Treating domestic effluent wastewater treatment by aerobic biofilter with bioballs medium

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Abstract. This laboratory scale research aimed to treat wastewater effluent with advanced treatment utilizing aerobic biofilter with bio-balls medium to obtain effluent quality in accordance with DKI Jakarta Governor Regulation No. 122 of 2005. The seeding and acclimatization were conducted in 4 weeks. The effluent were accommodated in a 150 L water barrel supported by a submersible pump. The effluent were treated in two boxes shaped reactors made of glasses with 36 L of each capacity. These reactors were equipped with aquarium aerators, sampling tap is 10 cm from the base of reactors, and bio-balls with 3 cm diameter are made of PVC. Reactors operated continuously with variations of retention time of 4 hours, 8 hours, 12 hours, 18 hours, and 24 hours and also variations of Carbon: Nitrogen: Phosphor = C: N: P ratio were, 100:5:1, 100:8:1, 100:10:1, 100:12:1, 100:15:1. The results showed that the optimum variance of retention time was 24 hours and the ratio of C:N:P was 100:10:1 yielded the largest removal efficiency for 83,33% of COD, 87,33% of BOD, 82,5% of Ammonia, 79,1% of Nitrate, 92% of Nitrite, 84,82% of Oil and Grease. The concentration parameter resulted from outlet biofilter has met the domestic wastewater quality standard of DKI Jakarta.

Keywords: aerobic biofilter, bioball, domestic wastewater, retention time, removal efficiency

1. Introduction
Biofilter is a biological filter with attached biomass on the filter-media. The microorganism attaches on the surface of media and grows up to biofilm will degrade the organic compounds present in the water. For the development of advance biological treatment process, WWTPs need to be more compact, low in operational costs and stable in operation, while at the same time minimize the noise and odor, and space requirements as well as generate high performance. However, with the continuing need to increase wastewater effluent quality, one of the advanced biological treatment systems, the biological aerated filters, proves to be more reliable [1]. This process has several advantages that are easy to operate, less sludge production, and are resistant to fluctuations of flow and concentration of wastewater [2].

In a biological treatment process, the optimum ratio of C: N: P in the aerobic process is 100: 5: 1 (C:N = 20-30 and N:P = 5). Domestic waste water has the C: N: P ratio of 100: 5: 1, which is sufficient for most microorganisms [3]. Aerobic microorganisms work most effective in the pH range of 6.5 - 8.5 [4]. According to study conducted to investigate the effect of using aerobic biological filter system for improving the effluent quality of two-stage anaerobic reactors, average overall removal efficiencies up to 85%, 69%, 88%, 91% and 89% were achieved for COD Total, COD Soluble, BOD₅, TSS and VSS, respectively [5]. The purpose of this research is to treat wastewater effluent with advanced treatment
utilizing aerobic biofilter with bio-balls medium to obtain effluent quality in accordance with the effluent quality standard.

2. Research Method

2.1. Reactor Description
This laboratory scale research, two boxes shaped biofilter reactors is made of glasses 8 mm thick. Design dimension is 20 cm x 30 cm x 70 cm with treated capacity of 36 L (Figure 1). Bio-balls medium with 3 cm diameter are made of PVC. There is a buffer from the wire as a media holder at 10 cm up from the base of reactors. The sampling tap is 10 cm from the base of reactors and sludge tap placed under the base of reactors. Other devices that complement the biofilter reactor are waste barrel, submersible pumps, recirculation pumps, and aerators. The effluent were accommodated in a 150 L water barrel provided by submersible pump. Aerators serve to keep the microorganisms in the reactor remains in aerobic conditions.

![Figure 1. Design of aerobik biofilter reactor.](image)

2.2. Seeding and Acclimatization
Reactors were seeded with microorganisms directly by circulating wastewater. Seeding was used EM₄ diluted with aquadest with a ratio of 1/10 (10%). Use of 10% EM₄ refers to the EM₄ procedure for liquid waste treatment. One liter of EM₄ is mixed with 10 L aquadest and added 5 tbsp of liquid brown sugar, then fermented for 4 days in tightly closed condition with room temperature. This process aims to seed and activate the existing microorganisms in EM₄ so that microorganisms can work optimally when mixed with wastewater in the reactors. EM₄ which has been fermented, mixed into the waste with the amount of 34.2 L of waste water + 1.8 L EM₄ (5%) [6].

Every day nutrients were added to provide food to microorganisms in wastewater based on composition of COD : N: P = 100: 5: 1. Nutrients were added as follows, glucose, NH₄Cl, KH₂PO₄, MgSO₄.7H₂O, CaCl₂.2H₂O, and FeCl₂. During seeding, VSS was analyze to determine the biomass content. The seeding is carried out until the level of VSS ± 2000 mg/L.

Acclimatization started by replacing the wastewater from seeding with the effluent wastewater gradually. The water replacement starts with the ratio of 1/3 to 100% of the original waste water. Acclimatization operated continuously with a residence time of 24 h. Acclimatization was stopped when the concentration of COD removal reached 80%.

2.3. Operation of Reactors
Reactors operated continuously with 5 variations of retention time, started with the longest time as follows, 24 hours, 18 hours, 12 hours, 8 hours, and 4 hours. The flows for each retention time were 1.5 L/h, 2 L/h, 3 L/h, 4.5 L/h, and 9 L/h, respectively.
After the residence time with the largest removal efficiency was obtained, variation of Carbon : Nitrogen : Phosphor = C:N:P ratios added were 100:5:1, 100:8:1, 100:10:1, 100:12:1, 100:15:1 with the optimum retention time.

2.4. Sampling Methods and Parameter Analysis

The representative sampling method was collected with combined sample of time type (composite samples). To get a combined sample of time, each mixed sample should have the same volume. Parameters analyzed were COD, TSS, BOD, Ammonia, Nitrite, Nitrate, Phosphate, and Oil and Grease. COD, Ammonia, Nitrite, Nitrate parameters were analyzed daily for each retention time. As for the parameters of TSS, BOD, Phosphate, and Oil and Grease were analyzed at each transition of retention time.

2.5. Substrate Degradation Kinetics

The rate of substrate degradation kinetics aims to determine the extent of substrate reduction in wastewater treatment. The process of removing pollutants is very specific depending on the characteristics of wastewater, biomass colonies, and media characteristics. Microbial growth based on Monod equation [7]:

\[
\frac{\partial x}{\partial t} = \mu x
\]  

\( \frac{\partial x}{\partial t} \) = cell growth rate, (mass/(vol.time)), \( \mu \) = specific growth rate, time\(^{-1}\), \( x \) = biomass concentration

The growth coefficient based on Monod Equation developed into Burk-Lineweaver Method:

\[
\frac{1}{\mu} = \frac{K_s}{\mu_{max}} \frac{1}{S} + \frac{1}{\mu_{max}}
\]  

\( \mu_{max} \) = maximum specific growth rate, time\(^{-1}\), \( K_s \) = half-velocity constant"—the value of S when \( \mu/\mu_{max} = 0.5 \), \( S \) = concentration of the limiting substrate for growth

The growth yield (Y) is defined as the amount of biomass increase as a result of the use of substrate amounts. If the microorganisms culture condition is constant, then Y is also constant. The growth yield is calculated by the following formula:

\[
x - x_o = Y(S - S_o)
\]  

\( x_o, S_o \) = Initial concentration of biomass and substrate, \( x, s \) = Concentration at time of growth

In every process, not all microorganisms cells are in the growth phase, but there are also microorganisms cells in the phase of death and respiration form. These factors effect the cell mass to decrease and proportional to the reduction of microorganism concentration lead to the mortality rate of microorganisms (K_d) [8].

\[
\mu = \mu_{max} \frac{S}{K_s + S} - K_d
\]  

2.6. Removal Efficiency

The removal efficiency of wastewater treatment is the ratio between organic content that is set aside through the process of processing with initial concentration. The removal efficiency of wastewater treatment is calculated as follows:

\[
\eta = \frac{C_o - C_e}{C_o} \times 100\%
\]  

\( \eta \) = Removal efficiency (%), \( C_o \) = initial concentration (mg/L), \( C_e \) = final concentration (mg/L)
3. Results and discussion

3.1. Characteristics of Wastewater
The effluent wastewater used in this research was sourced from wastewater treatment in Gedung M, Universitas Trisakti, Jakarta Barat. The characteristics of effluent wastewater were presented in Table 1.

| Parameters | Unit | Concentration | Governor Reg No. 122/2005 | National Government Reg 82/2001 Class IV |
|------------|------|---------------|---------------------------|----------------------------------------|
| BOD        | mg/L | 112 – 130     | 50                        | 12                                     |
| COD        | mg/L | 320 – 416     | 80                        | 100                                    |
| TSS        | mg/L | 150 – 270     | 50                        | 400                                    |
| pH         |      | 6.5 – 7.5     | 6 - 9                     | 5 – 9                                  |
| Ammonia    | mg/L | 24.15 – 24.44 | 10                       | -                                      |
| Nitrite    | mg/L | 0.63          |                           | -                                      |
| Nitrate    | mg/L | 18 – 19       | 20                       |                                        |
| Phosphate  | mg/L | 2.4           | 5                        |                                        |
| Oil and Grease | mg/L | 6.8 – 7.2     | 10                       | -                                      |

3.2. Influence of Retention Time on Removal Efficiency
Aerobic biofilter reactors operated continuously with the variation of retention time used as follows, 24 h, 18 h, 12 h, 8 h, and 4 h.

Based on the Figure 2, the largest removal efficiency of COD was obtained at retention time of 24 h with the percentage of 83.33%, then 18 h, 12 h, 8 h, and 4 h with the percentage of removal efficiency were 81.13%, 79.50%, 76.86%, and 73.14%, respectively. The removal efficiency of TSS with the variation of retention time ranged between 79.59% - 83.56% with the largest percentage of 83.56% at the retention time of 24 h. Based on the Figure 3, the largest removal efficiency of Ammonia, Nitrate, and Nitrite at the retention time of 24 h with the percentage 84.62%, 79.17%, and 76.92%, respectively. Concentrations of COD, TSS, and Ammonia had complied with the quality standard of DKI Jakarta in Governor Regulation No. 122 of 2005. Nitrate concentration had fulfilled the quality standard of National Government Regulation No. 82 of 2001.

3.3. Influence of C:N:P Ratios on Removal Efficiency
The variation in the C: N: P ratios used were 100: 5: 1, 100: 8: 1, 100: 10: 1, 100: 12: 1, 100: 15: 1 with optimum retention time 24 h. According to Fig. 4, the largest removal efficiency of COD was 83.33% obtained at C: N: P = 100: 1: 1 ratio, then 79.57%, 81.84%, 80.39 %, and 81.72% were obtained at C: N: P = 100: 15: 1, C: N: P = 100 : 12: 1, C: N: P = 100: 8: 1, and C: N: P = 100: 5: 1 ratios, respectively. The largest TSS removal efficiency was 83.56% obtained at a C: N: P = 100: 10: 1 ratio, then 80%, 82.01%, 82.55%, and 83.14% were obtained at C: N: P = 100: 15: 1, C: N: P = 100: 12: 1 , C: N: P = 100: 8: 1, and C: N: P = 100: 5: 1 ratios, respectively.
In Figure 5, the removal efficiency of BOD with variation in C: N: P ratios ranges from 75.23% - 82.5% with the largest percentage of 82.5% for C: N: P = 100: 10: 1 ratio. In Figure 6, the largest Ammonia, Nitrite, and Nitrate removal efficiency was obtained in the C: N: P = 100: 10: 1 ratio with the percentage of 82.5%, 79.1%, and 92%, respectively.

The removal efficiency of Oil and Grease with variation in C: N: P ratios ranges from 71% - 84.8% with the largest percentage of 84.8% for C: N: P = 100: 10: 1 ratio. In Figure 7, the removal efficiency of Phosphate with variation of C: N: P ratios ranges from 64% to 70.83% with the largest percentage 70.83% for C: N: P = 100: 10: 1 ratio. The concentration of each parameter has fulfilled the wastewater quality standard of DKI Jakarta in Governor Regulation No. 122 of 2005 and National Government Regulation No. 82 of 2001.

3.4. Reaction Kinetics in Removal of COD
Figure 8 showed reaction kinetics in degradation of COD obtained linear equation was $y = -6.604x + 101.3$ with regression value $R^2 = 0.903$, and values of $\mu_{max} = 0.0767/h$, $Y=0.19$ mg VSS/mg COD, $K_d = 0.0006/h$, and $K_s = 119.14$ mg/L.

4. Conclusion
The results showed that the optimum variance of retention time was 24 hours and the ratio of C:N:P was 100:10:1 yielded the largest removal efficiency for 83.33% of COD, 87.33% of BOD, 82.5% of Ammonia, 79.1% of Nitrate, 92% of Nitrite, 84.82% of Oil and Grease, and 70.83% of Phosphate. The concentration parameter resulted from outlet biofilter has met the domestic wastewater quality standard of DKI Jakarta. Reaction kinetics in degradation of COD obtained regression value of 0.903 close to 1 with value of $\mu_{max} = 0.0767/h$, $Y=0.19$ mg VSS/mg COD, $K_d = 0.0006/h$, and $K_s = 119.14$ mg/L.

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