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Environmental applications of fine bubble generating apparatus with low energy and high treatment efficiency

Yong-Jun Jung[a,b], Jae-Ouk Jung[c], Yuki Kamimoto[b], Kyungik Gil[d], Dong-Hyun Kim[c,*]

[a]*Department of Environmental Engineering, Catholic University of Pusan, 9 Bugok3-dong, Geumjeong-gu, Busan 609-757, Korea,*
[b]*Institute of Materials Innovation, Institutes of Innovation for Future Society, Nagoya University, Furo-cho, Chikusa-ku, Nagoya 464-8603, Japan*
[c]*Department of Radiological Science, Catholic University of Pusan, 9 Bugok3-dong, Geumjeong-gu, Busan 609-757, Korea, email: dhkim@cup.ac.kr (D.-H. Kim)*
[d]*Department of Civil engineering, Seoul National University of Science and Technology, 232, Nowon-gu, Seoul 01811, Korea*

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ABSTRACT

A fine bubble generating equipment maintaining 12 mg L^{-1} of dissolved oxygen concentration with low energy consumption was developed, on a trial basis, to solve various kinds of environmental problems such as heavy metals, high concentration of T-N, malodor and hydrogen sulfide from the sewage treatment plant. Such heavy metals as Fe, As of acid mine drainage from stormwater runoff were effectively oxidized depending on aeration period. Almost 90% of T-N removal efficiency was obtained at around 10,000 mg L^{-1} concentration. On average, 55.6% removal efficiency for hydrogen sulfide was achieved in the reactor. The development of a novel reactor generating fine bubbles may be of use not only to protect water qualities polluted but also to keep clean air qualities.

Keywords: Fine bubble; Heavy metals; Stormwater runoff; T-N

1. Introduction

A lot of efforts are being continuously focused on the development of novel treatment systems in order to cope with environmental issues namely: water environment, air quality, waste, chemicals, and soil conservation. More interests of a systematic approach to the management of water quality have been drawn usually on the basis of diffuse pollution, where the pollution source is mainly caused by land use such as manufacturing plant, farm area, forest, mining, etc.

In particular, the wastewater from mining leads to the deterioration of farmland nearby due to the precipitation of iron-hydroxide untreated, which is generated by the oxidation of pyrite in case of exposure to air.

Since the acid mine drainage (AMD) is a strong acidic wastewater rich in a high concentration of dissolved ferrous and non-ferrous metal sulfates and salts, it has been a great focus of researches over the last 50 y [1]. Several methods such as chemical precipitation, solvent extraction, reverse osmosis, electrodialysis, ion exchange/adsorption, and wetland have been currently employed to treat AMD [2]. Less enough researches on the treatment of AMD wastewater by fine bubbles has been made although many works have been observed in the employment of chemicals. Among the low concentrations of toxic heavy metals generated from AMD, such metals as iron, aluminum, and manganese can form insoluble compounds through the extensive presence of air.

* Corresponding author.

Although total nitrogen is essential nutrients for most plants and animals, an excess amount of nitrogen which is mainly composed of ammonia, nitrates, and nitrites in water bodies may lead to low levels of dissolved oxygen (DO) and negatively alter organisms and various plant lives. Nitrogen is usually found in human waste, foods, and discharges from commercial and industrial sources, where urine and feces are the largest sources of nitrogen in residential wastewater. Especially, both runoffs from fertilized laws/croplands and runoff from animal manure/storage areas are being considered as main sources of nitrogen. Depending on removing objectives set forth in an environmental program, a variety of options are commonly used to control total nitrogen from each effluent source [3–6].

The generation and emission of hydrogen sulfide have been known to be a major cause of malodor as well as the bad effect on the use of methane recovery process in sewer systems, where several strategies to control sulfide production are employed in the use of chemicals such as oxygen and iron salts for different purposes.

In recent, more attention has been drawn to the potential applications of fine bubbles for wastewater treatment requiring oxidation due to the ability to generate highly reactive free radicals [7]. Although micro-bubbles are able to be generated through such methods as acoustic cavitation, microfluidic oscillation, porous membranes and hydrodynamic cavitation [8], the fine bubbles from the enhanced reactor of venturi scrubber were successfully generated via the air atomizing process in the published studies [9–11] and played an important role in the application of the environmental field.

It is clear that the oxidation process through aeration provides a variety of potential benefits in environmentally caused treatment practices such as polluted water, mixed impurities, and malodors.

In order to improve water quality when the water is polluted with excessive levels of ammonium ion from the agricultural area or piggery wastewater as well as heavy metals from AMD or highway runoff, dip injection wet scrubber (DIWS) facility is expected to be designed to provide oxidation necessity.

As proper best managment practice, the aim of this work is to provide the potential possibility of oxidation process generating fine bubbles, where various kinds of pollution sources such as heavy metals from AMD, high concentration of T-N and hydrogen sulfide from sewage sludge and chlorine gas from wastewater treatment plant were examined on the basis of DIWS performance.

2. Experimental

2.1. Dip injection wet scrubber

Different from the general formation methods of microbubble with mechanical means [12] described in the paper, we have developed a new concept of micro-bubble generation reactor as shown in Fig. 1 [9–11]. Based on the established technique of venturi scrubber, the device called DIWS was employed in this work, where the micro-bubbles were successfully produced through the air atomizing process with a high velocity of more than 60 m s^{-1}. With the ability to generate highly reactive free radicals and to make turbulence associated with the collapsing, more attention has been consistently given to the oxidation requiring applications of microbubble for water and wastewater treatment. With the help of the negative pressure, the air is continuously circulated in the DIWS, and the sucked air is broken into a large number of micro-bubbles by a high shearwater flow with strong turbulence, then the DIWS can discharge a water jet with fine-bubbles from the exit [13]. In general, the researchers have most yet reached conformity on the definition of micro-bubbles with a respective diameter of 10–50 μm [14]. Although the size of fine-bubble was not able to measure in this work, the significant increase with a short period of time and the maintenance of high DO concentration with a long time was observed in the course of the treatment process.

2.2. Pollution source

The treatment performance of DIWS was evaluated by 4 different types of pollution sources from wastewater and malodor assuming that all pollutants are generated from stormwater depending on land use. For heavy metals, AMD wastewater was collected to verify the possibility of the oxidation process. T-N rich wastewater with more than 10,000 mg $L^{-1}$of T-N concentration was employed from an ammonia manufacturing plant. Hydrogen sulfide of the sewage treatment plant and chlorine gas of storage tanks were also collected from an industrial plant, where the concentrations were ranged from 1,000 to 2,000 mg L^{-1} and 100 to 200 mg L^{-1}, respectively.

2.3. Analytical methods

Heavy metals were measured by ICP (OPTIMA 7300DV, Perkin Elmer, USA) and NH_4^+ concentration was detected by ion chromatography (IC850, Metrohm, Swiss) equipped with Metrosep C4–150 (Metrohm, Swiss). Malodors were collected and analyzed by detection tube (200SA, 200SB; Komyo Rikagaku Kougyo, Japan). For DIWS systems, because the flow patterns become relatively complex, the computational fluid dynamics (CFD) is suggested to study the flow and velocity field distribution in the reactor.

3. Results and discussion

3.1. DIWS performance

On line DO monitoring system was established in the DIWS tank to trace the variation degree in real-time as shown in Fig. 2. After the DIWS system was turned on, the patterns of DO concentration steadily maintained 6.7 mg L^{-1} within 5 h. However, the amount of DO rapidly increased to about 12 mg L^{-1} continuously, which indicated that the DIWS system was of use to oxygen transfer. Oxidation-reduction potential (ORP) was steadily kept around 407 mV that fully reflected aerobic conditions. Potentially, the device developed in this work was recommended in various fields of polluted sites [15,16] to keep aerobic conditions continuously solving environmental problems.

For numerical simulation, CFD plays important role in analyzing and developing a microfluidic system. We have

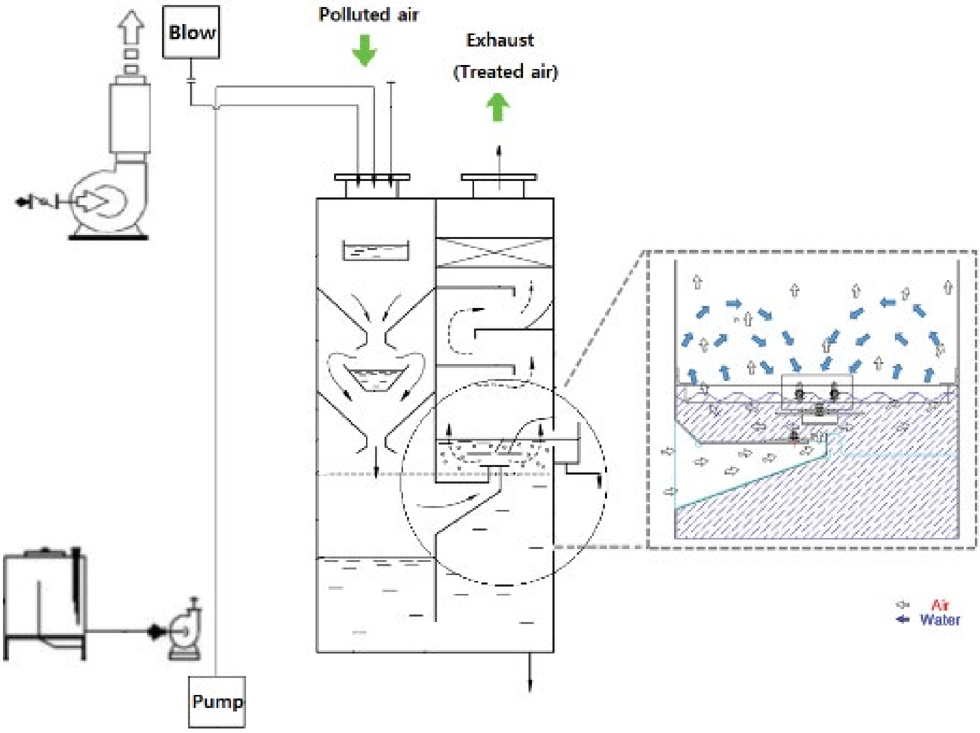

Fig. 1. Schematic of dip injection wet scrubber generating fine bubbles through the air atomizer.

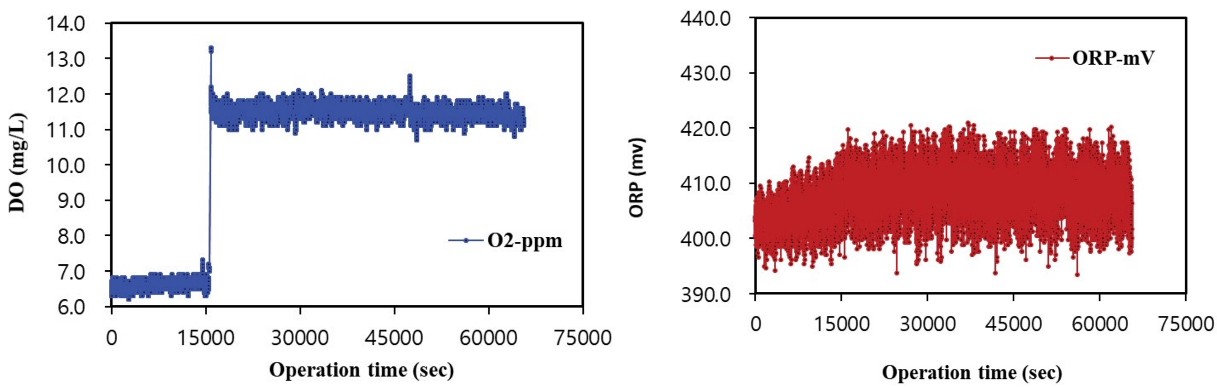

Fig. 2. Variation of DO and ORP profiles with DIWS in the water function of time.

found the flow pattern in the DIWS system using CFD as shown in Fig. 3. The hydrostatic pressure of the internal flow field distribution has an important influence on the fine bubble generation performance. In sucking fine bubble generation at the air inlet, it should have a larger negative pressure. Fine bubbles larger than general bubbles tend to behave as solid colloid particles in solution instead of floating to the surface and bursting, which proved to be successful in breaking large bubbles into very fine bubbles for further purposes such as water treatment, disinfection, algae harvesting, etc [17]. The air atomizing device in the DIWS system was effectively introduced with a high velocity of more than 60 m s^{-1} in this work although a lot of variables affect the fine-bubble generation process.

In an attempt to reduce power costs and increase treatment efficiency, a fine-bubble generating device was retrofitted with a combination of atomizer and eliminator. The comparison of blower consumption between the conventional devices and DIWS was presented in Table 1. Since the DIWS system utilizes atmospheric pressure and circulation system, low energy, and high efficiency to generate high DO concentration are to be obtained.

3.2. Wastewater treatment

The results from both 10 h of aeration as short period monitoring and 20 d as long period monitoring of AMD were presented in Fig. 4 [11]. Arsenic was fully oxidized within

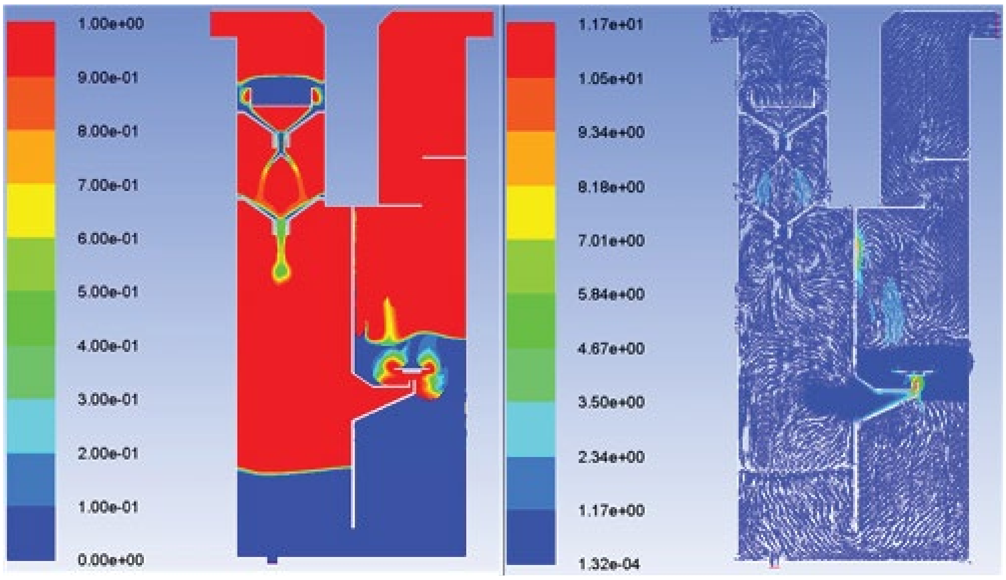

Fig. 3. CFD analysis during the operation: air and water are fully mixed (left), then the velocity is rapidly increased through the collapsing of the atomizing devices.

Table 1
Comparison of operating power consumption

Equipment	Blower (50 Nm^3 min^{-1})		Circular pump (0.44 m^3 min^{-1}, kw)	Total power (kw)
	Power (kw)	Pressure (mmAq)		
Conventional	50.3	4,000	0	50.5
DIWS	4.4	350	1.43	5.83

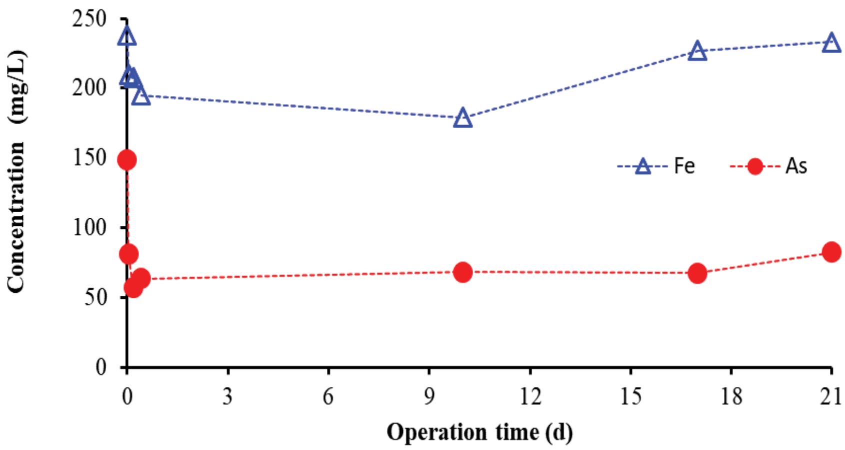

Fig. 4. Profiles of Fe and As from AMD treatment.

10 h from 149 to 56.9 μgL^{-1} in which removal efficiency was 61.8%. In the case of a long period of aeration more than 10 d, the repetition of oxidation and leaching of heavy metals was observed in As and Fe behaviors, which is almost similar to Cd and Al. Although the behavior of heavy metals depends on the environmental surroundings and/or chemical properties in water systems, DIWS aeration system generating fine-bubble is recommended to oxidize pollutants within a relatively short period. Higher than 10,000 mg L^{-1} of ammonium ions was introduced to the DIWS system and almost more than 90% of T-N removal efficiency was obtained in the previous work [10].

Even in the range between pH 10 and pH 12 that usually present as both dissolved gases and ammonia ions, the favor

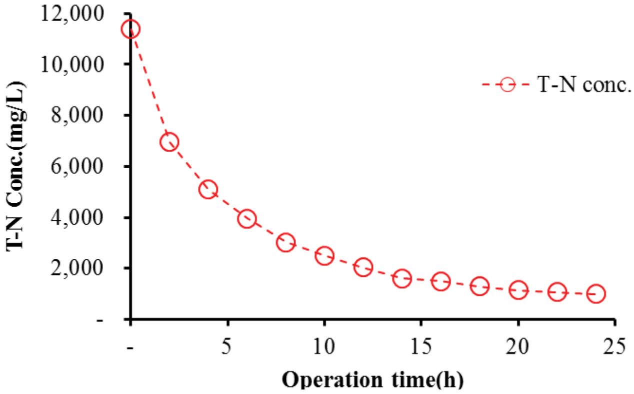

Fig. 5. Variation of T-N concentration from the ammonia manufacturing plant.

removal of ammonia from solution was given in this work because DIWS reactor is able to determine the amount of air necessary to provide adequate flow for the ammonia at any given temperature and pH condition.

3.3. Management of malodor

Since anaerobic stabilization of sewage sludge has the advantages of costs, energy efficiency, and environmental protection, the anaerobic digestion for waste sludge is the best solution for sewage treatment plants. Particularly, the raw biogas needs to be dried and such harmful gases as hydrogen sulfide and other trace substances to be removed in order to occupy a beneficial combustible gas and avoiding corrosion or unwanted deposition in the facility. Six times of biogas from sewer systems were collected and evaluated by DIWS to purify noxious gases from beneficial gas. Fig. 6 shows the variation of influent and effluent H_2S concentration with the function of the sampling number. When above 1,000 mg L^{-1} of H_2S was introduced to the DIWS system, below 500 mg L^{-1} of H_2S was exhausted outside the DIWS system, where the removal efficiencies were almost 50% on average depending on the condition of influent concentration.

Chlorine gas discharged from the storage tank of the industrial plant was also introduced to the DIWS system, where the influent concentration of chlorine ranged from 110 to 200 mg L^{-1}. As shown in Fig. 7, the effluents through the system were below 4 mg L^{-1} and the removal efficiencies were similarly 98%. When the mixture of gases with water flows into the DIWS system, the fine bubbles are rapidly adhesive to chlorine gases rising the surface in a liquid and exhausted into the atmosphere.

4. Conclusions

Novel treatment system generating a fine bubble with low energy and high treatment efficiency was developed in order to introduce environmental issues. The design and construction of a fine bubble generating device have

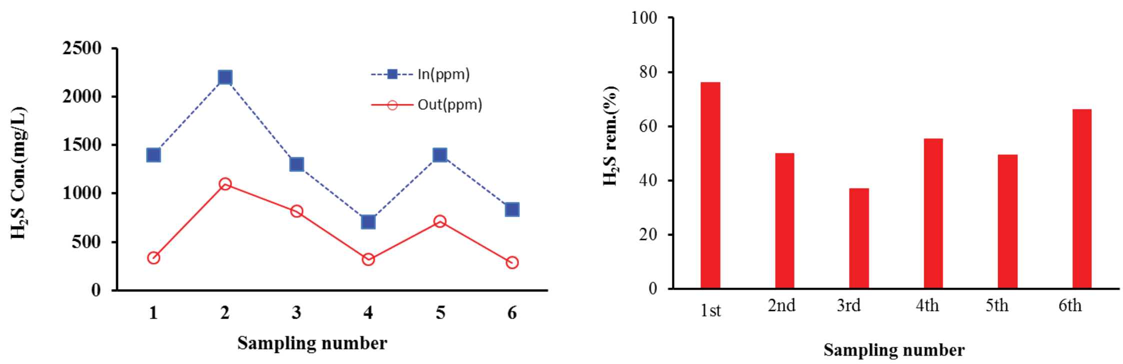

Fig. 6. Variation of influent and effluent H_2S concentration and removal efficiency with the function of sampling times.

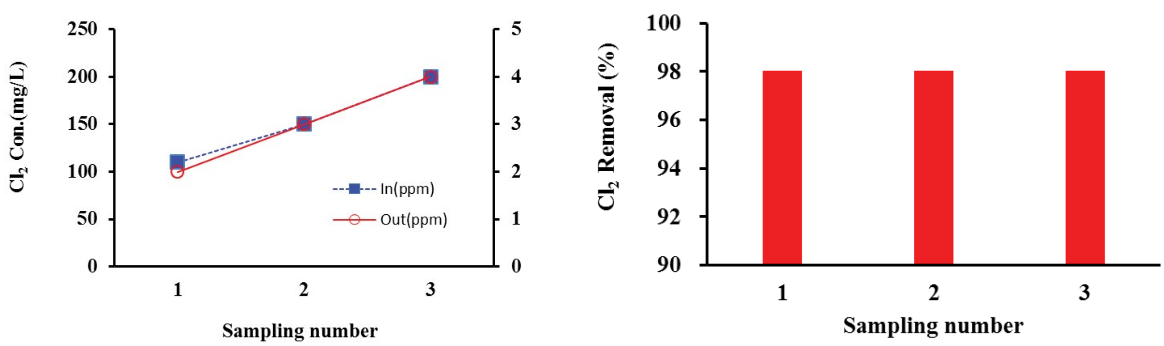

Fig. 7. Variation of influent and effluent chlorine concentration and removal efficiency with the function of sampling times chlorine gas treatment.

led to an alternative solution to maintaining a high concentration of DO more than 12 mg L^{-1}. Such heavy metals as Fe, As of AMD from stormwater runoff were effectively oxidized within 10 h of short period and other heavy metals were fluctuated due to the repetition of oxidation and leaching within the long period. More than 90% of T-N removal efficiency was obtained at above 10,000 mg L^{-1} concentration. On average, 55.6% removal efficiency with above 1,000 mg L^{-1} of hydrogen sulfide was observed in the reactor, and chlorine gas was also effectively removed up to 98%. The development of a novel reactor generating fine bubbles may be of use not only to protect water qualities polluted but also to keep clean air qualities.

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