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Full Length Research Paper

Design and application of new type of oxygen supplier for water and wastewater treatment

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A new oxygen supplier was designed to inject both ozone and air into the water under high pressure. The oxygen transfer coefficient (K_La) of the system with air and ozone were 0.0264 and 0.4900, respectively. The oxygen transfer efficiencies of the system with ozone and air were 73.58 and 52.17%, respectively. The system could be applied to increase the dissolved oxygen (DO) in domestic wastewater. DO of the wastewater from septic tank was increased from 0.0 to 4.9 ± 0.5 mg/L within 1.6 h by the system with air injection and up to 8.0 ± 0.5 mg/L within 1.6 h with ozone injection. The system with ozone injection could reduce the COD and BOD_5 by 54.6 ± 3.5 and 50.9 ± 3.4%, respectively, by increasing the DO. The system could be also be applied into shrimp ponds to increase DO. The DO of the water was increased from 2.5 to 4.3 ± 0.5 and 6.1 ± 0.7 mg/L within 20 and 80 min, respectively, by the system with ozone injection. Also, the system could reduce the organic matter during operation. The COD and BOD_5 were reduced by 81.2 ± 1.2% and 57.1 ± 3.0%, respectively, within 1.6 h by the system with ozone injection.

Key words: Aeration, dissolved oxygen, high pressure, ozonizer, plasma.

INTRODUCTION

Nowadays, water pollution has become a more serious problem in the world due to increasing population (Benefield et al., 1982; Chu, 2001). The main pollutants or impurities in the wastewater come from human activities such as cooking and washing, industry, agriculture and transportation (Metcalf and Eddy Inc., 2004). The main component of the impurities might be the organic compounds or reducing materials that could consume oxygen (dissolved oxygen; DO) from the river or reservoir which received the above wastewater (Metcalf and Eddy Inc., 2004). Several biological wastewater treatment systems have been introduced to stabilize or remove organic matter in wastewaters; these can broadly be classified into aerobic and anaerobic treatment system (Metcalf and Eddy Inc., 2004; Neralla et al., 2000; Sirianuntapiboon and Nimnu, 1999; Tritt, 1992). The aerobic process is more suitable than anaerobic process due to the higher removal efficiency and no bad smell being produced during operation (Metcalf and Eddy Inc., 2004; Tritt, 1992; Carucci et al., 1999). But the operating cost of the aerobic process is higher than anaerobic process due to the energy consumption for aeration (Metcalf and Eddy Inc., 2004). Low energy consuming aeration process or systems have been investigated. Two types of aeration system are commonly used; mechanical aeration system (aerator or agitator) and air blower or air injector. However, to aerate the water or wastewater by air injection or air blower might be good but it still consumes more energy and the efficiency is not so high.

Some researchers have tried using ozone instead of oxygen or air for increasing DO in water and wastewater, especially to clean up the water or to treat the water of the aquatic farm such as shrimp farm and fish farm (Metcalf and Eddy Inc., 2004; Sheng and Wang, 2003; Helmer and Kunst, 1998). Ozone not only increases the dissolved oxygen in the water and wastewater but also oxidizes some organic or reducing materials (Koch et al., 2002; Nishijima et al., 2003; Gehr et al., 2003). Also, ozonizers have shown higher oxidation and aeration efficiencies than convention system such as pure oxygen injection or mechanical aeration (floating aerator), but

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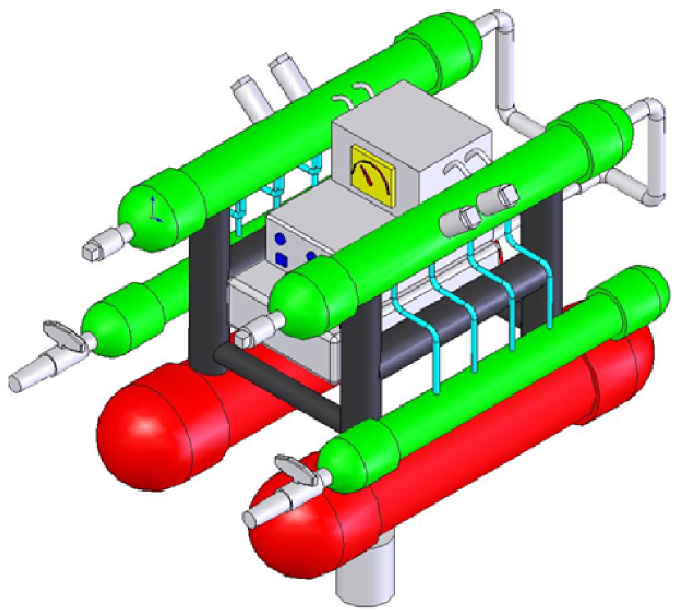

Figure 1. Photograph of the designed ozonizer.

they consume more energy (Blair and Hittington, 1975; Zhou and Smith, 2000). In this study, a new type of oxygen supplier and a new type of ozonizer were designed and the operating parameters investigated for the highest efficiency. Also, the oxygen transfer coefficient (K_La) of the systems was determined.

MATERIALS AND METHODS

Designed-oxygen supply apparatus

The laboratory oxygen supply apparatus was designed and constructed for testing the oxygen transfer yield under various operation conditions as shown in Figures 1 and 2, the ozonizer reactor was of cylindrical shape made by the Stainless steel pipe (25.0 centimeter in diameter). The oxygen supply apparatus consisted of many important components as follows:

Ozone production part

Designed-ozone production part (laboratory scale): This was designed and constructed for testing the ozone production yield under various operation conditions. The ozonizer reactor was cylindrical shape. Its case was made by the Stainless steel pipe (25.0 cm in diameter). The major components of the designed ozonizer consisted are followed:

1. Energy generation source component: Variable voltage transformer (Voltac Co. Ltd, Thailand, Model TSB-5M): This compo-nent is an AC transformer whose voltage could be varied from 12 - 220 volts.
2. Moving coil component (Pasco Scientific Co. Ltd, Denmark, Model SF9586): This component was used to generate voltage of 1.200 - 20,000 volts at an electric current of 35 mA.
3. Frequency kit component: Function Generator (Trio Co. Ltd, Japan, Model AG 203): This component was used to generate current frequency of 50 - 1,000 Hz.
4. Heat resistant glass tube (Pyrex type) (2 mm in diameter, 240 mm in length, and I mm thick): This component was used as the reaction tube for generation of the ozone.
5. Tapelon tube: heat resistance type tube (50 mm in diameter. 240 mm in length and 2 mm thick).
6. Electrode pole: A needle type of electric poles, made from stainless steel, was used in the designed ozonizer.
7. Air pump component (GAST Co. Ltd, USA, model 0.25 PH): This air pump system was used to control both oxygen and air flow at a capacity of up to 200 L/mim.
8. Humidity and nitrogen removing component (Eliasson and Kogelschatz, 1987): This component was the chamber for removal of humidity and nitrogen from the air. The chamber was made from a PVC pipe (0.05×0.04 m) and contained zeolite type 5 A [(Na_{89}[($A10_2$) 86 ($Si0_2$)]276 H_20)] (BDH Chemical Co. Ltd, Thailand).
9. Oxygen and Ozone gas tubes: Size: 10 mm in diameter, tapelon type.
10. Pressure meter (Nuovafima Co. Ltd, Japan, Model MS1-DS ISO): This pressure meter was used to determine the pressure of the gas in the range of 1.0×10^5 - 1.5×10^5 N/m^2.
11. Voltage meter (Tamadensoku Co. Ltd, Japan, Model 20 ADS): This component was used for measurement of the voltage of the designed ozonizer.
12. Current frequency meter (Trio Co. Ltd, Japan, Model AG 203): This component was used for measurement the current frequency of the designed ozonizer.
13. Current ampere meter (Yokogawa Hokushin Electric Co. Ltd, Japan, Model 76AA4318): This component was used for measuring the electric current of the designed ozonizer

Ozone or air injection part

The ozone or air injection part was made from stainless steel and PVC as shown in Figures 1 and 2. The major components for this part are as follows:

1. Ozone production unit with the capacity of 50 - 200 mg/h. This detail of this unit was mentioned above.
2. Air pump component (GAST Co,Ltd. USA, model 0.25 PH). This air pump system was used to control both oxygen and air flow at a capacity of up to 200 L/min
3. Pressure meter (Nuovafima Co,Ltd. Japan, Model MSI-DS 150). This pressure meter was used to determine the pressure of the gas in the range of 1.0x105 – 1.5x105 N/m^2
4. Voltage meter (Tamadensoku Co,Ltd. Japan, Model 20 ADS). This component was used for measuring the voltage of the designed ozonizer.
5. Current ampere meter (Yokogawa Hokushin Electric Co, Ltd. Japan, Model 76 AA4318). This component was used for measuring the electric current of the designed ozoniser.
6. Water pump (Guangdong Risheng Group Co, Ltd. China Model Hx-4500). Water flow capacity of up to 2800 L/h.
7. Water flow meter (ESSOM INSPECTION TAG Co,Ltd. Thailand Model HB 016 water flow capacity of up to 60 L/min).

Operation condition

The system consisted of 2 main parts: ozone or air production part and ozone or air injection part as mentioned above. The ozone production part was operated under high air pressure of 1.3×10^5 N/m^2, voltage of 220 volts, current frequency of 50 Hz and distance of electric dipolar 0.003 m with the needle shape type pole to generate ozone at a capacity of 150 mg/h. The equation model was developed as follows: The generated ozone or air was injected into water directly from the ozone or air production part at various water

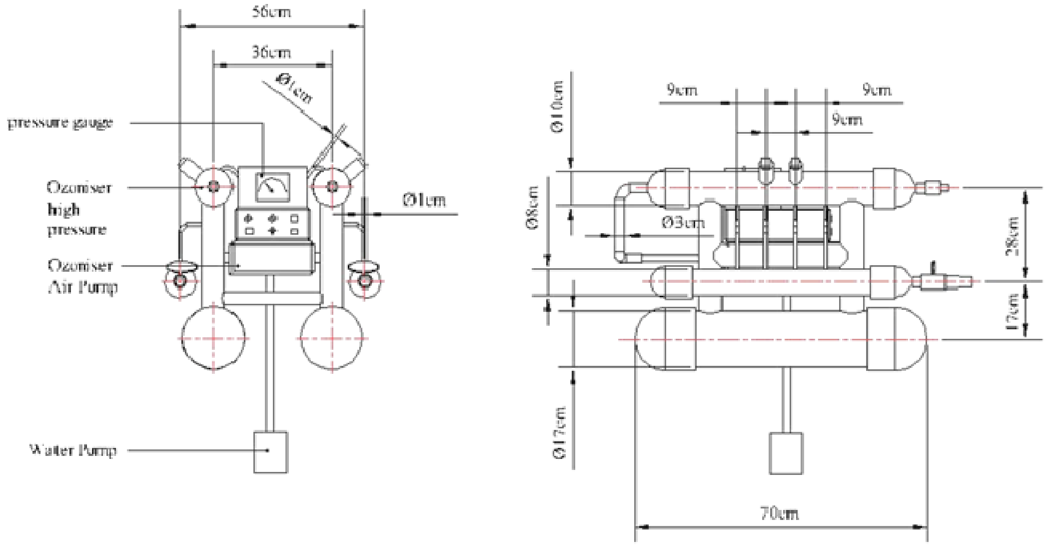

Figure 2. Schematic diagram of the designed ozonizer.

Table 1. Chemical properties of domestic wastewater and shrimp farm water.

Chemical compositions	Domestic wastewater	Shrimp farm water
	Average	Average
COD, mg/L	118 ± 7	138 ± 8
BOD_5, mg/L	110 ± 6	119 ± 7
TS, mg/L	350 ± 13	109 ± 5
TKN, mg/L	20 ± 2	1.2 ± 0.3
TP, mg/L	4.0 ± 0.5	0.05 ± 0.01
pH	7.2 ± 0.8	7.8 ± 0.8
Temperature (^{0}C)	28 ± 2	28 ± 2

flow rates. The designed ozonizer was tested with tap water, domestic wastewater and shrimp cultivation water to observe the oxygen transfer coefficient and efficiency as follows:

System efficiency for increasing DO in the tap water

A 100 mL sample of tap water was treated with sodium sulfite to eliminate the DO before use (7.88 mg Na_2SO_3 (AR grade) was required to eliminate 1 mg of DO). Then, the DO-less tap water was aerated or ozonized under various water flow rates of 25, 50, 75, 100, 125, 150 L/10 min. The water samples were taken every 10 min for DO determination.

Treatment of wastewater by the new type of oxygen supplier

A 100 L sample of wastewater was used in this study. The experiment was carried out in the laboratory under optimal ozonizer conditions of 10 L/min water flow and 50 L/min of air flow under high pressure of 1.3 x 10^5 N/m^2. Samples were taken every 10 min for DO, COD and BOD_5 determination.

Wastewater

Two types of wastewater were used in this study as domestic wastewater and shrimp cultivation water. The domestic wastewater sample was collected from the sump tank of wastewater treatment plant of King Mongkut's University of Technology Thonburi, Bangkok, Thailand. The chemical composition of the domestic wastewater was shown in Table 1. The shrimp cultivation water was collected from a shrimp farm near Smuthpakarn province, Thailand. The chemical composition is shown in Table 1.

Chemical analysis

Dissolved oxygen (DO), Chemical oxygen demand (COD) and biological oxygen demand (BOD_5) were determined using standard methods for the examination of water and wastewater (APHA, AWWA, WPCF, 1998).

Statistical analysis method

Each experiment was repeated at least 3 times. All the data were subjected to two-way analysis of variance (ANOVA) using SAS Windows Version 6.12 (SAS Institute, 1996). Statistical significance was tested using the least significant difference (LSD) at the $p < 0.05$ level and the results are shown as the mean ± standard deviation.

RESULTS AND DISCUSSION

Dissolved oxygen profile of tap water during aeration

The experiment was carried out at the laboratory scale using oxygen supplier with air. The results are shown in Table 2. The DO of the water (in that tank and outlet of the system: end pipe) was increased with the increase of water flow rate and reaction time. DO of the water was

Table 2. Dissolved oxygen profile of tap water during aeration.

Time (min)	R = 25 L/10 min		R = 50 L/10 min		R = 75 L/10 min		R = 100 L/10 min		R = 125 L/10 min		R = 150 L/10 min	
	In tank	End pipe	In tank	End pipe	In tank	End pipe	In tank	End pipe	In tank	End pipe	In tank	End pipe
0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
10	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.7 ± 0.0	2.0 ± 0.0
20	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.0	0.0 ± 0.0	1.0 ± 0.0	0.6 ± 0.0	0.8 ± 0.0	0.1 ± 0.0	0.9 ± 0.0	2.4 ± 0.6	2.3 ± 0.3
30	0.0 ± 0.0	0.0 ± 0.0	0.6 ± 0.0	1.4 ± 0.1	0.6 ± 0.0	1.4 ± 0.1	1.0 ± 0.0	1.8 ± 0.1	1.1 ± 0.0	1.6 ± 0.2	3.0 ± 0.8	3.1 ± 0.5
40	0.0 ± 0.0	1.2 ± 0.1	1.8 ± 0.1	2.1 ± 0.2	1.8 ± 0.2	2.1 ± 0.1	2.0 ± 0.1	2.7 ± 0.1	1.8 ± 0.0	2.0 ± 0.3	3.9 ± 0.5	4.4 ± 0.5
50	0.0 ± 0.0	1.3 ± 0.1	2.0 ± 0.2	2.9 ± 0.3	2.0 ± 0.5	2.9 ± 0.1	2.9 ± 0.2	3.7 ± 0.2	2.4 ± 0.2	3.0 ± 0.5	4.3 ± 0.9	4.6 ± 0.8
60	0.4 ± 0.0	1.7 ± 0.2	2.2 ± 0.3	3.4 ± 0.2	2.2 ± 0.4	3.4 ± 0.1	3.8 ± 0.2	4.1 ± 0.2	3.9 ± 0.2	3.5 ± 0.5	4.8 ± 0.8	5.3 ± 0.8
70	1.4 ± 0.1	1.9 ± 0.2	2.8 ± 0.4	3.9 ± 0.3	2.8 ± 0.5	3.9 ± 0.3	4.0 ± 0.3	4.2 ± 0.3	4.3 ± 0.5	4.0 ± 0.4	5.4 ± 0.8	5.7 ± 0.9
80	2.1 ± 0.3	2.8 ± 0.3	3.8 ± 0.3	4.4 ± 0.5	3.8 ± 0.6	4.4 ± 0.2	4.7 ± 0.5	4.8 ± 0.3	4.9 ± 0.5	4.8 ± 0.5	6.0 ± 0.9	6.2 ± 1.0
90	2.4 ± 0.2	3.1 ± 0.5	4.3 ± 0.5	4.5 ± 0.5	4.3 ± 0.6	4.5 ± 0.2	4.8 ± 0.5	5.1 ± 0.5	5.0 ± 0.4	5.0 ± 0.8	6.1 ± 1.0	6.4 ± 1.1
100	2.8 ± 0.3	3.6 ± 0.4	5.0 ± 0.5	6.1 ± 0.5	5.0 ± 0.7	6.1 ± 0.3	4.9 ± 0.5	5.5 ± 0.2	5.7 ± 0.5	5.8 ± 0.9	6.4 ± 0.9	6.7 ± 1.1

Table 3. Dissolved oxygen profile of tap water during ozonization.

Time (min)	R = 25 L/10 min		R = 50 L/10 min		R = 75 L/10 min		R = 100 L/10 min		R = 125 L/10 min		R = 150 L/10 min	
	In tank	End pipe	In tank	End pipe	In tank	End pipe	In tank	End pipe	In tank	End pipe	In tank	End pipe
0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
10	0.0 ± 0.0	0.6 ± 0.0	0.0 ± 0.0	1.1 ± 0.0	1.1 ± 0.0	1.1 ± 0.0	0.5 ± 0.0	1.7 ± 0.0	1.5 ± 0.0	2.2 ± 0.0	0.6 ± 0.0	1.7 ± 0.0
20	0.0 ± 0.0	2.5 ± 0.2	1.9 ± 0.0	2.1 ± 0.0	1.3 ± 0.0	2.1 ± 0.0	2.5 ± 0.0	3.3 ± 0.1	3.5 ± 0.1	3.7 ± 0.2	2.3 ± 0.1	3.5 ± 0.1
30	0.8 ± 0.0	3.5 ± 0.3	2.0 ± 0.1	3.4 ± 0.2	2.4 ± 0.1	3.4 ± 0.3	3.1 ± 0.5	4.5 ± 0.2	4.8 ± 0.2	5.4 ± 0.3	3.7 ± 0.2	4.0 ± 0.3
40	1.7 ± 0.1	3.8 ± 0.6	3.0 ± 0.2	4.1 ± 0.5	3.4 ± 0.2	4.1 ± 0.5	4.8 ± 0.5	5.2 ± 0.2	5.9 ± 0.5	6.0 ± 0.8	4.4 ± 0.3	4.5 ± 0.8
50	2.2 ± 0.5	4.5 ± 0.5	3.5 ± 0.2	5.1 ± 0.5	4.9 ± 0.5	5.1 ± 0.6	5.4 ± 0.5	5.8 ± 0.3	6.4 ± 0.5	6.2 ± 0.8	5.4 ± 0.8	6.0 ± 0.8
60	4.4 ± 0.5	5.0 ± 0.8	4.4 ± 0.3	5.6 ± 0.5	5.2 ± 0.6	5.6 ± 0.8	5.9 ± 0.4	6.7 ± 0.4	6.7 ± 0.9	7.0 ± 0.9	6.5 ± 0.9	6.4 ± 0.9
70	4.9 ± 0.5	5.8 ± 0.7	5.6 ± 0.3	5.8 ± 0.6	5.7 ± 0.5	5.8 ± 0.9	6.5 ± 0.3	6.8 ± 0.5	6.9 ± 0.9	7.1 ± 0.9	6.7 ± 1.0	7.0 ± 0.7
80	5.0 ± 0.5	6.0 ± 0.5	5.7 ± 0.5	6.4 ± 0.5	6.5 ± 0.4	6.4 ± 1.0	7.4 ± 0.8	7.4 ± 0.6	7.2 ± 1.0	7.4 ± 1.0	7.0 ± 1.1	7.4 ± 0.7
90	5.3 ± 0.4	6.2 ± 0.5	6.4 ± 0.5	6.5 ± 0.8	6.7 ± 0.5	6.5 ± 0.8	7.6 ± 0.8	7.6 ± 0.6	7.6 ± 1.0	7.6 ± 1.1	7.2 ± 1.1	7.6 ± 0.9
100	5.9 ± 0.2	6.4 ± 0.6	6.7 ± 0.4	6.7 ± 1.0	7.0 ± 0.6	6.7 ± 1.0	7.8 ± 0.8	7.8 ± 0.8	7.8 ± 1.1	7.8 ± 1.2	7.8 ± 0.8	7.8 ± 1.0

increased up to 6.7 mg/L within 100 min at a water flow rate of 15 L/ min. This might be the effect of the mixing performance (Metcalf and Eddy Inc., 2004). Under the highest water flow rate of 15 L/min, the injected air was easily-mixed with the water. Thus, the DO increased more rapidly when compared with the conventional floating aerator (low speed type) (Metcalf and Eddy Inc., 2004).

Dissolved oxygen profile of tap water during ozonization

The experiment was carried out at the laboratory

Table 4. Dissolved oxygen profile of the domestic wastewater during aeration.

Time (min)	DO R = 100 L/10 min	
	In tank	End pipe
0	0.0 ± 0.0	0.0 ± 0.0
20	1.1 ± 0.0	1.8 ± 0.0
40	2.0 ± 0.3	2.8 ± 0.2
60	3.8 ± 0.2	4.2 ± 0.2
80	4.2 ± 0.5	5.1 ± 0.2
100	4.9 ± 0.5	5.8 ± 0.2

Table 5. Dissolved oxygen profile of the domestic wastewater during ozonization.

Time (min)	DO R = 100 L/10 min	
	In tank	End pipe
0	0.0 ± 0.0	0.0 ± 0.0
20	2.8 ± 0.1	3.6 ± 0.0
40	4.9 ± 0.5	5.8 ± 0.5
60	6.2 ± 0.5	7.1 ± 0.5
80	7.3 ± 0.5	7.5 ± 0.6
100	8.0 ± 0.5	8.0 ± 0.8

scale using oxygen supplier with ozone. The results and is shown in Table 3. The results were similar to those with aeration using dissolved oxygen. DO of the water was increased with the increase of reaction time and water flow rate. The DO was increased up to 7.8 mg/L within 100 min under water flow rate of 10 L/min under ozonization. It was higher than that obtained with aeration. It could be suggested that ozone is the strongly oxidizing agent and more easily dissolved in the water (Sheng and Wang, 2003; Zhou and Smith, 2000). Thus, the DO with ozonation was higher than with aeration under the same reaction time or water flow rate (Metcalf and Eddy Inc., 2004; Cramarosss et al., 1978).

Dissolved oxygen and organic matter profiles of the domestic wastewater

The oxygen supply apparatus was used with the domestic wastewater under water flow rate of 10 L/min. The results are shown in Tables 4 and 5. The dissolved oxygen of the domestic wastewater increased with increase of reaction time. The DO of the domestic wastewater increased up to 5.8 mg/L with the oxygen supply apparatus with aeration while it was up to 8.0 mg/L within 100 min for ozonization. The results suggest that the oxygen supply apparatus with both aeration and ozonization could be used for supplying the oxygen to the system (Metcalf and Eddy Inc., 2004; Sheng and Wang, 2003; Zhou and Smith, 2000; Steve Carr and Rodger Baird, 2000; Bell and Kwong, 1972). The DO of the system was increased up to higher than 4 mg/L. However, for the aerobic treatment systems such as activated sludge system, the dissolved oxygen of the system has to be controlled between 1.0 - 2.0 mg/L (Metcalf and Eddy Inc., 2004; Sirianuntapiboon and Nimnu, 1999; Kornmuller et al., 2000). For such application, the system could be operated for only 40 and 20 min with the designed apparatus using aeration and ozonation for increasing the DO up to 2.0 mg/L. This might be the benefit of the designed apparatus. Moreover, the oxygen supply apparatus with ozonation showed better performance than that with aeration as indicated by the shorter retention for increasing the DO up to 2.0 mg/L. The oxygen supply apparatus with ozonization could also reduce organic matter of the wastewater as COD and BOD_5. This might be the other advantage of the system. The BOD_5 and COD of the wastewater were reduced by 39.09 and 22.03% within 100 min of operation. This might be the effect of the oxidizing power of the ozone (Sheng and Wang, 2003; Steve Carr and Rodger Baird, 2000). Thus, if the wastewater contained high BOD_5 and low DO, this apparatus with ozonation might be suitable to increase DO and reduce BOD_5 concentration (Metcalf and Eddy Inc., 2004; Sheng and Wang, 2003; Nishijima et al., 2003; Kornmuller et al., 2000).

Dissolved oxygen and organic matter profile for shrimp farm water

The oxygen supply apparatus was used with the shrimp farm water at a water flow rate of 10 L/min. The results are shown in Tables 7, 8 and 9. The dissolved oxygen of the water was up from 2.5 ± 0.1 mg/L to 4.3 ± 0.5 mg/L within 40 min by oxygen supply apparatus with aeration, while it was up to 4.2 ± 0.2 mg/L for ozonization. The apparatus with ozonation showed more effect than that with aeration on the oxygen supply. This might be the property of ozone which is a strong oxidizing agent (Blair and Hittington, 1975; Cramarosss et al., 1978; Bell and Kwong, 1972; Francis Evans, 1972). Moreover, the system with ozonization showed the additional advantage of the reduction of organic matter in the water as COD and BOD_5. The COD and BOD_5 were reduced to 41.18 and 52.17%, respectively. This might be a big advantage of the apparatus, because it could be applied instead of the normal aeration system such as surface aerator or air jet system (Metcalf and Eddy Inc., 2004; Zhou and Smith, 2000; Carr and Baird, 2000). It could increase the DO of the water up to 4 mg/L within 20 min and reduce the organic matter in the water at the same time. This apparatus might be suitable for supplying oxygen at the shrimp farm because the DO level need to be maintained at adequate level at all time to prevent shrimp death.

Analysis of K_{La}, oxygen consumption and oxygen transfer of the apparatus

Equation for oxygen transfer during oxygenation (Metcalf and Eddy Inc., 2004)

Oxygen consumption water: $dC/dt = K_La\ (C_s - C_t)$

Table 6. COD and BOD_5 removal efficiencies of domestic wastewater after ozonization uner water flow rate of 10 L/min.

Reaction time (min)	COD		BOD_5	
	Effluent (mg/L)	% removal	Effluent (mg/L)	% removal
0	110 ± 7	-	119 ± 9	-
20	96 ± 5	12.7 ± 1.1	105 ± 8	11.8 ± 1.2
40	80 ± 5	27.3 ± 1.3	79 ± 7	36.4 ± 4.2
60	74 ± 5	32.7 ± 1.5	72 ± 7	39.5 ± 4.0
80	60 ± 5	45.5 ± 2.3	66 ± 5	44.5 ± 3.0
100	54 ± 4	50.9 ± 3.4	59 ± 5	54.6 ± 3.5

Table 7. Dissolved oxygen profile of the shrimp farm water during aeration.

Time (min)	DO R = 100 L/10 min	
	In tank	End pipe
0	2.5 ± 0.1	2.5 ± 0.1
20	3.2 ± 0.2	3.8 ± 0.2
40	4.3 ± 0.5	4.9 ± 0.5
60	5.1 ± 0.7	5.4 ± 0.5
80	6.1 ± 0.7	6.3 ± 0.5
100	6.4 ± 0.7	6.7 ± 0.5

Table 8. Dissolved oxygen profile of the shrimp farm water during ozonization.

Time (min)	DO R = 100 L/10 min	
	In tank	End pipe
0	2.5 ± 0.1	2.5 ± 0.0
20	4.2 ± 0.2	5.1 ± 0.5
40	6.4 ± 0.3	6.9 ± 0.5
60	7.2 ± 0.5	7.6 ± 0.6
80	8.0 ± 0.5	8.0 ± 0.5
100	8.0 ± 0.9	8.0 ± 0.8

C_s = Concentration in equilibrium with gas as given by Henry's law Saturated oxygen concentration in water (mg/L); C_t = concentration of oxygen in liquid bulk phase at time t, mg/L; C = concentration of oxygen in solution; and K_La = oxygen consumption coefficient (overall liquid film coefficient), t^{-1}.

To determine the K_La according to the equation of Metcalf and Eddy (2004)

$$K_La = 2.303 \times \text{slope} \times 60$$

According to Figure 3, the slope is 0.058.

Then, $K_La = 2.303 \times 0.058 \times 60$
$= 8.014\ h^{-1}$

To determine the oxygen supply capacity of the equipment (oxygenation capacity: OC)

V = Volume of the water, 200 L

$$OC = K_La C_s V \quad mgO_2/h$$

Then, OC = 8.014 × 8.84×200 mg-O_2/h
= 14168.752 mg O_2/h

To determine the oxygen transfer rate (R_0)

$$R_0 = \frac{OC}{P}$$

P = energy consumption = VI.

In the experiment, V was controlled = 200 volts
I was controlled = 0.05 Ampere

Then, P = 0.010 kW

$$R_0 = \frac{14168.752}{0.010} = 1{,}416{,}875.20 \text{ mg } O_2/\text{kWh}$$
$$= 1{,}417 \text{ kg } O_2/\text{kW h}$$

To determine the oxygen transfer efficiency

$$E = \frac{OC}{A} \times 100$$

A = Amount of air or oxygen supply at STP, mg O_2/h

$$= \frac{14{,}168.752 \times 100}{(0.008\,m^3/\text{min} \times 60\ \text{min/h})(282{,}900\text{mg } O_2/m^3)}$$

= 10.43%

Equation form the oxygen transfer of the ozonation

Oxygen consumption water: $dC/dT = K_La\,(C_s - C_t)$

C_s = Concentration in equilibrium with gas as given by

Table 9. COD and BOD_5 removal efficiencies from shrimp farm water after ozonization at water flow rate of 10 L/min.

Reaction time (min)	COD		BOD_5	
	Effluent (mg/L)	% removal	Effluent (mg/L)	% removal
0	119 ± 7	-	138 ± 7	-
20	98 ± 7	17.6 ± 0.9	99 ± 7	28.3 ± 2.0
40	96 ± 7	19.3 ± 1.2	79 ± 7	42.8 ± 2.1
60	84 ± 7	29.4 ± 1.4	79 ± 8	42.8 ± 2.8
80	72 ± 4	39.5 ± 2.0	59 ± 4	57.3 ± 2.5
100	51 ± 4	57.1 ± 3.0	26 ± 4	81.2 ± 1.2

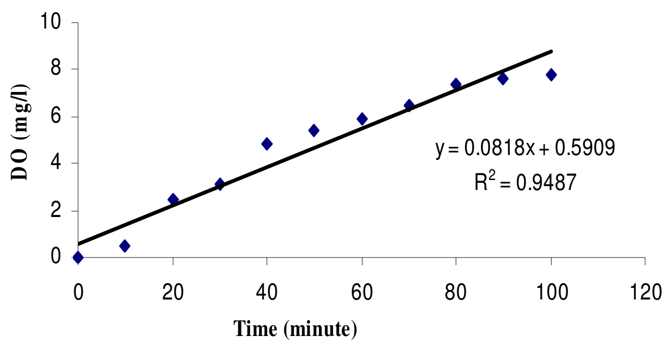

Figure 3. Relationship between DO and reaction time of the ozonization in tap water.

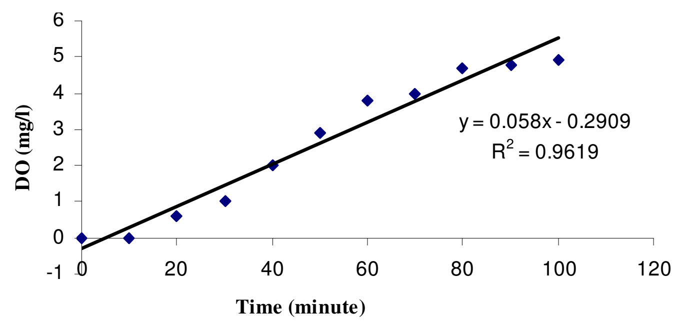

Figure 4. Relationship between DO and reaction time of aeration in tap water.

Henry's law saturated oxygen in water (mg/l); C_t = concentration in liquid bulk phase at time t, mg/L; C = concentration of oxygen in solution; and K_La = oxygen consumption coefficient (overall liquid film coefficient).

To determine the K_La according to the equation of Metcalf and Eddy (2004)

$$K_La = 2.303 \times \text{slope} \times 60$$

According to Figure 4 he slope is 0.0818

Then, $K_La = 2.303 \times 0.0818 \times 60$
$= 11.303\ h^{-1}$

To determine the oxygen supply capacity of the equipment (oxygenation capacity: OC)

$$OC = K_LaC_sV \qquad mg\ O_2/h$$

V = Volume of the water, 200 L

Then, OC = $11.303 \times 8.84 \times 200$ mg O_2/h
= 19,983.704 mg O_2/h

To determine the oxygen transfer rate (R_0)

$$R_0 = \frac{OC}{P}$$

P = energy consumption = VI

In the experiment, V was controlled = 200 volts
I was controlled = 0.054 Ampere

Then, P = 200 X 0.054 = 0.011 kW

$R_0 = \frac{19983.704}{0.012}$ = 1,816,700.364 mg O_2/kWh
= 1816.7 kg-O_2/kW h

To determine the oxygen transfer efficiency

$$E = \frac{OC}{A} \times 100$$

A = Amount of ozone supply at STP, mg O_2/h

$$= \frac{19983.704 \times 100}{(0.008\ m^3/\ min \times 60\ min/h)\ (282900\ mg\ O_2/m^3)}$$

= 14.72%

The above results (Table 10) confirm that both types of

Table 10. Specific parameters of oxygen supply apparatus.

Parameter	Apparatus	
	Ozonization	Aeration
K_La	11.303	8.014
OC	19,983.704 mg O_2/h	14,168.752 mg O_2/h
RO	1.1816 kgO_2/kW-h	1.417 kgO_2/kW-h
E	14.72%	10.43%

dissolved oxygen supply equipment are more suitable than the conventional floating aeration (low speed type) (Metcalf and Eddy Inc., 2004; Sheng and Wang, 2003; Koch et al., 2002; Zhou and Smith, 2000; Carr and Baird, 2000; Kornmuller et al., 2000; Carr and Baird, 2000) due to the higher oxygen transfer rate. Also, the dissolved oxygen supply equipment with ozone might be more suitable than the conventional aerator because it not only supplies the DO to the system, but also reduces the organic content in the water. Thus, the system might be suitable to apply in the shrimp farms for increasing the dissolved oxygen in the water and reducing the organic matter content (COD or BOD_5)

Conclusion

The designed oxygen supplier could be used for supply both ozone and air to the water under high pressure to increase DO. K_La of the system with air and ozone were 0.0264 and 0.4900, respectively. Also the oxygen transfer coefficients of the system with ozone and air were 73.58 and 52.17%, respectively. The apparatus could be applied to treat both domestic wastewater and shrimp farm water. The system with air could increase the dissolved oxygen of the domestic wastewater from 2.5 to 6.4 mg/L within 1.6 h. But, the system with ozone could increase the dissolved oxygen of domestic wastewater from 2.5 to 8.0 mg/L within 1.6 h. Also, the system with ozone gave the addition advantage of reducing COD and BOD_5 during treatment. The COD and BOD of the wastewater were reduced by about 82.14 and 57.50% within 1.6 h. The system also showed the same pattern for water from the shrimp farm. The dissolve oxygen of the domestic wastewater and water of the shrimp farm was increased up to 8.0 mg/L when treated with the system using ozone. Also, the BOD_5 and COD were reduced by 50% within 1.6 h operation.

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REFERENCES

APHA, AWWA, WPCF (1998). Standard Method for the Examination of Water and Wastewater, 20th Ed. United Book Press, Ind., Maryland, USA.

Bell AT, Kwong K (1972). Dissociation of oxygen in a radiofrequency electric discharge, A. I. Ch. E. J. 18: 990-998

Benefield L, dkins F, Weand BL (1982). Process Chemistry for Water and Wastewater Treatment, New Jersey, Prentice-Hall, pp. 365-404.

Blair DTA, Hittington HW (1975). Ionization and breakdown in oxygen, J. Phys. D. Appl. Phys. 8: 405-415.

Carucci A, Chiavola A, Majone M, Rolle E (1999). Treatment of tannery wastewater in a sequencing batch reactor, Water Sci. Technol. 35: 253-259.

Chu W (2001). Dye Removal from textile dye wastewater using recycled alum sludge. Water Res. 35(13): 3147-3152.

Cramarosss F, Agostino DR, Molinari E (1978). Kinetics of oxygen atom production in RF discharges at moderate pressure, Beitr. Plasmaphyo. 18: 301-315.

Eliasson B, Kogelschatz U (1987). Ozone build up from atomic oxygen–possibilities and limitations. Proc. 5th Int. symp. On plasma chemistry, Edinburgh, pp. 415-420.

Francis Evans IIIL (1972). Ozone in Water and Wastewater Treatment. Ann arbor Science Pub. Inc., Michigan, pp. 50-185.

Gehr R, Wagner M, Veerasubramanian P, Payment P (2003). Disinfection Efficiency of Peracetic Acid, UV and Ozone After Enhanced Primary Treatment of Municipal Wastewater, Water Res. 37: 4573-4586.

Helmer C, Kunst S (1998). Simultaneous nitrification / denitrification in aerobic bio-film system, Water Sci. Technol. 37(4-5): 183-187.

Koch M, Yediler A, Lienert D, Insel G, Kettrup A (2002). Ozonation of Hydrolyzed Azo Dye Reactive Yellow 84 (CI), Chemosphere 46: 109-113.

Kornmuller A, Karcher S, Jekel M (2000). Cucurbituril for Water Treatment. Part II: Ozonation and Oxidative Regeneration of Cucurbituril. Water Res. 35(14): 3317-3324.

Metcalf, Eddy Inc (2004). Wastewater engineering, Treatment and reuse, International Edition, McGrew-Hill Companies, Inc, New York, pp. 545-1026.

Neralla S, Wever RW, Lesikar BJ, Persyn R (2000). Improvement of domestic wastewater quality by subsurface flow constructed wetlands, J. Bioresour. Technol. 75: 19-25.

Nishijima W, Mukaidani TF, Okada M (2003). DOC Removal by Multi-Stage Ozonation-Biological Treatment, Water Res. 37: 150-154.

SAS Institute (1996). The SAS System for Windows, Version 6.12, SAS Inst., Cary, NC.

Sheng HL, Wang CH (2003). Industrial Wastewater Treatment in a New Gas Induced Ozone Reactor, J. Hazard. Mater. 98: 295-309.

Sirianuntapiboon S, Nimnu N (1999). Management of water consumption and wastewater of seafood processing industries in Thailand, Suranaree J. Sci. Tech. 6(3): 158-167.

Steve CA, Rodger BB (2000), Mineralizatioin as a Mechanism for TOC Removal: Study of Ozone/Ozone-Peroxide Oxidation Using FT-IR. Water Res. 34(16): 4036-4048.

Tritt WP (1992), The anaerobic treatment of slaughterhouse wastewater in fixed-bed reactor, J. Bioresour. Technol. 41: 201-207.

Zhou H, Smith DW (2000). Ozone mass transfer in water and wastewater treatment: experimental observations using a 2D laser particle dynamics analyzer, Water Res. 34(3): 909-921.