivalent to an anatase with a bandgap of 3.2 eV, that is, ultraviolet light having a wavelength shorter than about 380 nm. This means that the air purification ability by the photocatalyst is limited by the amount of light received.

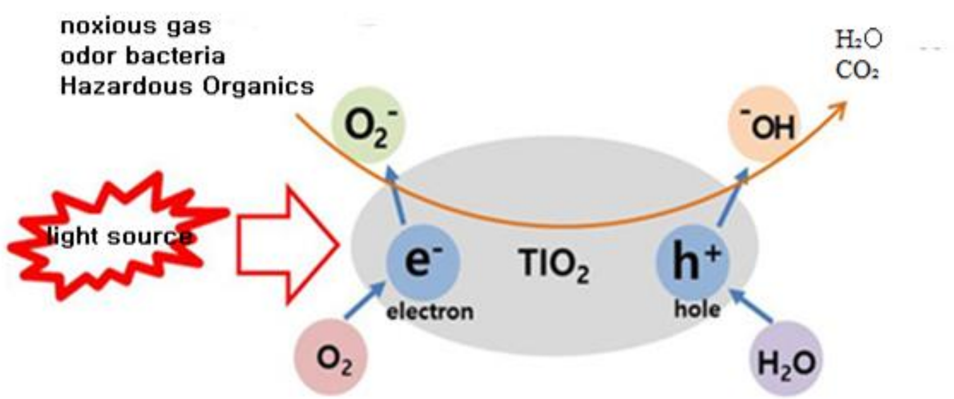

Figure 1: Photocatalytic reaction mechanism

Plasma is generated by applying a high voltage between the electrodes. Although the electron temperature (normally 10,000K or more) is high, the gas temperature is close to room temperature, so it can be formed with low electrical energy, thereby exerting its power to improve the environment.

In such a plasma state, charged particles such as electrons or ions and neutral radicals represented by oxygen radicals are mixed. When this plasma and odor molecules come into contact with a gas containing harmful gas, they decompose into water or carbon dioxide to remove the odor. Plasma deodorization methods currently in practical use are divided into direct plasma methods and indirect plasma methods.

Figure 2 shows the reaction mechanism of plasma. An air purifier by indirect plasma allows gas to flow through a plasma reactor to form radicals activated by high-speed electrons. These radicals are emitted as clustered, anion clusters.

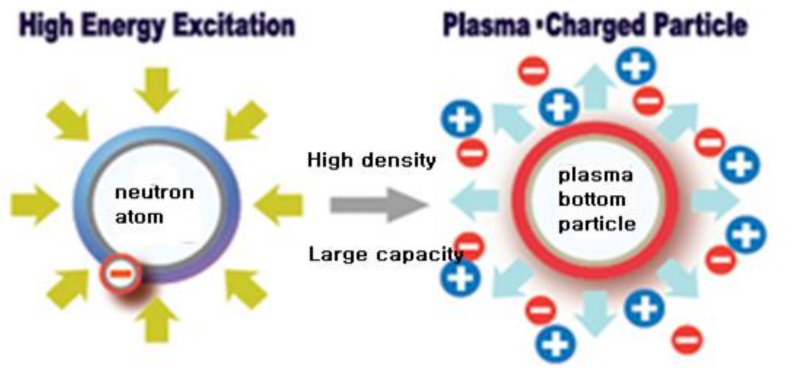

Figure 2: Plasma reaction mechanism

It is thought that facilities that improve field operation and responsiveness are preferable for facilities with altered outdoor air through complex module configuration than fixed type facilities. Depending on the site, the composition and environment of the complex odor are different for each site, so there are places where the efficiency of any deodorization method is high and there are places where it is low.

In order to solve this part, two or more deodorization methods were configured to be variably applied to the field, and it was composed of a module with higher deodorization efficiency and field adaptability.

3. Research Methods

A composite module was constructed by arranging two types of dry deodorization equipment (catalyst, adsorbent) in one module.

This method was designed to increase the responsiveness to the components of complex odors and the environment. The internal parts are designed in consideration of specifications and electrical wiring for easy replacement.

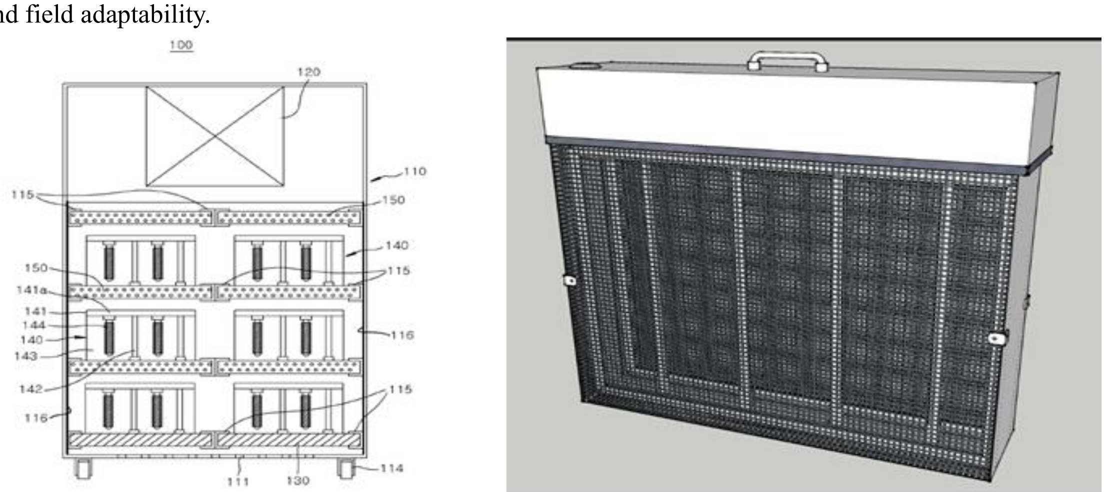

Figure 3: Complex module design

A form that can amplify the UV lamp light source of the photocatalyst is designed using the principle of specular reflection by installing a specular reflector inside. When considering the amount of reflection, diffuse reflection and spread reflection are advantageous. These two reflective types have the disadvantage that it is difficult to achieve an economical effect because they require a coating of a different material, so the specular reflective method was adopted.

By applying MnO_2 catalyst and CuS catalyst plate, the ozone concentration is lower than 0.1ppm, so that it can be reduced to 0.07ppm. In addition, to prevent ozone generation, Oxidation-Reduction Reaction(ORR) units were designed in the form of oxidation-reduction.

The multi-step Oxidation-Reduction Method (ORM) was improved to prevent ozone generation. When only activated carbon was used, an ozone removal rate of 16.7% was observed after 5 minutes. However, in the case of using activated carbon immobilized with a manganese catalyst of 9.1 × 10-6 M, an ozone removal rate of 76.7% was observed after 5 minutes.

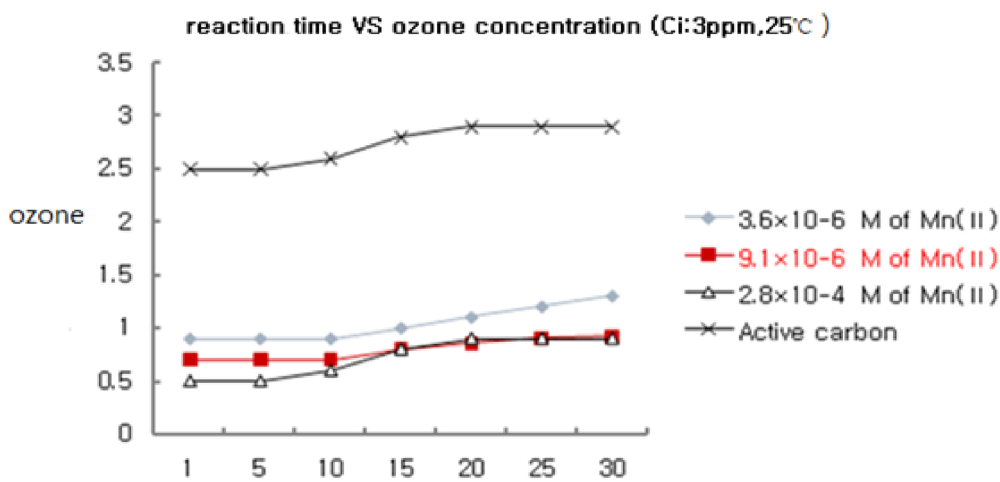

Figure 4: Changes in ozone concentration before & after improvement by ORM

Techniques for light source reflectors include specular reflection, diffuse reflection, and spread reflection. In a specular reflector, the angle of incidence and the angle of reflection are the same with respect to the normal of the reflective surface, and the incident light, the normal of the surface, and the reflected light are on the same plane.

The reflective surface is microscopically very flat, and as a mirror-like surface with little diffusion, the shape of the reflective plate determines the distribution of reflected light. The specular reflector used in lighting fixtures specularly reflects about 60-95% of incident light.

Metals used for the mirror plate include aluminum, gold, silver, and copper, and among them, aluminum is widely used because of its low price. In addition, although silver has good properties, it is weak to ultraviolet rays, and gold and copper have better performance than aluminum in the IR and red regions. However, copper quickly discolors in air. The diffuse reflector is a surface that diffuses the reflected light over the entire hemisphere in a cosine pattern no matter what angle the incident light is incident on.

It has the same luminance when viewed from any direction regardless of the angle of incidence.

Such a surface is called a perfect diffusion surface. There is no material that actually diffuses completely, but magnesium oxide used for coating in the integrating sphere for measuring the luminous flux reflects close to perfect diffusion.

The distribution of reflected light is very different depending on the surface material and the viewing angle, and the shape of the reflector does not affect the distribution of the wide reflected light. Diffusing surfaces that can be used for actual lighting reflectors include porcelain enameled steel, white painted surfaces, magnesium oxide, titanium oxide, and the like. The diffuse reflective surface contains a certain part of the specular reflective component. This can be a very difficult factor in some applications, so it must be processed by abrading, etching, and flocking.

Although the diffuse reflection surface does not perform precise beam adjustment, it can be used inexpensively to reflect light on a wide working surface. Since the shape of the reflector does not have a great influence on the distribution of reflected light, the shape is mainly determined by the appearance and cost.

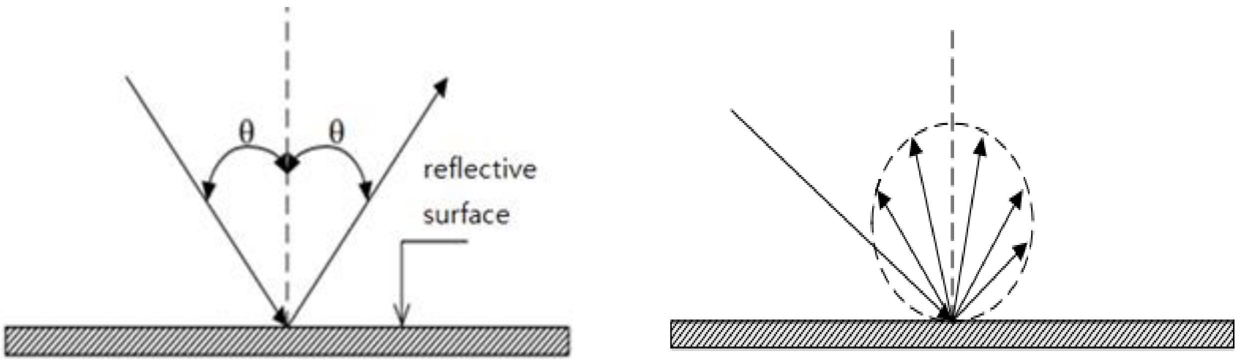

Figure 5: Mural (left) and diffuse reflections (right)

Expanded reflection is a kind of specular reflection and can spread reflected light at a limited angle. That is, the incident beam is reflected by broadening it within a limited angle.

The developed reflection can be obtained by processing such as patterning, figuring, embossing, ribbing, peening, and shot blasting on the specular reflector.

If chemical etching is performed on mirror metal, diffusion components are added, which may not be good. However, if you put a pattern on the glossy mirror, you can control the light as you want. Figure 6 shows an example of a spread reflection and the beam spread angle when a spherical peen process is applied to a specular reflector.

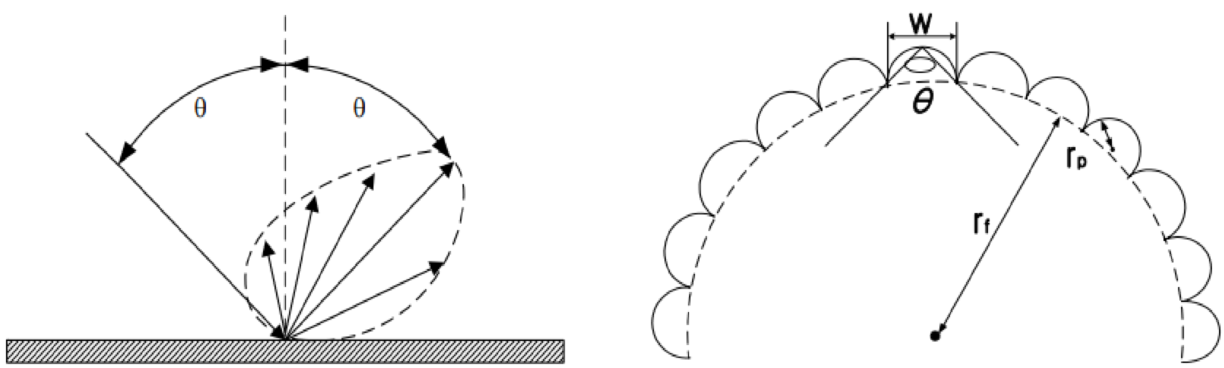

Figure 6: Expanded reflection

4. Results and Discussions

The odor evaluation criteria were evaluated based on the complex odor of the sewage disposal plant in Seoul, hydrogen sulfide, ammonia, and residual ozone. Composite odors were targeted at 80% reduction in generation, 80% reduction in hydrogen sulfide, 80% reduction in ammonia, and less than 0.07ppm in residual ozone.

Among the 22 designated odor substances, the representative substances generated in the sewage disposal plant are hydrogen sulfide and ammonia, and the average ammonia of the sewage disposal plant in Seoul is shown in Table 2. (Seoul Metropolitan Government's plan to strengthen odor management in public environment facilities)

Table 2: Designated odor substances in sewage disposalfacility

Designated substances (Unit)	2014 (year)	2015 (year)	mean	Standard value
Ammonia (ppm)	0.13	0.11	0.12	1.00
Hydrogen Sulfide (ppm)	0.01	0.09	0.043	0.2

Field Self-test and accredited test were conducted at the Suwon Sewage Disposal Plant as shown in Table 3. As a result of the field test, the complex odor in the first test was 88%, the second 93%, the third 97%, the fourth 97%, the fifth 92%, showing an average disposal efficiency of 93%.

Ammonia showed an average disposal efficiency of 82% with the first 80%, the second 83%, the third 86%, the fourth 79%, and the fifth 81%. Hydrogen sulfide was processed with 100% of all orders, and ozone was 0.01ppm, which was below the target value of 0.07ppm.

Table 3: The results of the field experiment(self-experiment)

	First		Second		Third		Fourth		Fifth		Disposal efficiency (%)
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Combination odors	250 times	30 times	300 times	21 times	300 times	10 times	300 times	10 times	250 times	21 times	93
Ammonia	0.15 ppm	0.03 ppm	0.12 ppm	0.02 ppm	0.14 ppm	0.02 ppm	0.14 ppm	0.03 ppm	0.16 ppm	0.03 ppm	82
Hydrogen Sulfide	0.29 ppm	N.D	0.36 ppm	N.D	0.56 ppm	N.D	0.31 ppm	N.D	0.45 ppm	N.D	100
Ozone	-	0.023	-	0.03	-	0.03	-	0.02	-	0.025	<0.07ppm

Table 4: The results of the field experiment (Authorized test report)

	First		Second		Third		Disposal efficiency (%)
	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	
Combination odors	100 times	30 times	300 times	21 times	300 times	10 times	92
Ammonia	0.05 ppm	0.03 ppm	0.2 ppm	0.06 ppm	0.04 ppm	0.03 ppm	50
Hydrogen Sulfide	0.29 ppm	N.D	0.39 ppm	N.D	0.56 ppm	N.D	100
Ozone	-	N.D	-	0.01	-	N.D	<0.07ppm

In the official test report of the field test result, the complex odor disposal efficiency was 92%.

Ammonia was processed with 50% hydrogen sulfide and 100% hydrogen sulfide, and ozone was 0.01ppm, achieving a target value of 0.07ppm or less (Table 4). During the study, ozone was generated in the existing co-catalytic oxidation method, making it difficult to use the catalytic oxidizer.

During oxidation and reduction reaction, it was found that ozone was reduced by more than 76% compared to the amount of ozone when oxidized, and complex odor and ammonia hydrogen sulfide were also reduced.

5. Summary and Conclusion

This study is a study to increase the responsiveness to the components of complex odors and the environment by constructing a complex module by arranging two types of dry deodorization equipment (photocatalyst, plasma) in one module. The target was to reduce the amount of compound odor by 80%, hydrogen sulfide by 80%, ammonia by 80%, and the amount of residual ozone to be less than 0.07ppm.

As a result of the study, the processing efficiency of complex odor was 93%, ammonia was processed 82%, and hydrogen sulfide was processed 100%.

Ozone achieved the target value of 0.07ppm or less.

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