Attached growth anoxic-aerobic system treatment of domestic wastewater

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Abstract: An integrated water quality management system involves both treatment of wastewater and appropriate reuse of the effluent. Treated wastewater from commercial establishments such as hotels, high-rise residential or office buildings and shopping malls are potential source of non-potable water for use as landscape watering and toilet flushing. This study aimed to determine the performance of a full-scale aerobic activated sludge system and a bench-scale attached growth anoxic-aerobic growth wastewater treatment system (WWTS), which operated at shorter HRT and higher organic loading rate (OLR) than the present full-scale system. The effect of HRT on the bench-scale performance was also determined. Furthermore, this study assessed the effluent water quality for possible reuse.

In the full-scale WWTS, at 2.06 ± 0.18 days HRT and 0.396 ± 0.123 kg COD/m3/d OLR, the COD, BOD, FOG and TSS removal efficiency values were 97.2 ± 2.3%, 95.3±2.0%, 91.6±15.0% and 85.96±13.4%, respectively.

In the bench-scale attached growth anaerobic-aerobic WWTS, the BOD, COD, FOG and TSS removal efficiency were 97.9±2.3%, 93.6±5.9%, 87.8±22.9% and 71.4±18.5%, respectively, at 6.35 h HRT and 2.42±0.40 kg COD/m3/d OLR. The efficiencies were better at longer HRT and lower OLR. At 12.70 h HRT and 1.50 ± 0.30 kg COD/m3/d OLR, the BOD, COD, FOG and TSS removal efficiencies were 98.1 ± 2.4%, 94.7 ± 4.6%, 95.0 ± 5.1% and 91.4 ± 2.4, respectively. The effluent of the bench-scale WWTS after an additional tertiary treatment could be used for landscape watering and flushing toilet.

Key Words: aerobic; anoxic; attached growth; reuse; wastewater

1. Introduction

Generators of wastewater such as manufacturing industries and business establishments are mandated to be responsible for the collection, treatment of wastewater and the ultimate disposal of the treated wastewater, as well as the separated solids, in a manner that is safe and within the prescribed government water quality standards as specified by the Department of Environment and Natural Resources Administrative Order No. 35 series of 1990, and as amended through Department of Environment and Natural Resources Administrative Order No. 2016-08. With the implementation of RA 9275 otherwise known as the Philippine Clean Water Act of 2004, and its Implementing Rules and Regulations, wastewater reuse after treatment will have several benefits to the wastewater generator.

Treated wastewater from other commercial establishments such as shopping malls is a potential source of non-potable water that can be used for toilet flushing and landscape watering. The aerobic wastewater treatment plant of the shopping mall in this study was primarily designed to treat 700 m^3 of wastewater per day. Upon expansion sometime in 1996, the design flow rate of the wastewater treatment plant was increased to 1,500 m^3/d. Sometimes, due to high wastewater load to the treatment plant, which is due to increase of people going to malls and occupants in the offices, the effluent quality fails against the standards. Likewise, wastewater treatment plant had unstable performance system. The system had shock loads and if the operator were not careful, it would result in malodor, which is a nuisance problem.

The research area covers the bench-scale attached growth anoxic-aerobic treatment system and the full-scale activated sludge aerobic treatment plant of a shopping mall. To assist in the company enterprise energy conservation program, this study discussed the possibility of reusing the effluent of the bench-scale attached growth anoxic-aerobic treatment system, for instance, flushing water in public toilets. The result of the study was expected to serve as a guide in the effective and efficient operation and maintenance of the treatment system at lesser cost.

2. Characteristics of Domestic Wastewater

Normal domestic and municipal wastewater is composed of 99 mass% water and 0.1% suspended, colloidal and dissolved solids – organic and inorganic compounds, including macronutrients such as nitrogen, phosphorous and potassium as well as essential micronutrients. Different tests have been developed to determine the organic matter of wastewater. Generally, tests are divided into those used to measure gross concentrations of organic matter greater than about 1 mg/L and those used to measure trace concentrations in the range of 10^{-12} to 10^{-3} mg/L (Techobanoglous, 1991).

2.1 Organic Matter Removal

Whether soluble or suspended, degradable organic matter in wastewater can be removed through microbial degradation. The microbes responsible for the degradation are generally associated with slimes or films that develop on the surfaces of soil particles, vegetation, and litter. Natural systems are designed and operated to maintain aerobic conditions so that degradation is performed predominantly by aerobic microorganisms. Aerobic decomposition is more rapid and complete than anaerobic decomposition. The capacity of natural treatment systems to degrade organic matter aerobically is limited by the transfer of oxygen from the atmosphere to the system (Metcalf & Eddy, Inc. 1991).

Under strictly anaerobic conditions, the acetate is then converted to methane by acetotrophic methanogenic microorganisms while CO_2 and H_2 produced from preceding processes are also converted to methane by hydrogenotrophic methanogens. In the presence of nitrates and sulfates, the denitrifiers and sulfate-reducing bacteria will outcompete the methanogens for carbon source (Grady, et al, 1980).

2.2 Nutrients Removal

The so-called nutrient in wastewater are plant nutrients such as N and P. Excessive loads of these nutrients from disposed wastewater causes eutrophication of the receiving body of water. In wastewater, nitrogen is usually in the form of ammonia or organic nitrogen, which is quickly converted to ammonia. Ammonia is one of the major constituents of domestic wastewater. Its concentration commonly ranges from 10 to 50 mg total ammonia N/l, but might be as high as 200 mg total ammonia N/l in domestic wastewater (Gaudy, et al., 1992).

Ammonia is used by autotrophic bacteria, and is oxidized in the presence of oxygen to nitrite. This occurs at the wastewater treatment plant by giving the relatively slow-growing bacteria enough time to grow in the reactors. The nitrite produced is then subsequently oxidized by nitrite oxidizing bacteria to nitrate. This process is called nitrification (Barnard et al., 1989).

2.3 Pathogen Removal

The fate of bacterial pathogens and viruses in the wastewater is determined by their survival characteristics and their retention. For bacteria and probably viruses, the die-off rate is approximately doubled with each 10^oC rise in temperature between 5 and 30^oC. The physical and chemical characteristics of the wastewater also play a major role in determining survival and retention of microorganisms. Water properties influence moisture holding capacity, pH, and organic matter. All of these factors control the survival of bacteria and viruses in the wastewater. Resistance of microorganisms to environmental factors varies among different species and strains. Bacteria are believed to be removed largely by filtration processes, but adsorption is the major factor controlling virus retention (Gaudy, et al, 1992).

4. Methodology

The present system consists mainly of (1) an equalization tank, (2) three aeration tanks, (3) a clarifier and (4) a chlorination tank. The main problem encountered in the full-scale system is that the effluent fats, oil and grease (FOG) level sometimes exceeds the standard maximum level. Nevertheless, on the average total chemical oxygen demand (COD), biochemical oxygen demand (BOD) and total suspended solids (TSS) levels were within standard. Hence, in this study, a modification of the present treatment process was tried in view of improving the FOG removal. For this purpose, a bench-scale system was made consisting of (1) a non-aerated tank with plastic screen as filter and microbial support media, (2) an aerated tank and a settling tank (3). As the first tank is non-aerated and the mall wastewater is expected to have dissolved organic matter and nitrates in it, denitrifying microorganisms are expected to grow in the first reactor. This part would serve to partly remove the nitrogen in the wastewater. In exploring the possibility of recycling the treated wastewater as toilet flushing water, the wastewater treatment system must also have a partial removal of nitrogen. The bench-scale model tried in this study has a relatively shorter hydraulic retention time and therefore higher loading rate than the full-scale system in view of a possible saving in bioreactor space and aeration power requirement.

5. Profile of full-scale wastewater system

The mall is composed of a five (5) level shopping area with a total of 457 establishments consisting of shops, dining outlets, entertainment facilities and service centers. The main mall was constructed in 1989 and eventually an extension mall was constructed in 1996. In meeting the challenges and adopting changes to be ready for the demands of growing and changing market, renovations of the mall shall be a continuing process. The treated wastewater from the mall is perceived as a reliable source of water for reuse. Wastewater reuse such as non-potable and landscaping watering purposes is being considered as an important element of the mall water resources planning.

5.2 Process flow diagram of the full-scale wastewater treatment system

The full-scale existing conventional STP has a design BOD load of 750 kg/day; MLVSS of 2,500 mg/L; FM ratio of 0.20; volumetric loading of 0.67 kg BOD/cubic meter per day. While the bench-scale

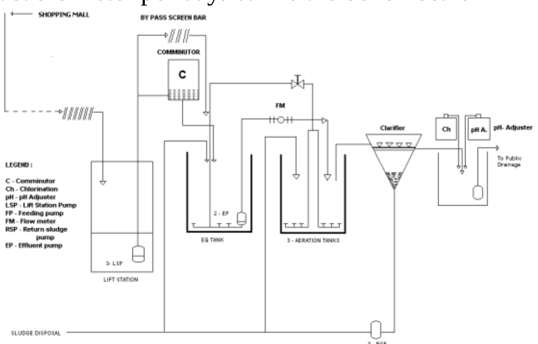

Figure 1. Process Flow Diagram of the Full-Scale Wastewater Treatment System

system was operated; the full-scale system monitoring was also monitored. Samples before the equalization tank, aeration tank and after aeration tank (treated effluent) were obtained for COD, BOD, TSS and FOG tests.

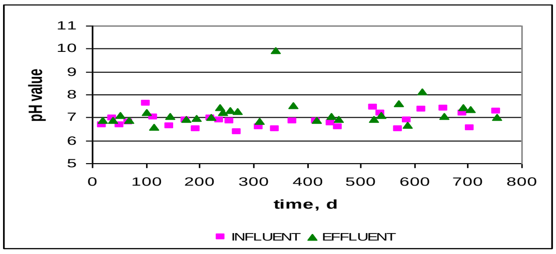

Figure 2. pH values of full scale wastewater treatment system

5.3 The bench-scale attached growth anoxic-aerobic treatment system

The bench-scale treatment system had an anoxic reactor (47 cm W x 40 cm L x 50 cm height but 40 cm liquid depth, effective volume of 75.2 L), aerobic tank (28 cm W x 40 cm L x 50 cm height but 40 cm liquid depth, effective volume of 44.8 L) and a clarifier tank (40 cm W x 40 cm L x 50 cm depth, with inclined bottom, effective volume 56 L) and the treated effluent tank (7 cm W x 40 cm L c 50 cm depth). All have a depth of 50 cm. There was chlorination at the effluent tank. The chlorine (70% purity) dosage was 121 g Cl/d. A tertiary treatment tank with activated carbon was installed connected to the effluent tank. The purpose is for further treatment so in view of the possibility of reusing the effluent. Part of the effluent wastewater (0.0847 m^3/h) was recycled from the clarifier tank back to aerobic tank.

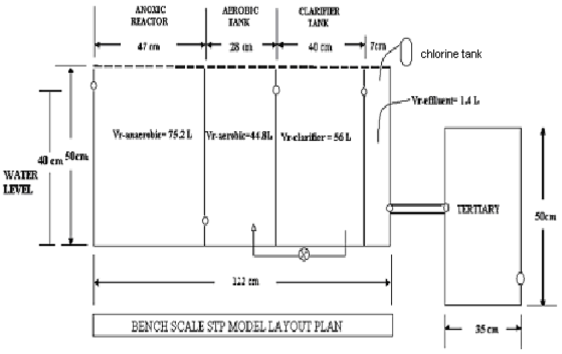

Figure 3 Layout Plan of Bench-Scale Model Anaerobic-Aerobic WWTS

5.4 Bench-scale anaerobic-aerobic wastewater treatment system sampling points

There were four (4) sampling points: sampling point 1 at the influent, sampling point 2 at the anoxic reactor, sampling point 3 at the aeration tank and sampling point 4 at the effluent. For all the sampling points, samplings of wastewater were conducted weekly for a month to measure the following parameters on pH, temperature, total COD, BOD, FOG and TSS. Due to laboratory problems, sampling for these parameters were conducted twice a month, to be parallel with the sampling conducted at the same time with the existing full-scale conventional activated sludge STP.

5.5 Analysis of wastewater

Sampling was done in order to analyze the pH, BOD, COD, TSS, FOG at the influent and effluent. These analyses were done using standard methods (APHA 1998). At the anaerobic reactor, aerobic tank and effluent, sampling was conducted to analyze nitrate; while ammonia was analyzed from samples taken from anaerobic reactor and aerobic tank. In view of the wastewater for possible reuse of the effluent, an additional tank with activated carbon was added to the system. It was connected to the effluent tank. In this tank, final effluent samples were collected for analysis of nitrate, ammonia, pH, BOD, COD, TSS and FOG.

6. Results and discussion

The HRT was relatively shorter than the full-scale while the OLR values were higher. The purpose was to let the microorganisms grow at a higher rate and accumulate in the system and try to run the system at higher loading rate and shorter retention time than the full-scale system. As the performance in terms of removal efficiencies was not as high as those of full-scale, the HRT was increased and subsequently, the OLR decreased in the later periods.

The COD, BOD, FOG and TSS levels in the influent, inside the anaerobic tank, inside aerobic tank and the effluent (after clarifier) were rather high inside the anaerobic tank and even exceeded the influent level. This was because the sample was taken inside the tank and the sample thus contained particles of sludge, which must be occupying the reactor. The highest BOD level in the influent was 591.52 mg/l. At the effluent the highest was 199.87 mg/l. This BOD level was still below the effluent regulations maximum limits.

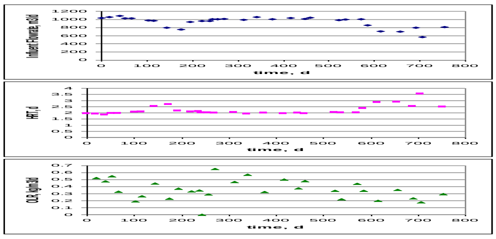

Figure 4. Operating conditions in the full scale aerobic wastewater treatment system

At 6.35 h HRT, the effluent pHs was within the government regulation, except during the sampling conducted on October 5, 2006, with a pH of 11.11. The COD level was high in the influent and aerobic tank and effluent (839.46 mg/l and 510 mg/l, respectively). The highest BOD level in the influent was 537.25 mg/l. At the effluent, the highest BOD level was 22.15, which was within standard limits.

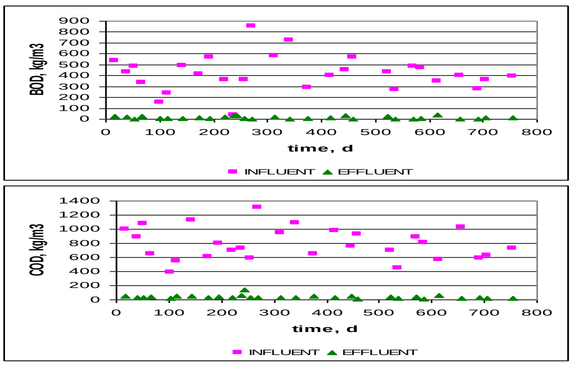

Figure 5. BOD and COD levels in the influent and effluent of full scale aerobic wastewater treatment system

In the same 6.35 h HRT, The oil and grease (FOG) was a perennial problem that likely caused the low removal of organic matter in the wastewater and likely affected the operation of the STP. The oil and grease were coming from operation of restaurants and other food tenants. The lowest FOG value influent for this period was 40.56 mg/l and the highest was 102.13 mg/l. Almost all samples failed with respect to oil and grease (FOG) standard. In the same period, the TSS levels in the influent, anaerobic tank, aerobic tank and effluent, were all very high, compared to the government standards. At the effluent, the high TSS was 95 mg/l.

At 12.70 h HRT, COD levels in the effluent for this period were within the government regulations, except on sampling conducted on January 11, 2007 which was 101.70 mg/l. This COD result was due to some factors in the operation of the mall.

The organic matter removal efficiency values for the different periods and plotted against OLR, TSS and FOG loading rate. At the highest HRT (12.70 h), the overall-removal efficiency of the bench-scale system was 94.7±4.6% for COD, 98.1±2.4% for BOD, 91.4±4.6% for TSS and 95.0±5.1% for FOG. The removal efficiencies were rather lower at shorter HRT or higher OLR. At higher loading rates, the removal efficiency values tend to fluctuate to lower values while at the lower end of the OLR, FOG and TSS loading, the removal efficiency was rather consistently high.

7. Conclusion and recommendation

In the full scale WWTS, the COD, BOD, FOG and TSS removal efficiency values were 97.2±2.3%, 95.3±2.0%, 91.6±15.0%, respectively, at 2.06±0.18 days HRT and 0.396±0.123 kg $COD/m^3/d$ OLR. One of the main objectives of this research was to investigate the applicability of the attached growth anoxic-aerobic treatment of domestic wastewater. Performance of the attached growth anoxic-aerobic treatment bench-scale model was affected by hydraulic retention time (HRT). In the bench-scale attached growth anoxic-aerobic WWTS, the BOD, COD, FOG and TSS removal efficiencies were 97.9±2.3%, 93.6±5.9%, 87.8±22.9% and 71.4±18.5%, respectively, at 6.35 h HRT and 2.42±0.40 kg COD/m3/d OLR. The efficiencies were better at higher HRT and lower OLR. The BOD, COD, FOG and TSS removal efficiencies were 98.1±2.4%, 94.7±4.6%, 95.0±5.1% and 91.4±4.6%, respectively, at 12.70 h HRT and 1.500±0.30 kg $COD/m^3/d$ OLR.

The effluent of the bench-scale WWTS after tertiary treatment using activated carbon could be used for landscapes watering and flushing toilet. The laboratory results of the samples collected from the tertiary treatment signify that it conforms to the USEPA standards for Class A Water Recycle.

The treatment of domestic wastewater is typically designed to meet water quality objectives based on TSS or turbidity, organic content (BOD), biological indicators (total coliform), *E. coli*, nutrient levels (nitrogen and phosphorous), and chlorine residual.

Technology development must be a continuing process in order to adapt to the changing environment. Future study is recommended not only to focus on the improvement of wastewater treatment plant operation and maintenance, but also, on the responsibility of the management for safety and protection of the environment, as part of the corporate social responsibilities.

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