Application of A\textsuperscript{2}/O bio-reactor & constructed wetlands for removing organic and nutrient concentrations from rural domestic sewage

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ABSTRACT

This paper examined the efficiency of integrated bio-reactor processes (A\textsuperscript{2}/O) combining anaerobic, anoxic, waterfall aeration contact oxidation (oxic) and constructed wetlands for removing organic and nutrient concentrations from rural domestic sewage. The study was carried from June 2012 to November 2012. Chemical oxygen demand (COD), total phosphorus (TP) and total nitrogen (TN) in the effluent from this process was stably below 50 mg/l, 0.6 mg/l and 13.2 mg/l respectively. The results of the system denoted that this integrated process was efficient in organics and nutrients removal from rural domestic sewage. COD was mainly removed in anaerobic, anoxic and in waterfall aeration contact oxidation (oxic) columns. Nitrogen was typically reduced by nitrification in contact oxidation unit and denitrification in anaerobic and anoxic column. Constructed wetland played an imperative role in phosphorus removal by filter interception, plant adsorption and microbial transformation. Scraped plaster added in the constructed wetland reacted with orthophosphate and relieved the influence of temperature on phosphorus removal in cold days. Overall, this integrated process was efficient and in rural domestic sewage treatment.

Keywords: A\textsuperscript{2}/O bio-reactor; constructed wetland; rural domestic sewage; waterfall aeration; orthophosphate.

1. Introduction

Continuous loadings of organic compounds and nutrient concentrations such as nitrogen and phosphorus from the domestic wastewater to receiving surface waters, particularly to lakes, artificial reservoirs and rivers, has lead to increase water pollution problems in rural areas. Over the past few years, aerobic treatment of domestic wastewater was employed for treating low strength wastewater (<1000 mg COD/L) like municipal wastewater. But since the aerobic process requires intensive energy use due to the high aeration requirement and it also produces large quantity of sludge which is costly for its operation and maintenance, the rural people have shifted to anaerobic process for domestic wastewater treatment. Accordingly, the anaerobic process is simple, more economical and holistic conceptually (Mergaert et al., 1992), particularly in the sub-tropical and tropical regions where the climate is warm consistently throughout the year. Anaerobic process does not require aeration and it produces biogas which can be utilize as source of energy and it also produces less sludge. Rural domestic sewage is one of the chief pollution sources of Taihu Lake and the surrounding water environment (Zhaoqian Jing, et al (2009), It contributes about 35.35% nitrogen and
about 59.65% phosphorus to Taihu loading (Li X., Lu X., et al, 2006). Due to the lack of economic resources and trained personnel in rural areas, the sewage treatment technologies should guarantee an effective performance, low costs and simple operation. Several authors reported experimental and full scale applications of combined A\textsuperscript{2}/O process configuration (Tilche et al., 1994; Bernet et al., 2000; Choi et al., 2005; Choi, 2007). For example, the Modified Ananox process (Tilche et al., 1994) represents a combination of anaerobic digestion and denitrification in hybrid upflow anaerobic filter (HUAF) integrated in an activated sludge nutrient removal treatment plant.

Several researches has shown that anaerobic systems such as the Anaerobic Filter (AF) (Ng and Chin, 1987; Chernicharo and Machado, 1998), the Upflow Anaerobic Sludge Blanket (UASB) (Behling and Sant’Anna, 1997; Barbosa et al., 1989) and the Anaerobic Sequencing Batch Reactor (AnSBR) (Sung and Dague, 1992; Ng, 1989) can successfully treat high-strength industrial wastewater as well as low-strength synthetic wastewater. Constructed wetlands may be an appropriate technology for treating domestic sewage in the rural areas of China with climatic, population, and socioeconomic considerations (Min Tao, et al2010). But there are still some questions and limitations to broader application of constructed wetlands. Among the problems is the poor performance of outdoor constructed wetlands in the cold climates. Cold temperatures rigorously affect microbial activities and water purification performance of constructed wetlands (Kadlec, R.H., Reddy, and K.R. 2001). Low aeration and oxygen levels are among the limiting factors for a better performance of constructed wetlands, mostly due to the dieback of aquatic macrophytes that could transport oxygen to their rhizospheres for microbial respiration (BRIX H., 1994).

The integration of A\textsuperscript{2}/O bio-reactor system and constructed wetland may be the best alternative for small scale rural domestic sewage treatment. However, there have been limited reports on using integrated anaerobic, anoxic, waterfall aeration (Oxic) and constructed wetland systems as a pretreatment for rural domestic wastewater. In order to meet the standard effluent quality discharge of China, single operation of anaerobic process can’t achieve that standard, hence, integrated process is considered to be the best option. However, the size of the waterfall contact oxidation system for the integrated anaerobic and aerobic treatment processes will be greatly reduced because the wastewater has been pretreated by the anaerobic and anoxic system. Hence, the A\textsuperscript{2}/O bio-reactor system is potentially a more cost-effective technology for treating rural domestic wastewater by reducing the aeration requirement and sludge production while meeting the Chinese standard of effluent discharge to the environment. Considering the factors mentioned above, this study was carried out with the aim of examining the efficiency and achievability of the A\textsuperscript{2}/O bio-reactor and constructed wetlands for removing organic and nutrient concentrations from rural domestic sewage.

2. Materials and method

2.1 Reactor operating conditions

For this study, the raw wastewater from a campus main manhole was pumped into a storing tank for sedimentation, and then fed into the A\textsuperscript{2}/O bio-reactor system. The seed sludge was taken from the Wuxi municipal sewage treatment plant which utilizes a typical change in the environmental state condition (anaerobic, anoxic, or aerobic) to treat municipal wastewater. The wastewater samples of the A\textsuperscript{2}/O bio-reactor system was collected from the sampling ports after every two days and stored at 5ºC before use. The reactor was continuously fed with sieved (2 mm size filter) raw domestic wastewater stored in a common feed holding tank.
The feed of all the integrated bio-reactor systems were maintained at 28 - 30°C by a thermal controller installed in a feed transfer tank. The hydraulic retention time (HRT) varies throughout the entire study. The experiments were designed to assess organic and nutrient concentrations with variable loading using different internal recycle flow rates. The variable operating parameter was the internal recycle ratio. The internal recycle ratio, R, can be defined as the ratio of returned flow rate (Qr) to that of the main influent flow rate (Q0),

Recycle ratio (r) = \( \frac{Q_r}{Q_0} \) ……………………………………………………………………………………(1)

The raw domestic wastewater composition is shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD (mg/L)</td>
<td>130.64</td>
<td>398.21</td>
<td>209.69</td>
</tr>
<tr>
<td>TN(mg/L)</td>
<td>25.21</td>
<td>39.35</td>
<td>30.32</td>
</tr>
<tr>
<td>TP(mg/L)</td>
<td>1.61</td>
<td>4.21</td>
<td>4.26</td>
</tr>
<tr>
<td>pH</td>
<td>7.5</td>
<td>7.9</td>
<td>7.7</td>
</tr>
<tr>
<td>VFA (SA) (mg/L)</td>
<td>67</td>
<td>89</td>
<td>71</td>
</tr>
</tbody>
</table>

2.2 Analytical methods

The liquid samples were filtered through low protein binding, non-pyrogenic membrane filters with 0.45 μm pore size prior to analysis. The influent and the effluent COD, TN and TP were analyzed according to standard methods (S.E.P.A. Chinese, 2002), TN was analyzed by analytikjena AG multi N/C 3000. Temperature and pH was measured by dissolved oxygen meter. Gas production was measured by wet gas meter. The flow rate was controlled by a valve and incessantly regulated by the help of a pump.

2.3 Apparatus and flow chart

This research was carried out in Wuxi Xinqu rural area, an area near Taihu Lake in Wuxi, Jiangsu Province. Sewage treatment system was built according to figure 1 & 2. This system integrated anaerobic system, anoxic, waterfall aeration contact oxidation (Oxic) and constructed wetland. The anaerobic & anoxic column was filled with a non-woven fabric filter materials of length 2500mm, width of 50mm, surface area of 150m²/m³ and with porosity of 97%. The bioreactor system constructed of PVC comprises of one 90L anaerobic column, 60L anoxic column, 27L waterfall contact oxidation column and constructed wetlands were set up respectively. The anoxic and waterfall contact oxidation column reactor was intermittently aerated (1 h aerating and 1 h non-aerating) at a flow rate of 2 L air/min so that simultaneous nitrification and denitrification (SND) will occur in the reactor. The waterfall contact oxidation columns were divided into three different-sized parts to create a plug-flow system. In order to achieve good nutrients removal efficiency, nitrifying bacteria must be able to oxidize ammonium ions completely. Hence, fixed-film filter materials were integrated into each compartment to support fixed biofilm growth and enhance nitrification. During the start-up period, there was no intentional biomass wasting for the anaerobic-anoxic & oxic systems while the solids retention time of anaerobic column was maintained at 30 hours. The anaerobic column mostly pretreated the sewage and reduced organic compounds by hydrolysis and acidification. The waterfall aeration column achieved organic compounds decomposition and nitrogen nitrification. The effluent from the oxidation column was partly
recycled to anoxic column for denitrification. The constructed wetland had a dimension of 2.3m×0.6m×0.4m with hydraulic loading rate (HRT) of 1.0 m/d. It was used to remove nutrients such as nitrogen and phosphorus and decrease residual organic compounds. By this process, the system integrated A^{2}/O with constructed wetland methods and consequently enhanced effluent quality.

Figure 1: Schematic flow chart of A^{2}/O bio-reactor system

Figure 2: Schematic flow chart constructed wetland system

2.4 Schematic structure of waterfall aeration contact oxidation

The waterfall aeration contact oxidation was alienated to three parts (Fig. 2). There was height difference between the columns. The domestic sewage water fell down to some porous baffles after it was pumped to a certain height. There were many tiny holes with diameter of about 2 mm in the baffles. As the sewage passes through the tiny holes, it fall down in fine flow, which increased the interface with air and encourage oxygen transfer and hence, the sewage was aerated. After waterfall, the aerated sewage entered one oxidation unit attached with biological fillings. The biofilm on the fillings oxidized organic compound and nitrogen with oxygen.

2.5 Efficiency of the reactor

For example, the removal of COD in the system (AF) refers to the difference between the influent and the effluent COD, thus the COD removal percentage is expressed by:

\[
COD(\%) = \frac{COD_{\text{in}} - COD_{\text{eff}}}{COD_{\text{in}}} \times 100
\]

\[(2)\]
The equation is also applied for calculating the efficiency of the reactors in regards to the nutrients.

**Figure 3:** Schematic flow chart of waterfall aeration contact oxidation

### 3. Results and discussion

During the start up process, A2/O bio-reactor column was fed with activated sludge from Wuxi municipal sewage treatment plant in order to reduce the acclimatization period. After 25 days, large amount of biofilm was observed on the medium in bio-reactor. The constructed wetland was planted with reed with density of 25 plants per m². The pH fluctuations of the influent and effluent in the bio-reactor system were monitored over time and the average pH
in the influent and effluent during experimental operations were 7.7 and 7.9 respectively. Effluent from the scheme was apparent and main indexes met the requirement of local discharge standard. This system was kept in normal operation continuously from that time.

3.1 Chemical oxygen demand (COD) removal

The variation of COD during the running period from June to November, 2012 is illustrated in figure 4. The concentration of COD in the influent fluctuates in the range of 53 mg/l to 475 mg/l, whereas the concentration of effluent was quite stable under 50 mg/l, which met national discharge standard of China. In the anaerobic unit organic compounds were transformed into volatile fatty acids (VFA) and other low-molecular compounds (Gopala Krishna G.V.T., et al, 2008) and then the latter were decomposed into methane and carbon dioxide. The amount of average gas produced with time varied between 5.8 to 8.7 L/d in the experimental operations. By this process, more than 50% of COD in the influent was removed. Consequently, COD loading on the contact oxidation unit was greatly relieved. By three columns waterfall aeration, sufficient dissolved oxygen (DO) was obtained for COD decomposition and nitrogen nitrification. Residual COD was reduced further in the constructed wetland by microbial decomposition and filter interception. It can be concluded that the A2/O bio-reactor system was very efficient in maintaining a fairly high and stable COD removal throughout the experimental period.

![Figure 4: Average COD removal efficiency by the A2/O bio-reactor and CW system](image)

3.2 Total phosphorus removal

In this system, the removal efficiency of TP was stable despite the range of TP in the influent was 0.97mg/l to 2.74mg/l. The effluent TP was mostly below 0.61 mg/l (fig. 5). In the constructed wetland, most of the TP removal was accomplished by medium interception, microbial transformation and plant adsorption. In rural places nearby Taihu lake region, abandoned molds can be seen everywhere. In order to improve TP removal, scraped plaster of
abandoned molds (react with orthophosphate) was added in the front part of the constructed wetland. Even though temperature fluctuates and reed in the constructed wetland withered steadily from October, TP removal in this system wasn’t affected obviously due to the help of the scraped plaster.

![Figure 5: Average TP removal efficiency by the A\textsuperscript{2}/O and CW bio-reactor system](image)

3.3 Total nitrogen removal

Nitrification was observed by measuring the concentrations of nutrient nitrogen in the effluents of the combine bio-reactor system. In the waterfall aeration contact oxidation column, nitrogen was oxidized into nitrite and nitrate, and part of the domestic sewage after nitrification was recycled to anoxic column, in which nitrate and nitrite was denitrified by denitrifiers with VFA as electron donor (Elefsiniotis P., Li D. 2006). About half of TN was removed by this means. The anoxic reactor column was intermittently aerated so that simultaneous nitrification and denitrification (SND) could take place. The average DO concentration during aeration and non-aeration was 2.5 and 0.95 mg O2/l, respectively. Residual nitrogen after A\textsuperscript{2}/O columns was then further removed by microorganisms and plants in the constructed wetland. Influent TN changed between 3.5 mg/l and 37mg/l, and effluent TN was always below 13.2 mg/l (Fig. 6). During the period between August and September, average removal ratio of TN in this process attained 85.7% as a result of high temperature and hence, accelerated the activities of nitrifiers and robustly reeds in constructed wetland increased nitrogen adsorption.

4. Conclusion

The integrative A\textsuperscript{2}/O bio-reactor, investigated in the present study, represents an efficient pre-treatment process for rural domestic sewage. This method consisting of anaerobic column,
anoxic column, waterfall aeration contact oxidation and constructed wetland, attained satisfactory results in which COD, TN and TP in the influent sewage could be stably removed. Concentration of COD, TN and TP in the effluent was kept below 50 mg/l, 13.2 mg/l and 0.6 mg/l respectively.

**Figure 4:** Average TN removal efficiency by the A²/O bio-reactor and CW system

COD was decomposed by anaerobic - anoxic and aerobic microorganism and nitrogen was removed by nitrification and denitrification in anaerobic, anoxic columns and waterfall aeration contact oxidation columns. Constructed wetland played an imperative role in phosphorus removal by filter interception, plant adsorption and microbial transformation. Scraped plaster added in the constructed wetland reacted with orthophosphate and relieved the influence of temperature on phosphorus removal in cold days. Overall, this integrated process was quite efficient in rural domestic sewage treatment.

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5. **References**


