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Continuous treatment of hydrogen sulfide on a large scale using wet-electrostatic precipitator

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HIGHLIGHTS

- This study was conducted to treat H₂S continuously on a large scale.
- The Wet-ESP system consists of wet process and electrostatic precipitation (ESP).
- In the wet process, H₂S was converted by chemical reaction with alkaline materials.
- In the ESP reactor, solid salts were collected on anode surface by corona discharge.
- Odor gas can be removed more quickly by using the Wet-ESP system than typical methods.

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ABSTRACT

A large amount of hydrogen sulfide (H₂S) was continuously removed by a wet-electrostatic precipitator (Wet-ESP) system. The Wet-ESP system consists of wet process for the conversion of H₂S and electrostatic precipitation process for the collection of dust. H₂S was neutralized by the mist of NaOH or KOH alkaline solution supplied by an ultrasonic humidifier in the wet process. Chemical reactions between H₂S and alkaline solution produced salts such as Na₂S and K₂S at room temperature. Dusts of salts and unreacted mist were collected in the electrostatic precipitator where a corona discharge device was installed. The total flow rate of H₂S and air mixture was controlled in the range of 0.5–2.0 Nm³/min at the fixed H₂S flow rate of 1.2 × 10⁻³ Nm³/min. The removal efficiency of H₂S was over than 99% when the liquid–gas ratio in the case of KOH and the gas residence time were more than 4.94 and 0.504 s, respectively. In order to reduce dust emission to the same level with that in the air, the corona discharge power of 124 W was required for a short dust residence time of 0.163 s, while 44 W was required for a relatively long dust residence time of 0.65 s.

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1. Introduction

Sulfide compounds such as hydrogen sulfide (H₂S), dimethyl sulfide ((CH₃)₂S), dimethyl disulfide ((CH₃)₂S₂), and methyl mercaptan (CH₃SH) bring about odor pollution problem [1]. Especially, H₂S is colorless, highly toxic, and corrosive gas with a rotten egg smell [2,3]. H₂S causes diverse symptoms of mental stress, hysteria, headache, vomit, and even death for human beings [4,5]. Major sources of H₂S emission are oil refinery, landfill, sewage treatment, food waste treatment and gasification processes. In addition, H₂S gas is used as a reactant in synthesis processes of ammonia and methanol [6].

Traditional methods for the removal of odor substances are activated carbon [7,8], catalytic decomposition [9–11], adsorption [12–14], chemical scrubbing [15,16], and biofiltration [17–20]. In

order to replace the traditional methods, atmospheric pressure plasma processes such as dielectric barrier discharge [21,22], pulsed corona discharge [23,24], gliding arc [25–27], silent discharge [28], glow discharge [29], and radio frequency discharge [30] have been also introduced to remove odor gases. Although atmospheric pressure plasma technologies have been received considerable attention in the field of waste treatment due to abundant radicals and energetic electrons at atmospheric pressure, they have suffered from a limited treatment capacity. Therefore, the traditional methods are still used in the industrial field for the treatment of odor gas despite several drawbacks. Catalyst and adsorption methods have limitations of insufficient removal efficiency of odor gases and short lifetimes of catalyst and adsorbent. Biofiltration has long residence time in the reactor in order to achieve the high removal efficiency and biofiltration system is difficult to be controlled because microorganisms are sensitive to the survival environment. Therefore, chemical scrubbing is widely used for the removal of odor gases on a large scale. However,

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chemical scrubbing in a packed tower requires high installation and operating costs due to large sized equipment, long and expensive pipes and powerful fans. In order to improve the economic feasibility in odor gas treatment, the size of chemical scrubbing system must be compact by reducing the gas–liquid contact time in the reactor. In this case, compact gas scrubbers can be installed at each emission source of odor gas. Therefore, many researchers have been focused on the development of compact scrubber. A notable recent example is the wet scrubbing system designed for the removal of H₂S gas using sodium hypochlorite (NaClO) and mesh packing materials at the gas residence time of 30 ms [31].

Therefore, this work was carried out to suggest a new method for the removal of H₂S on a large scale with short residence time and to evaluate the effectiveness of the Wet-ESP system compared with various methods for odor gas treatment. The Wet-ESP system is composed of two-step treatments which are wet chemical process and electrostatic precipitation (ESP) process [32]. In the wet process, H₂S gas was spontaneously neutralized by chemical reactions with the mist of neutralizer solutions at room temperature. As a result, dusts of solid salts and unreacted mist were emitted from the chemical reaction region. Dusts were negatively charged up and collected by the corona discharge plasma generated in the ESP reactor. In the experiments, effects of NaOH and KOH neutralizer flow rates, gas residence time in the chemical reaction region, electric power of corona discharge plasma, and residence time of dust in the ESP reactor on H₂S removal efficiencies and dusts emission were examined to find out an appropriate operating condition of the Wet-ESP system.

2. Experimental details

2.1. Chemical reaction region

Fig. 1 presents the Wet-ESP system composed of a gas supply system, spontaneous chemical reaction region, the ESP system, and an exhaust port with a blower. A constant H₂S flow rate of 1.2×10^{-3} Nm³/min (0.054 mol/min) was controlled by a mass flow controller (TSC-220, Korea Instrument T&S, Korea). Since a pure H₂S was difficult to dilute with air, it was mixed with nitrogen in a gas mixing chamber at first. The molar mixture ratio of H₂S to N₂ was fixed at 1:3. Then the gas mixture was diluted with air at the entrance of the chemical reactor to be used as waste gas. The total gas flow rate was calculated by the average gas velocity using anemometer (416, Testo, Germany) at the exhaust port. Since the total

flow rate of waste gas was controlled from 0.5 Nm³/min to 2.0 Nm³/min by the input frequency of blower using inverter (CIMR-J7AA20P7, Yaskawa Electric, Japan), the concentration of H₂S was changed from 600 ppmv to 2400 ppmv as shown in Table 1.

Cheap and water-soluble NaOH and KOH were used as alkaline materials for the neutralization of H₂S. Neutralizer solutions were injected into the cylindrical reaction tube with balance air as the form of mist by an ultrasonic atomizer (DRW-4000s, Meakyong, Korea). And then, the gas mixture of H₂S and N₂ was injected into the reaction tube through 4 holes which are placed toward to the axis of the reaction tube with the inner diameter of 6 mm. H₂S gas was selectively neutralized by the mist of NaOH or KOH solution in the chemical reaction region. The molar concentration of NaOH or KOH in solution was varied from 0.1 mol/L to 2 mol/L to control the molar flow rate of neutralizer from 0.013 mol/min to 0.267 mol/min at the fixed flow rate of neutralizer solution mist of 8 L/h. The size of mist was distributed from 1 μm to 5 μm. H₂S diluted in air was spontaneously neutralized by the mist of NaOH or KOH solution at atmospheric pressure producing dusts of solid salt such as Na₂S and K₂S and unreacted mist.

The volume of chemical reactor was changed to examine the effect of gas residence time on removal efficiency of H₂S. The chemical reactor was a plastic pipe with the inner diameter of 0.047 m. The length of the plastic pipe was changed from 1.1 m to 5.2 m, to control the gas residence time from 0.126 to 0.63 s at the fixed total flow rate of 2 Nm³/min.

2.2. Electrostatic precipitator

A high voltage DC power supply (20 kV, Plasma Technology, Korea) which provides high voltage of 12.8–9.3 kV and low current of 0.5–6.4 mA was employed for the corona discharge in the ESP reactor. Dusts produced from the neutralization reaction were charged up by the corona discharge plasma and collected on the anode surface of the ESP reactor. Four corona discharges were generated in each pin-to-plate type stainless steel electrode configuration. The gap distance between a pin cathode and a plate anode was 24 mm. The cathode has equally spaced 256 pins and the anode was a cylindrical which is 0.35 m in length and 0.308 m³ in cross sectional area.

In the experiment, the input power of corona discharge was controlled from 6 W to 124 W. Both of voltage and current were increased with increasing the input power. The discharge voltage was increased from 12.8 kV to 19.3 kV and the discharge current was increased from 0.5 mA to 6.4 mA when the input power was increased from 6 W to 124 W. In a high voltage, negatively charged dust particles are strongly accelerated to the anode surface. In addition, dusts are easily charge up in a high current condition due to abundant electrons. Therefore, it was expected that more dust particles can be removed in the short time with increasing the input power.

The residence time of dusts in the ESP reactor was controlled from 0.16 s to 0.65 s by changing the total flow rate of waste gas from 0.5 Nm³/min to 2 Nm³/min. The change of waste gas flow rate may affect not only dust collection in the EPS but also the

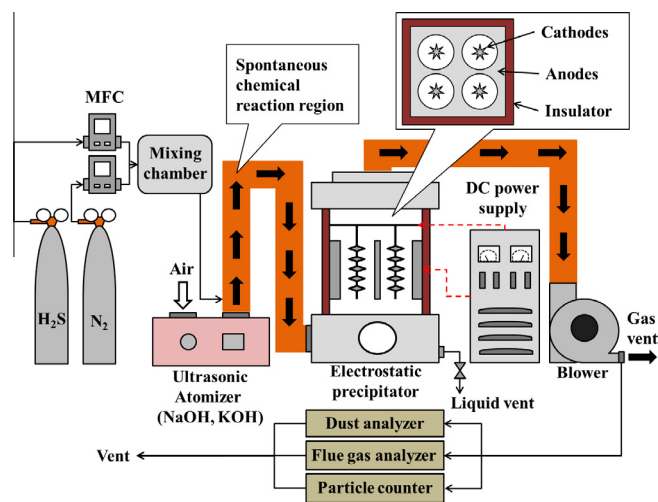


Fig. 1. Schematic diagram of the Wet-ESP system for the continuous treatment of H₂S gas in air on a large scale.

Table 1
Experiment variables for the removal of H₂S by using the Wet-ESP system.

Total gas flow rate (Nm ³ /min)	0.5–2
Molar flow rate of H ₂ S (mol/min)	0.054
Concentration of H ₂ S (ppmv)	600–2400
The type of neutralizer	NaOH or KOH
Molar flow rate of neutralizer (mol/min)	0.013–0.267
Gas residence time in chemical reaction region (s)	0.126–0.630
Electric power of ESP (W)	6–124
Dust residence time in ESP (s)	0.163–0.650

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