

Dissolved Oxygen Control System for Upgrading Conventional Activated Sludge Process for Latex Rubber Industrial Wastewater: Removal Efficiencies from Simultaneous Nitrification-Denitrification

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ABSTRACT

In this study, pilot-scale experiments on the single-stage activated sludge process (ASP), as operating in existing ASP in southern Thailand by using wastewater from para rubber industry, was investigated under conditions of simultaneous nitrification-denitrification. However, to achieve these conditions required appropriate dissolved oxygen (DO) concentrations, thus, an aeration control system is needed. This study investigated the possibility of using the oxidation-reduction potential (ORP) value as the parameter for aerobic control system in the simultaneous nitrification-denitrification system. The aeration control system was functioned by controlled ORP values, varying from -325 to -150 mV. The results of this study indicated that the simultaneous nitrification-denitrification process might be suitable for improving nitrogen removal in the para rubber industry. Total nitrogen (TN) removal could reach up to 55 percent at controlled ORP of -150 mV. Results also showed that the volume of air supplied per mg of TN removed per minute was least when ORP was controlled at -150 mV (0.55 mL of air supplied per mg of removed TN per minute). This work also showed the requirement of equalization tank if improving capacity of existing treatment plant is required.

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

INTRODUCTION

In the southern part of Thailand, industry is based mainly on latex rubber. The wastewater from these factories contains high organic carbon and ammonia. Nowadays, the Activated Sludge Process (ASP) has been applied to these factories in order to reduce the land requirement for treatment plant and to avoid

odor problem. However, it appears that only carbon and solid removal (in terms of BOD₅ and suspended solids) is 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 (Chevakidagarn et al., 2001a, 2001b). 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 was widely introduced 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 application in order to control the aeration applied for sequencing batch reactor (SBR) system occurred separately between nitrification and denitrification reaction, to use the knee point of ORP profile (Sasaki et al., 1996) or to use ORP value to control the rate of denitrification reaction in anoxic tank (Isaacs et al., 1998). Some researchers (Munch et al., 1996; Pochana and Keller, 1999; Bernal-Martinez et al., 2000; Dangcong et al., 2000) persisted in the successful SBR system, used to increase the efficiency of the nitrogen removal in the activated sludge system. Goronszy (1992) proposed that nitrification and denitrification reaction could occur. The perfect reaction in the same aeration tank also occurs in the same time by referring to the principle of the difference between activated sludge floc-levels. Bertanza (1997) applied the ASP operating under DO less than 0.6 mg/L in order to increase an efficiency of an extended aeration activated sludge process referring to the principle of nitrification and denitrification reaction simultaneously. Collivignarelli and Bertanza (1999) proposed to control the aeration by the ORP value controlling 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. However it could control the DO value to remain only 0.3-0.6 mg/L. Ndegwa et al., (2007) reported that the ORP was the good parameter for aeration control system, better than the DO concentration when system needed to be controlled at low DO concentrations.

Chevakidagarn et al., (2006) reported the first phase of the pilot-scale experiments fed with wastewater from latex rubber industry. The model was operated as a single-stage activated sludge process with simultaneous nitrification-denitrification. Their work showed that the Dissolved Oxygen (DO) sensor could not be a suitable parameter for aeration control system in such a high organic concentrations. Their work also suggested to investigate an appropriate ORP value which would be suitable for the high organic concentrations. Wanseng et al., (2006) presented the results of comparing the removal efficiencies when using controlled ORP at -500 and -325 mV. With the same model and source of wastewater, the results showed that there was simultaneous nitrification-denitrification in both controlled values. However, at -500 mV, the COD and Total Nitrogen (TN) removal

efficiencies were very low when compared with the same rate of supplied air at controlled ORP of -325 mV. Therefore, it was the main objective of this study to vary controlled ORP values to investigate the removal efficiencies and energy saving.

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 exceeding. Their treatment system requires the nitrogen removal process.

METHODOLOGY

Scope of experiment

The complete-mixed activated sludge process fed with wastewater from a representative latex rubber industry was investigated in the pilot-scale experiments. The experiments were conducted with various operational conditions, in 4 periods. The first three periods were fed constantly with hydraulic retention time (HRT) of 36 hours. The influent fed in the fourth period was fluctuated with average HRT of 48 hours. The inflow was distributed with the same volumetric loading as the representative plant to concern the effect of equalization tank.

The ASP processes in these experiments were the simultaneous nitrification-denitrification without temporal or spatial alternating anoxic/oxic conditions. The pilot-scale 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. An air pump in the experiments was automatically controlled based on the ORP values. The volume of surplus sludge was controlled to maintain solid content of 3.5-4.0 g/L. The sludge retention time (SRT) was not a concern because in the actual situation, it is very rare to find the local treatment plant in which surplus sludge was discharged continuously. Most of the operators are concerned only with the SV30. The ORP values were observed and controlled by means of the 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.

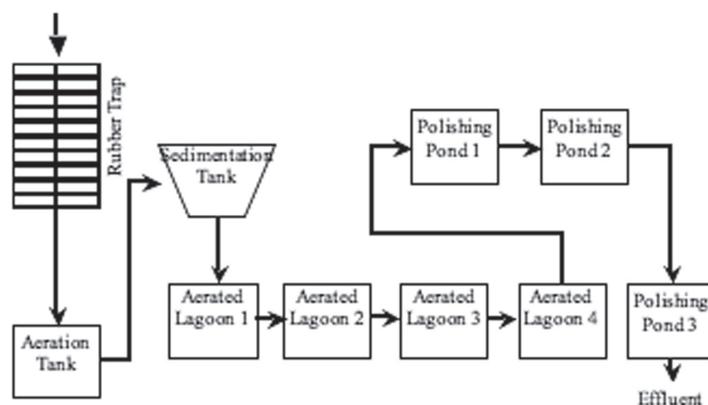
The main objective of this study is to determine the optimal aeration control system which would make nitrogen concentration in the effluent minimal. Therefore, control of the volume of air supplied is very important. The aeration rate could vary from 1 to 75 L/min, but, the system required at least 10 L/min for the well-mixed condition. The aeration control system was programmed. The actual situation was continuously recorded at about 5-15 minute time interval, with the help of computer programming.

Table 1. Control factors in the experiments.

Control factor	Phase 1	Phase 2	Phase 3	Phase 4
HRT (hrs)	36	36	36	48
Return sludge (%)	100	100	100	100
ORP (mV)	-325	-200	-150	-150

Representative wastewater treatment plant from latex rubber industry

This wastewater treatment plant is for the latex rubber industry. Its wastewater has a high concentration of ammonia. The treatment plant is a conventional ASP designed for only carbon removal. The facility consists of the ASP and ponds in series (see Fig. 1). Because of the high organic concentration, the ASP itself could not remove all organic content, therefore, the factory needs to install ponds in series to reduce BOD₅ before discharging to the environment. However, the nitrogen was not removed, but changed to be nitrate-nitrogen which caused the algae bloom in the polishing ponds. This phenomenon caused the effluent SS concentrations to become higher than the discharge standard. Therefore, it was the original idea to improve the nitrogen removal capacity of this plant. For this pilot study, samples were obtained only from the effluent of the rubber trap once a week, during August 2005 to February 2006, fed to the pilot experiments.

**Figure 1.** Schematic diagram of the representative treatment plant.

RESULTS AND DISCUSSION

Results of removal efficiencies versus the various controlled ORP values

From four experimental phases, with various controlled ORP, the total removal efficiencies of COD, total nitrogen (TN) and total suspended solids (TSS) are calculated. Table 2 shows the results of each period of experiments. According to the expected simultaneous nitrification-denitrification process, the nitrogen removal efficiency was concerned, instead of separately ammonia-nitrogen and nitrate-nitrogen.

$$\text{Where } \text{TN} = \text{TKN} + \text{NO}_2\text{-N} + \text{NO}_3\text{-N}$$

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

Parameter	Unit	Controlled ORP (mV)			
		-325	-200	-150	-150
F/M	kgCOD/ kgMLSS/d	1.33	1.27	3.08	1.90
DO	mg/L	ND*	0.17	0.32	0.41
TCOD Influent	mg/L	5,516.25±189.72	8,930.00±0.00	17,872.00±620.92	10,056.67±410.20
Effluent	mg/L	3,168.75±159.47	995.74±112.31	7,480.00±652.38	3,634.44±306.24
TCOD removed	gCOD/L/d	1.58±0.18	5.33±0.07	6.98±0.28	3.21±0.13
Removal	(%)	42.47±3.84	88.85±1.26	58.20±2.63	63.90±2.15
TN Influent	mg/L	353.50±42.43	1,222.00±0.00	1,687.00±59.42	924.33±98.34
Effluent	mg/L	263.15±29.85	977.07±34.84	759.56±178.44	436.36±51.99
TN removed	gTN/L/d	0.06±0.01	0.16±0.02	0.62±0.08	0.24±0.03
Removal	(%)	25.44±3.02	20.04±2.85	55.16±8.32	52.78±2.97
SS Influent	mg/L	347.13±239.15	730.00±0.00	849.80±63.47	805.00±100.42
Effluent	mg/L	188.13±147.68	348.00±40.98	344.60±46.01	315.56±47.05
Removal	(%)	48.78±9.25	52.33±5.61	59.58±3.50	60.89±1.78

ND* = non detectable

The result showed that the single aeration tank permitted both carbon and nitrogen removals. With controlled ORP at -325 mV to -150 mV, total COD removal varied from 42 to 88 percent. Total nitrogen removal varied from 20 to 55 percent. Suspended solid removal varied from 49 to 61 percent. These low removal efficiencies might be caused by the high F/M ratio. Therefore, the removed TN and COD were concerned in terms of gram of TN and COD removed per liter per day, as shown in Table 2. The results showed that the highest TN removal rate was 0.62±0.08 gTN/L/d at controlled ORP of -150 mV (the 3rd period). Similarly, the highest rate of COD removal was 5.33±0.07 gCOD/L/d at controlled ORP of -150 mV.

The DO concentrations in this study were, on average, between 0.17-0.41 mg/L. However, the results of nitrogen removal showed that both nitrification and denitrification processes took place simultaneously in the same aeration tank. It might be explained with the concept of different layers in the activated sludge floc. Normally, the biofilm particle size in the ASP plant was in the range of 10-110 µm (Venkata et al., 2005). Pochana and Keller (1999) reported that the biofilm floc of 200 µm size and above will have an anoxic microniche 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 -150 mV. Floc size distribution was measured in triplicate with a Laser Particle size analyzer (COULTER LS 230). The floc size varied from 1.832-1377 µm, with mean = 67.29µm, S.D. = 110.8 µm.

Aeration energy consuming

From the results, it can be concluded that the single aeration tank could permit simultaneous nitrification-denitrification process. Total nitrogen removal reached up to 55 percent at controlled ORP at -150 mV (the 3rd period). The simultaneous nitrification-denitrification process also has benefit on the reduction of aeration energy consumption. In the experiment periods 1 to 4, the volume of air supplied to the aeration tank was observed, to define the aeration energy consuming (see Fig. 2). Volumes of air supplied per milligram of removed COD in each period were calculated because each period of experiments was fed with different influent loadings. From the 1st period to the 4th period, they were 0.12, 0.06, 0.05 and 0.14 L/mg., respectively.

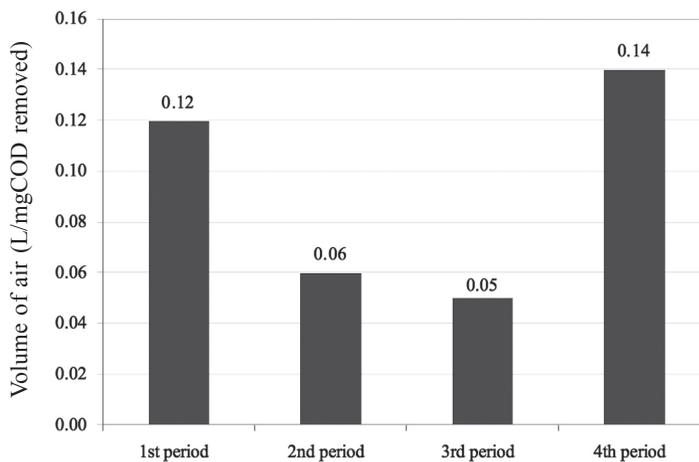


Figure 2. The volume of air supplied per milligram of COD removed in each period of experiments.

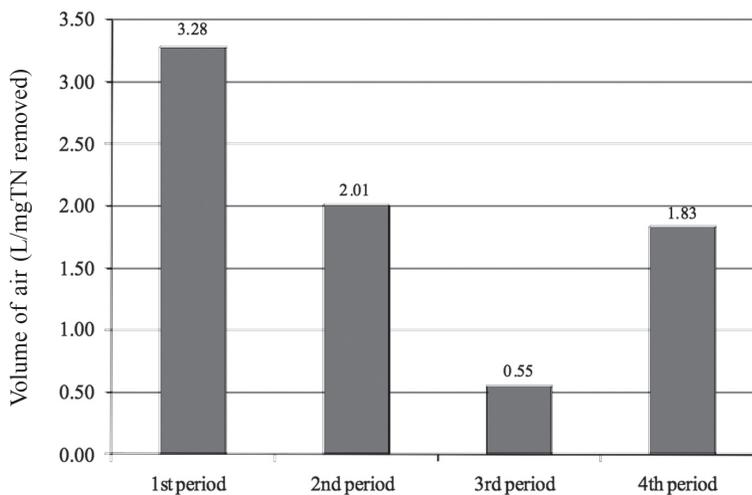


Figure 3. The volume of air supplied per mg of TN removed under various controlled ORP values.

Meanwhile, the volumes of air supplied to the aeration tank were between 0.55 and 3.28 L/mg of TN removed from process (see Fig.3). It is noticeable that low controlled ORP did not necessarily consume less aeration energy as previously expected. The results show that the volumes of air supplied per mg of TN per minute at ORP -150 mV were lower than those at -325 or -200 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 less volume of air supplied to the aeration tank means less energy consumption.

The volumes of air supplied per mg of COD and TN removed in the 3rd period were lower than those in the 4th period, even with the same controlled ORP at -150 mV. The removal efficiency for TN in the 4th period was lower than that in the 3rd period, even with higher HRT. These phenomena confirmed the need of equalization tank.

CONCLUSION

The results from this study indicated that the 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 following:

1. 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 confirmed that the ORP could be applied as an aeration control system.
2. Results showed that the volume of air supplied per mg of TN removed per minute was least when ORP was controlled at -150 mV (0.55 mL of air supplied per mg of removed TN per minute). Less aeration energy consumption was not necessarily for low controlled ORP. However, this result could not be definitely concluded for every type of wastewater.
3. The equalization tank would be required for constant loading to the ASP. The fluctuated organic load could consume air supplied for carbon and nitrogen removals.

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