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Characteristics of UV Photolysis Reactor and Its Application for H_2S Treatment

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Abstract. Malodorous gas is an important air pollutant which can damage people's health and bring uncomfortable experiences. H_2S is a common malodorous gas in people's living environment. This work proposed a UV photolysis reactor with double-tube used for H_2S contral. Performance of the reactor is evaluated by O_3 generation and H_2S removal. The results show that, the UV photolysis reactor is stable and produces O_3 with high efficiency. The reaction conditions of lower humidity and higher input energy are benefit for O_3 generation. 214 mg m^{-3} of O_3 is produced in the UV photolysis reactor with relative humidity of 20% and input energy of 12 W at the gas flow of 1 L min^{-1}. H_2S can be decomposed efficiency in the UV photolysis process because of the high energy of UV light and O_3 oxidation. For the UV photolysis reactor with the input energy of 1.5 W, almost 100% of H_2S with the concentration of 8 mg m^{-3} can be decomposed. In the UV photolysis reactor, a higher humidity will lead to decompoe more H_2S because of the HO· generation from H_2O decomposed by UV light.

1. Introduction

Malodorous gas can be referred to any gas that damages the environment of human life, produces an unendurable odor, or produces unpleasant feelings. It comes from a wide range of sources, such as animal husbandry, agriculture, municipal facilities, industrial production, and daily life[1]. Hydrogen sulphide (H_2S) is a typical malodorous gas that produced from animals, industrial, and natural sources, especially waste treatment plants, farms, meat processing plants, slaughterhouses, and pesticide production[1]. The odor threshold value of H_2S is about 7.6×10^{-4} mg m^{-3}, so that very low concentrations of H_2S is enough to produce a strong odor[2]. The odor is absolutely the most complex of all the air pollution problem. Malodorous can damage human health by direct olfactory stimulation or indirectly affects the cardiovascular, respiratory, digestive, nervous, and endocrine systems of the human body[3].

The traditional treatment methods of malodorous gas mainly include adsorption, chemical absorption, biological filtration, and biological droplet filtration[1]. For these methods, a high removal efficiency is realized, but there still some problems such as large area reactor, high operating cost, and sometimes operation unstable. For the past few decades, the advanced oxidation technology such as non-thermal plasma and UV photolysis oxidation for odors treatment had been widely concerned[4]. In non-thermal plasma, the electron energy can be as high as 10-20 eV, so reactive processes that require extremely high activation energy can be realized[5], but there are still some problems such as energy consumption and t by-product emission that must be solved before widely applications[6]. In the UV photolysis process, the malodorous gas molecule can be activated directly by the UV light[7].

For the UV light with 185 nm wavelengths, the energy of the photon is about 6.7 eV, so that most of the odors molecules can be destroyed[8]. It is proposed that the UV photolysis oxidation is viable and high efficiency method for malodorous gas treatment, but the energy-efficient is still a problem.

In this research, a UV photolysis reactor with double-tube is discussed. The O_3 generation of the reactor is studied by the factors of input energy, gas flow and humidity. Compared of O_3 oxidation, decomposition of low concentration H_2S in this system is evaluated.

2. Experimental section

Figure 1 shows the experimental setup used in this work, in which the system can be regarded as the simulate gas generation part, UV photolysis reactor, and detection part with several monitor instruments. The experiments are carried out in air with different humidity at atmospheric pressure and ambient temperature. The H_2S mixed with certain amount of air as simulate gas. The humidity was regulated by the air flow into water bottle. For H_2S removal, the initial concentration of H_2S was about 8 mg m^{-3}, and the total gas flow rate was 1 to 5 L min^{-1} as the experiment needs. The exhaust was absorbed by sodium hydroxide solution in the absorption bottle. The UV photolysis reactor was a stainless-steel tube with an UV lamp, and it was powered by a power source. The concentration of H_2S and O_3 in the gas were monitored by a multi-gas monitor (MultiRAE, RAE Systems, USA) and an ozone analyzer (UV-100, Eco Sensors, USA), respectively. The temperature and humidity were monitored by a hygrothermograph (RS232, CENTER, China).

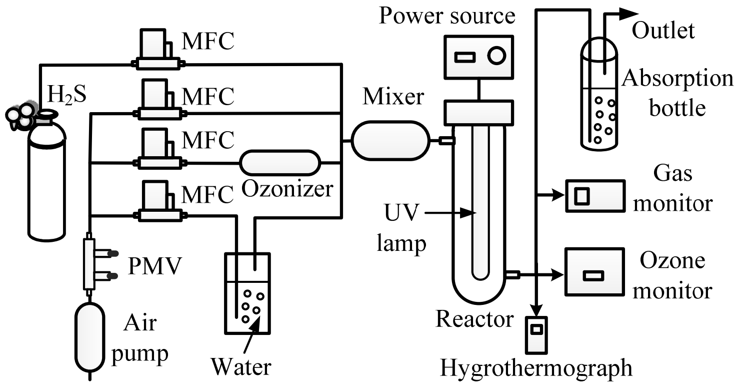

Figure 1. Schematic diagram of experimental setup.

3. Results and discussion

3.1. O_3 generation

In the process of photochemical reaction, oxygen in air was decomposed by high energy UV light, and the oxygen radical was produced simultaneously. And then the combination of oxygen radical and oxygen molecules produces O_3. The fundamental reactions can be expressed by the following equations[9, 10]:

$$O_2 + h\nu\ (\lambda<200\ \text{nm}) \rightarrow O\cdot + O\cdot \quad (1)$$

$$O_2 + O\cdot + M \rightarrow O_3 + M \quad (2)$$

Where M refers to oxygen and nitrogen in air.

The generation of O_3 represents the energy of UV light. Therefore, O_3 produced in the reactor is used to evaluate the performance of the reactor. Figure 2 shows the relationship between O_3 produced and operation time of reactor with different gas flow. A lot of O_3 is produced in the photochemical process. The O_3 concentration has reached steady level as the operation time increased. It is also indicated that the UV photolysis reactor is stable.

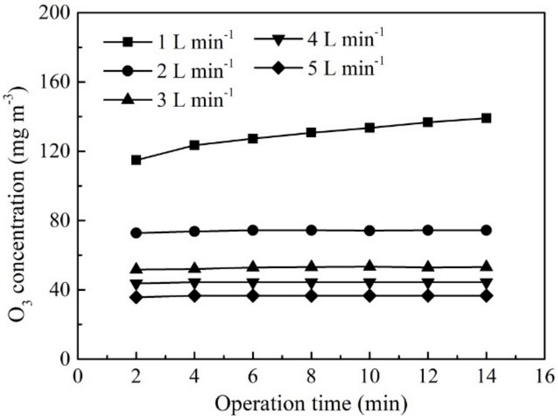

Figure 2. The relationship between O_3 produced and operation time of reactor with different gas flow.

Figure 3 shows effects of gas flow on O_3 produced with different input energy. The O_3 concentration decreases as the gas flow increased. For the same gas flow, the more the energy input, the more the amount of O_3 produced. Obviously, the input energy is the major factor in the production of O_3. Figure 4 shows Effects of input energy on O_3 produced with different humidity. The humidity has a negative effect to the O_3 generation, for example, at the input energy of 6 W, 148 mg m^{-3} and 81 mg m^{-3} O_3 produced at the relative humidity of 20% and 80%, respectively. As showed in the equations (3) and (4), H_2O can be decomposed by high energy UV light in the photochemical process, and the H_2O can consume O generated in the equation (1) as well, so that the energy used for O_3 generation decreased.

$$H_2O + h\nu\ (\lambda<200\ nm) \rightarrow H\cdot + HO\cdot \quad (3)$$

$$H_2O + O\cdot \rightarrow HO\cdot + HO\cdot \quad (4)$$

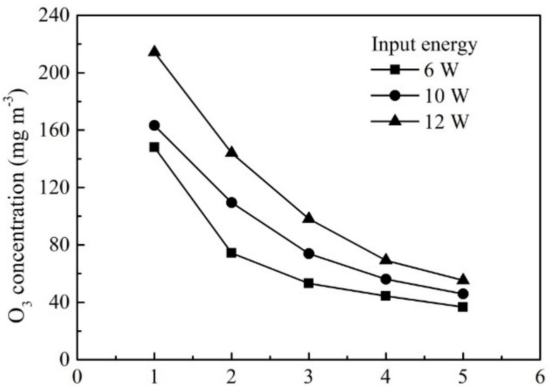

Figure 3. Effects of gas flow on O_3 produced with different input energy.

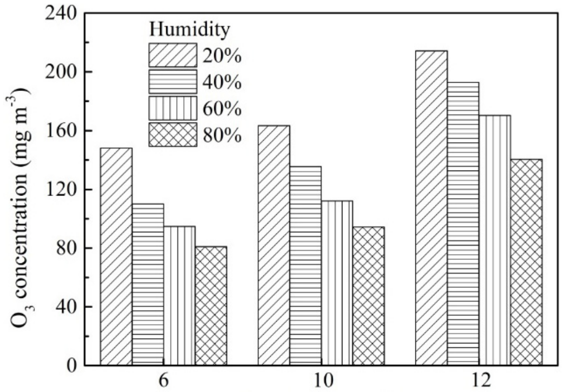

Figure 4. Effects of input energy on O_3 produced with different humidity.

3.2. H_2S decomposition

Figure 5 shows the relationship between H_2S removal and O_3 concentration in the same reactor with and without UV light. The O_3 concentration is monitored before the H_2S injected into the reactor. For O_3 oxidation process, the O_3 is produced by upstream ozonizer. The H_2S removal efficiency increases as the O_3 concentration increased. For UV photolysis process, H_2S removal efficiency is almost 100% when the O_3 concentration is about 35 mg m^{-3} at the input energy of 1.5 W, compared to the removal efficiency is about 46% with only O_3 oxidation.

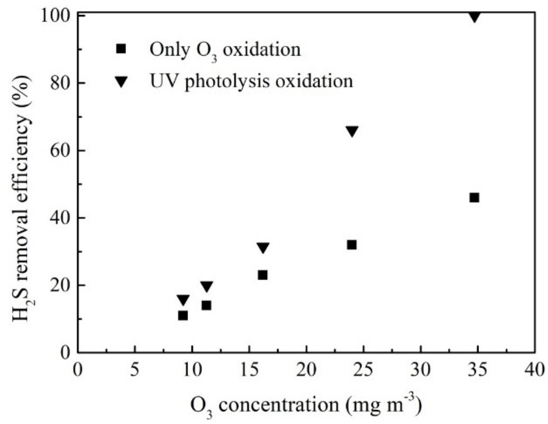

Figure 5. The relationship between H_2S removal and O_3 concentration in the same reactor with and without UV light.

Figure 6 shows the effects of humidity on H_2S removal in the UV photolysis reactor. For the same initial O_3 produced by UV light, the H_2S removal efficiency increased as the humidity increased. For example, the H_2S removal efficiency is about 84% at the relative humidity of 80%, which is much higher than that of relative humidity of 20% with removal efficiency of 44%. As showed in Figure 7, for the similar O_3 present in the reactor without UV light, the H_2S removal efficiency is almost the same in different humidity. It is obviously that H_2O promotes the H_2S decomposition in the UV photolysis oxidation process. At high humidity, H_2O can consume the energy which generate O_3, as a result, the O_3 concentration in the outlet decreased. The mechanism for the H_2S decomposition by O_3 can be described as equations (5) and (6). There is some S observed in the reactor and pipe wall downstream because of the equations (7) and (8)[11, 12]. The overall photolysis reaction of H_2S with high energy UV light is likely to be as equations (9)[7].

$$H_2S + O_3 \rightarrow SO_2 + H_2O \quad (5)$$

$$SO_2 + O_3 + H_2O \rightarrow H_2SO_4 + O_2 \quad (6)$$

$$H_2S + hv\ (\lambda<306\ \text{nm}) \rightarrow H\cdot + HS\cdot \quad (7)$$

$$HS\cdot + HS\cdot \rightarrow H_2S + S \quad (8)$$

$$H_2S + hv/O_3/HO\cdot/O\cdot \rightarrow \cdots \rightarrow \text{Final products} \quad (9)$$

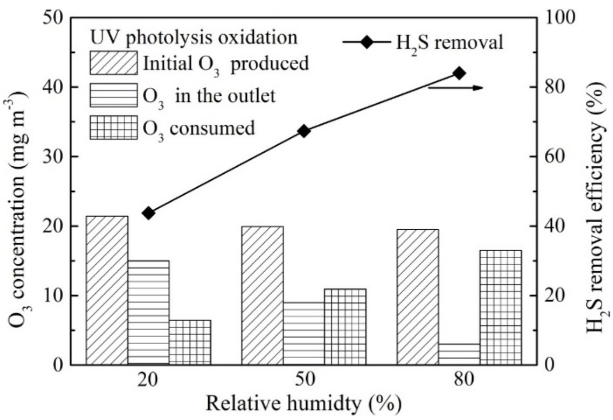

Figure 6. Effects of humidity on H_2S decomposed by UV light.

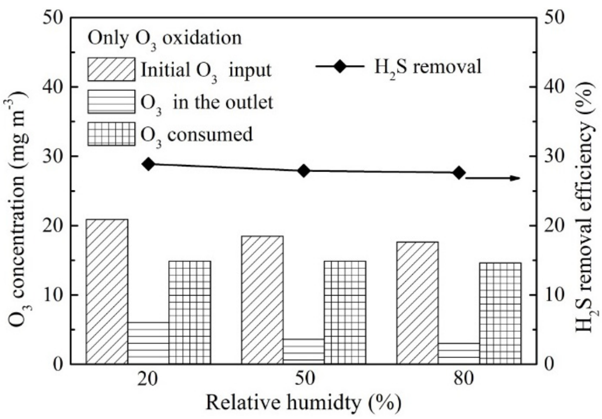

Figure 7. Eeffects of humidity on H_2S decomposed by O_3 alone.

4. Conclusions

Characteristic of O_3 generation in a UV photolysis reactor with double-tube is experimental investigated. The UV photolysis reactor has higher O_3 generation efficiency at the condition of lower humidity or higher input energy. For the gas flow of 1 L min^{-1}, 214 mg m^{-3} of O_3 is produced in the UV photolysis reactor with relative humidity of 20% and input energy of 12 W. H_2S can be decomposed efficiency in the UV photolysis process. For the UV photolysis reactor with the input energy of 1.5 W, H_2S with the concentration of 8 mg m^{-3} can be decomposed completely. A higher humidity will lead to consume more O_3. With regard to H_2S removal, a higher humidity is preferred to improve its decomposition efficiency in this experiment.

Acknowledgments
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