

Dissolved oxygen control system for upgrading conventional activated sludge process for seafood industrial wastewater in Southern Thailand

P. Chevakidagarn^{1,*}, A. P. Annachhatre²,
U. Puetpaiboon³ and T. Koottatep²

¹ Faculty of Environmental Management, Prince of Songkla University,
Hat Yai, Songkhla, Thailand

² Environmental Engineering and Management Program,
School of Environment, Resources and development,
Asian Institute of Technology, Klong Luang, Pathumthani, Thailand

³ Department of Civil Engineering, Faculty of Engineering,
Prince of Songkla University, Hat Yai, Songkhla, Thailand

Abstract: The objective of this study is to upgrade the operation of conventional activated sludge treatment plants for the purpose of saving aeration energy and at the same time providing better utilization of existing plant capacity for nutrient removal without major investment. In this study, pilot-scale experiments of the single stage activated sludge process (ASP), as operated in existing ASP in southern Thailand by using wastewater from seafood industry, was conducted under conditions of simultaneous nitrification-denitrification. However, achieving these conditions required appropriate dissolved oxygen

(DO) concentrations. An aeration control system is needed. This study investigated the possibility of using the oxidation-reduction potential (ORP) value as the parameter for controlling aeration in the simultaneous nitrification-denitrification system. The aeration control system was operated to control the ORP values varied between -300 to 100 mV. The results in this study indicated that the simultaneous nitrification-denitrification process might be suitable for improving nitrogen removal in the seafood industry. Total nitrogen removal could reach up to 82 percent at controlled ORP of 50 mV. Results also showed that the volume of air supplied per mg of TN removed per minute was least when ORP was controlled at 0 mV (0.1 mL of air supplied per mg of removed TN per minute). Less aeration energy consumption was not observed for a lower ORP setting. However, this result could not be definitely concluded for every type of wastewater.

Keywords: Activated sludge, Aeration control, Oxidation-reduction potential, Simultaneous nitrification-denitrification.

1. INTRODUCTION

In the southern part of Thailand, the industry is based mainly on seafood products. The wastewater from these factories contains high organic carbon and nutrients. Nowadays, the Activated Sludge Process (ASP) has been applied to these factories in order to reduce the land requirement for treatment plants and to increase the treatability of the wastewater. However, it appears that only carbon

and solids removal (in terms of BOD₅ and suspended solids) are the major function of the ASPs in this area. Excess nutrients from the treatment are a major source of pollution, which bring eutrophication problems to the Songkhla Lake basin.

Upgrading of the existing single stage activated sludge treatment plants in Thailand might be possible by introducing the simultaneous nitrification-denitrification process to them [1]. The process might allow both nitrification and denitrification to occur simultaneously in the same tank. However, to achieve a high nitrogen removal capacity in this process, an appropriate DO control system is required.

The Oxidation-Reduction Potential (ORP) value has been widely used as an efficient parameter for optimizing DO control. However, relatively little ORP data are available for the simultaneous, non-alternating, nitrification-denitrification process. In the past, most ORP value applications in order to control the aeration were applied for sequencing batch reactor (SBR) systems separately for nitrification and denitrification reaction [2] or to use ORP value to control the rate of denitrification reaction in anoxic tank [3]. Some researchers [4-7] successfully used SBR system to increase the efficiency of the nitrogen removal in the activated sludge system. Goronszy [8] proposed the complete nitrification and complete denitrification pathways take place in the same basin with nitrification taking place external to the activated sludge flocs and denitrification taking place within the interior of the flocs. Bertanza [9] applied the ASP operated under DO less than 0.6 mg/L in order to increase the efficiency of extended aeration activated sludge process for simultaneous nitrification

and denitrification. Collivignarelli and Bertanza [10] proposed to control the aeration by controlling the ORP value to be constant for the simultaneous nitrification-denitrification activated sludge system. However, their research was applied with the community wastewater having the low concentration and the sludge loading rate only 0.1 kg/day. The DO value could be controlled at a low range of only 0.3-0.6 mg/L.

Therefore, it is the objective of this study to upgrade the nutrient removal capacity of existing single-stage ASPs in the seafood industry having high concentration of influent, without major construction, by applying the ORP as an appropriate aeration control parameter for simultaneous nitrification-denitrification. Pilot-scale experiments are required to identify a strategy suitable for applying to the local seafood industrial wastewater.

It was noted that, the influent wastewater from the representative factory contained high concentration of nitrogen. The ratio of BOD:TKN:TP was not equal to 100:5:1. The influent nitrogen concentrations were normally much higher. Thus, the treatment system requires an additional nitrogen removal process.

2. METHODOLOGY

2.1 Scope of experiment

The complete-mixed activated sludge process fed with wastewater from a representative frozen seafood industry was investigated in the pilot-scale experiments. The experiments were conducted with various

operational conditions, in 5 periods. The experimental conditions were simultaneous nitrification-denitrification without temporal or spatial alternating anoxic/oxic conditions.

A pilot-scale reactor with about a 75 liter aeration capacity was used for the experiments. The temperature, ORP, pH, and the oxygen concentration were recorded every 5 to 10 minutes by online-analyzers (SensonLyt[®]700 IQ, WTW Co., Ltd.). An air pump in the experiments was automatically controlled based on the ORP values. The volume of surplus sludge was controlled to maintain solids content of 3.5-4.0 g/l. The sludge retention time (SRT) was not considered because in the actual situation, it is very rare to find local treatment plants where surplus sludge is discharged continuously. Most of the operators are concerned only with the SV_{30} values. The experiments were operated at a hydraulic retention time of 36 hours. The ORP values were observed and controlled by means of a real-time control system to achieve high removal capacities of carbon and nutrient, in terms of COD and total nitrogen, respectively. Table 1 shows the control factors in each phase of experiments.

Table 1. Control factors in the experiments.

Control factor	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
HRT (hrs)	36	36	36	36	36
Return sludge (%)	100	100	100	100	100
ORP (mV)	-300	-250	0	50	100

The main objective of this study is to determine the optimal aeration control system, which would make nitrogen concentration in

the effluent minimal. Therefore, control of the volume of air supplied is very important. The aeration rate could vary from 1 to 75 L/min, but, the system required at least 10 L/min for adequate mixing. The actual situation was continuously recorded at about 5-15 minute time intervals, with the help of computer programming.

After the steady state conditions were achieved in each phase, effluent from the settling tank was daily sampled for ten days. Analysis of wastewater characteristics from each sample was performed. All chemical tests in the laboratory were analyzed according to Standard Methods for the Examination of Water and Wastewater [11].

2.2 Representative wastewater treatment plant from frozen seafood industry

This wastewater treatment plant is for the frozen seafood industry (shrimp processing). Its wastewater concentration has a high concentration of nitrogen. The treatment plant is a complete ASP designed for both carbon and nitrogen removal. The facility consists of an Upflow Anaerobic Sludge Blanket (UASB), a nitrification tank, a denitrification tank and a settling tank and a post-treatment constructed wetland, as shown in Fig. 1. Plant capacity is currently 1,000 – 1,400 kgBOD₅/d.

This treatment plant was equipped with nitrogen removal units. However, the operator was unable to control anoxic condition in the denitrification tank. Because of the construction of both tanks, there was not absolute separation between the nitrification and denitrification tanks. Molecular oxygen is present in the denitrification

tank (observed by onsite DO measurement) reducing denitrification. The total nitrogen removal averaged 83.64 ± 6.32 percent. Nitrogen in the form of nitrate-nitrogen was discharged from the ASP (the average effluent nitrate-nitrogen concentration was at 17.9 ± 12.4 mg/L [12]). Therefore, the constructed wetland is required as post-treatment for this representative wastewater treatment plant, the capacities of the ASP could not be maximized.

However, for this study, samples were obtained only from the equalization tank once a week, during July 2005 and February 2006. The average COD and TKN concentrations were 1771.7 ± 860.8 and 173.3 ± 38.8 mg/L, respectively.

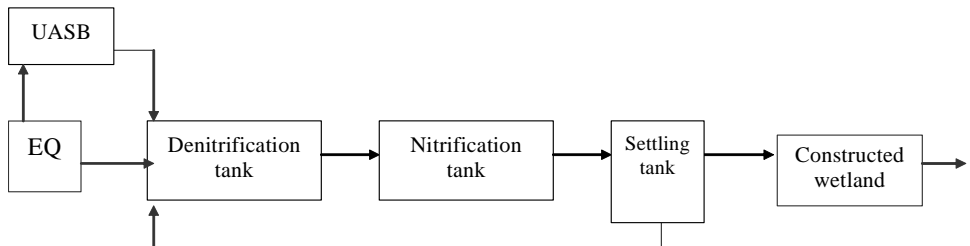


Figure 1. Schematic diagram of the representative treatment plant.

3. RESULTS AND DISCUSSION

3.1 Results of removal efficiencies versus the various controlled ORP values

In this study, the total removal efficiencies of COD, total nitrogen (TN) and total suspended solids (TSS) are defined by the following equation. The average values and standard deviation for each controlled ORP values are shown in Table 2.

$$R = \frac{(\text{Influent concentration} - \text{Effluent concentration})}{\text{Influent concentration}} \times 100\%$$

where R = Total removal efficiency
and TN = $\text{TKN} + \text{NO}_2^- \text{-N} + \text{NO}_3^- \text{-N}$

The result showed that the single aeration tank permitted both carbon and nitrogen removals. With controlled ORP at -300 mV to 100 mV, total COD removal varied from 82 to 98 percent. Total nitrogen removal varied from 14 to 82 percent. Suspended solids removal varied from 84 to 95 percent. Table 3 concludes the result of total nitrogen removal in term of conversion rate (kg TN per m³ of reactor per day). For the total nitrogen removed per volume, the best efficiency rate was at controlled ORP of 0 mV.

The DO concentrations in this study were fluctuated between 1.0 – 3.0 mg/L. However, the results of nitrogen removal showed that both nitrification and denitrification processes took place in the same aeration tank. This is in contradiction to Eckenfelder [13] who presented that the denitrification rate decreases linearly to zero when the DO concentration reaches 1.0 mg/l. It might be explained with the concept of different layer in the activated sludge floc. Normally, the biofilm particle size in the ASP plant is in the range 10–110 μm [14]. Pochana [15] reported that the biofilm floc of 200 μm size and above will have an anoxic microniches in the internal part of the thick flocs. In this study, the sample was drawn from aeration tank for measuring floc size, from controlled ORP at 100 mV. Floc size distribution was measured in triplicate with a Laser Particle size analyzer (COULTER LS 230).

The floc size varied from 2.423 – 1377 μm , with mean = 75.95 μm , S.D. = 87.09 μm .

Table 2. The average values and standard deviation for each controlled ORP values.

Controlled ORP	COD (mg/L)			SS (mg/L)			TN (mg/L)		
	Influent	Effluent	% Removal	Influent	Effluent	% Removal	Influent	Effluent	% Removal
-300 mV	2945	531.3 \pm 293.9	82 \pm 10	365	42.1 \pm 10.0	88 \pm 3	211	188.8 \pm 9.8	14 \pm 5
-250 mV	868	153.3 \pm 97.3	82 \pm 11	255	36.1 \pm 13.8	86 \pm 5	193	157.3 \pm 29.0	19 \pm 5
0 mV	2457 \pm 428	218.0 \pm 43.2	91 \pm 1.4	150 \pm 13	8.0 \pm 5.8	95 \pm 3	160 \pm 7	30.0 \pm 2.5	81 \pm 2
50 mV	2508 \pm 765	40.4 \pm 10.6	98 \pm 0.8	237.2 \pm 37.6	35.8 \pm 11.9	85 \pm 7	140.7 \pm 1.6	24.8 \pm 2.3	82.3 \pm 1.6
100 mV	1320 \pm 268	27.0 \pm 2.7	98 \pm 0.5	46 \pm 27	7.1 \pm 3.6	84 \pm 7	74 \pm 22	49.5 \pm 8.7	30 \pm 17

Table 3. The overall of total nitrogen removal capacities from the pilot scale experiments, under various controlled ORP values.

Parameters	at -300 mV	at -250 mV	at 0 mV	at 50 mV	at 100 mV
Total nitrogen (influent), mg/L	211.0	193.0	160.0	140.7	74.0
Total nitrogen (effluent), mg/L	181.8	157.3	30.0	24.8	49.5
Total nitrogen (removed), mg/L	29.2	35.7	130.0	115.9	24.5
Loading rate, kg TN/d	0.011	0.010	0.008	0.007	0.004
Conversion rate, kg TN/m ³ reactor/d	0.019	0.024	0.087	0.077	0.016

3.2 Aeration energy consumption

From the above results, it can be concluded that the single aeration tank could permit high rates of simultaneous nitrification-denitrification. Total nitrogen removal reached up to 82 percent when ORP was controlled at 50 mV. The simultaneous nitrification-

denitrification process also has the benefit of reducing aeration energy consumption. In the experiment of period 1 to 5, the volume of air supplied to the aeration tank was observed to calculate the amount of aeration energy consumption (see Fig. 2). Volumes of air supplied to the aeration tank with controlled ORP at -300, -250, 0, 50, and 100 mV were 16.1, 10.7, 14.9, 17.8, and 14.5 L/min, respectively.

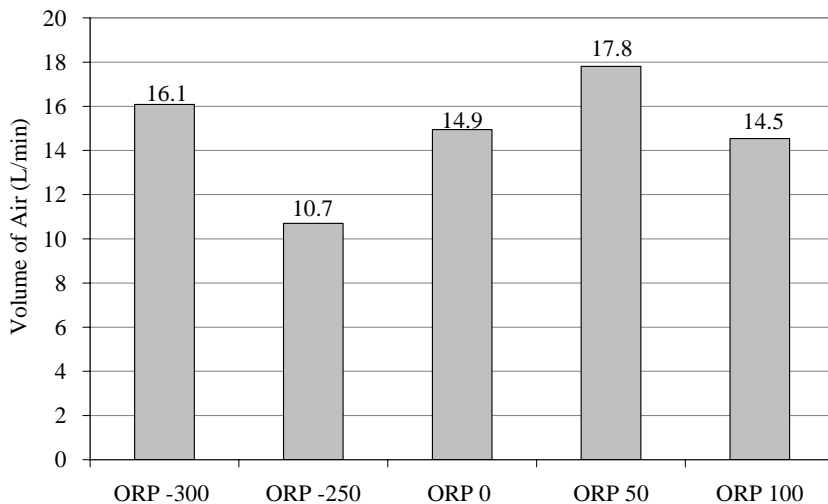


Figure 2. The volume of air supplied to the ASP operated at various ORP values.

However, the results in Fig. 2 could not show the significant effect of various controlled ORP values, because each period of experiments was fed with different influent loading. Therefore, volumes of air supplied to the aeration tank with controlled ORP at -300, -250, 0, 50, and 100 mV were observed and calculated in term of mL of air supplied per mg of removed total nitrogen per minute as

shown in Fig. 3.

Volumes of air supplied to the single aeration tank operated in this study were between 0.1 and 0.6 mL of air supplied per mg of TN removed from process per minute. It is noticeable that less aeration energy consumption is not necessarily dependent on low ORP setting. The results show that the volume of air supplied per mg of TN per minute at ORP 0 mV were lower than those at -300, or 100 mV.

Since the aeration energy is the main part of energy consumption from the whole system of the ASP treatment plants, it can be assumed that the less volume of air supplied to the aeration tank implies less energy consumption.

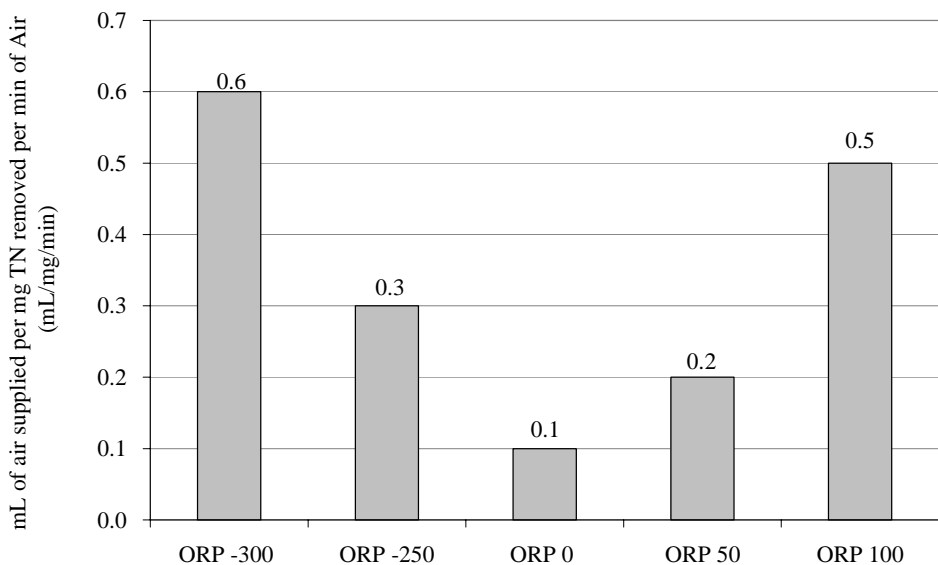


Figure 3. The volume of air supplied per mg of TN removed per minute under various controlled ORP values.

4. CONCLUSION

The results in this study indicate that simultaneous nitrification-denitrification process might be suitable for upgrading single-stage ASP for nitrogen removal in the seafood industry. The conclusions could be drawn as follows:

1. The proposed process could prevent the escaping of the sludge blanket caused by the rising sludge problem in the final settling tank.

2. The ORP was applied as the main parameter for oxygen control in this study. The observed results showed that the ORP was greatly affected by the change in air supply. This phenomenon confirms that the ORP can be applied for aeration control.

3. Results show that the volume of air supplied per mg of TN removed per minute was least when ORP was controlled at 0 mV (0.1 mL of air supplied per mg of removed TN per minute). Aeration energy consumption did not decrease with decreasing ORP. However, this result could not be definitely concluded for every type of wastewater.

Further research required:

1. This proposed process should be tested for other types of wastewater.

2. Further laboratory scale experiment is required for investigation the effect of floc size.

3. Further study about the economic evaluation of this process is required.

5. ACKNOWLEDGMENTS

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