Dissolved Oxygen Control System for Upgrading Conventional Activated Sludge Process for Seafood Industrial Wastewater in Southern Thailand

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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 investigated 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 aerobic control system in the simultaneous nitrification-denitrification system. The aeration control system was functioned by controlled ORP values varied from -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 consuming was not for low controlled ORP. 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, 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 plant and to increase the treatability. However, it appears that only carbon and solids 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 [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 was widely introduced as an efficient parameter for optimizing DO control. However, relatively little ORP data is available for the simultaneous, non-alternating, nitrification-denitrification process. In the past, most ORP value application in order to control the aeration applied for SBR system or systems occurred separately between nitrification and denitrification reaction clearly in order to regard the point changed the slope of graph showed ORP value [2] or to use ORP value to control the rate of denitrification reaction in anoxic tank [3]. Some researchers [4-7] persisted in the successful Sequencing Batch Reactor (SBR) system using to increase the efficiency of the nitrogen removal in the activated sludge system. Goronszy [8] 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 floe-levels. Bertanza [9] applied the ASP operated under DO less than 0.6 mg/L in order to increase an efficiency of an extended aeration activated sludge process referred to the principle of nitrification and denitrification reaction simultaneously. Collivignarelli and Bertanza [10] proposed to control the aeration by the ORP value controlling to be constant for the simultaneous nitrification-denitrification activated sludge process. However, their research was applied with the community wastewater having the low concentration and the sludge loading rate only 0.1 kg/day. But it could control the DO value to remain 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 value to the ASPs under the simultaneous nitrification-denitrification conditions. The 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 ration of BOD₅:TKN:TP was not equal to 100:5:1. The influent nitrogen concentrations were normally exceeding. Their treatment system requires the 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 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.

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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 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 experiments operated with hydraulic retention time of 36 hours. 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.

Table 1 Control factors in the experiments

<table>
<thead>
<tr>
<th>Control factor</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Phase 3</th>
<th>Phase 4</th>
<th>Phase 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>HRT (hrs)</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Return sludge (%)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>ORP (mV)</td>
<td>-300</td>
<td>-250</td>
<td>0</td>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

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 about 5-15 minute time interval, with the help of computer programming.

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). Complete denitrification could not happen. The total nitrogen removal averaged 83.64±6.32 percent. Nitrogen in form of nitrate-nitrogen was discharged from the ASP (the average effluent nitrate-nitrogen concentration was at 17.9±12.4 mg/L [11]). Therefore, the constructed wetland as post-treatment is required 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, orderly.

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.

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

where 
\[ R = \text{Total removal efficiency} \]

and 
\[ TN = \text{TKN} + \text{NO}_2^-N + \text{NO}_3^-N \]

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

<table>
<thead>
<tr>
<th>Controlled ORP</th>
<th>COD (mg/L)</th>
<th>SS (mg/L)</th>
<th>TN (mg/L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Influent</td>
<td>Effluent</td>
<td>%Removal</td>
</tr>
<tr>
<td>-300 mV</td>
<td>2945</td>
<td>331.3±293.9</td>
<td>82±10</td>
</tr>
<tr>
<td>-250 mV</td>
<td>868</td>
<td>153.3±97.3</td>
<td>82±11</td>
</tr>
<tr>
<td>0 mV</td>
<td>2457±428</td>
<td>218.0±43.2</td>
<td>91±1.4</td>
</tr>
<tr>
<td>50 mV</td>
<td>2508±765</td>
<td>40.4±10.6</td>
<td>98±0.8</td>
</tr>
<tr>
<td>100 mV</td>
<td>1320±268</td>
<td>27.0±2.7</td>
<td>98±0.5</td>
</tr>
</tbody>
</table>

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). With concerning the total nitrogen removed per volume, the best efficiency rate was at controlled ORP of 0 mV.

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

<table>
<thead>
<tr>
<th>Parameters</th>
<th>at -300 mV</th>
<th>at -250 mV</th>
<th>at 0 mV</th>
<th>at 50 mV</th>
<th>at 100 mV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total nitrogen (influent), mg/L</td>
<td>211.0</td>
<td>193.0</td>
<td>160.0</td>
<td>140.7</td>
<td>74.0</td>
</tr>
<tr>
<td>Total nitrogen (effluent), mg/L</td>
<td>181.8</td>
<td>157.3</td>
<td>30.0</td>
<td>24.8</td>
<td>49.5</td>
</tr>
<tr>
<td>Total nitrogen (removed), mg/L</td>
<td>29.2</td>
<td>35.7</td>
<td>130.0</td>
<td>115.9</td>
<td>24.5</td>
</tr>
<tr>
<td>Loading rate, kg TN/d</td>
<td>0.011</td>
<td>0.010</td>
<td>0.008</td>
<td>0.007</td>
<td>0.004</td>
</tr>
<tr>
<td>Conversion rate, kg TN/m³ reactor/d</td>
<td>0.019</td>
<td>0.024</td>
<td>0.087</td>
<td>0.077</td>
<td>0.016</td>
</tr>
</tbody>
</table>

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. Although, Eckenfelder [12] presented that the denitrification rate decrease 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 was in the range 10–110 µm [13]. Pochana [14] 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.

#### 3.2 Aeration energy consuming

After all 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, at controlled ORP at 50 mV. The simultaneous nitrification-denitrification process also has benefit on the reducing of aeration energy consuming. In the experiment of period 1 to 5, the volume of air supplied to the aeration tank was observed, to define the amount of aeration energy consuming (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, respectively.

![Fig. 2 The volume of air supplied to the ASP operated at various ORP values](image)

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 less aeration energy consuming, not for low controlled ORP as aspect. 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 mean the less of energy consumption.
4. CONCLUSION

The results in this study indicate 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 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 as an aeration control system.
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). Less aeration energy consuming was not for low controlled 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 type of wastewater.
2. Further laboratory scale experiment is required for investigation of floc size and its effect.
3. Further study about the economic evaluation of this process is required.

5. ACKNOWLEDGMENTS

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6. REFERENCES


