Greywater Treatment using Vermifilter

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1. Introduction

Surabaya is a densely populated city with a population growth of 2.89 million and 0.37% in 2019 (Santoso dan Nukyanto, 2020). The amount of wastewater is increasing along with the increase in population (van Puijenbroek et al., 2019). About 80% of clean water will turn into domestic wastewater (Ghasemi et al., 2020). Greywater contains organic materials, food particles, cooking oil and fat, nitrogen, phosphorus, and surfactants (Rakesh et al., 2019; Ratnawati et al., 2020).

Surabaya City has had ten communal Wastewater Treatment Plants (WTP) already with Anaerobic Baffled Reactor (ABR) and Anaerobic Filter (AF) technology. They are available in various districts (Nilandita et al., 2019). Some areas have not had communal properties yet. People dispose of blackwater domestic waste into septic tanks, while greywater is directly discharged into sewers without treatment (Hidayah et al., 2018; Tan et al., 2019), causing odors, puddles in the gutters during the dry season and water pollution (Hidayah et al., 2018; Kurnianingtyas et al., 2020).

Wastewater treatment with ABR and AF has not been optimal in the removal of pollutant loads, with the removal of 62.5%. Total Suspended Solid (TSS), 25% Biological Oxygen Demand (BOD), 17.23% Chemical Oxygen Demand (COD), 71.42% oil (Nilandita et al., 2019), suspended solid brought to the outlet (Kurnianingtyas et al., 2020). To reduce the polluting load of greywater waste, the Surabaya City government should apply a waste treatment that is more cost-efficient and electric, easy to operate, and applicable to households and communal (Ratnawati et al., 2020).

Vermifilter recommends treating greywater waste on a household scale. It is cost-efficient, odor-free, and does not produce sludge (Shokouhi et al., 2020), does not need chemicals (Ghasemi et al., 2020). The design is simple. It does not require sophisticated equipment, and it can reduce pollutants higher (Singh et al., 2019b). The vermifilter technology utilizes earthworms combined with vermicibed and filtration media in treating waste (Ghasemi et al., 2020). Thus, earthworms’ symbiosis with microbes occurs in degrading waste. Earthworms and microbes in the intestines of worms will degrade organic substances by eating and absorbing them through the intestinal wall. It results in a decrease in BOD, COD, TSS, and nutrients (Kumar dan Ghosh, 2019). The movement of earthworms in vermicibed can increase oxygen levels. Hence, it benefits aerobic microbes, degradation increases (Ghasemi et al., 2020), and reduce odors and sludge (Singh et al., 2019b). The earthworms produced can be used in the fields of fisheries, animal...
husbandry, pharmacy, and cosmetics (Persulessy et al., 2020).

Many studies on wastewater treatment use vermicomposting, including blackwater domestic waste treatment which can reduce TSS and Total Solid (TS) 99-100% & BOD 99%, COD 98%, nitrogen 99% and phosphate 99% (Kosliengar et al., 2020). The processing of dairy industry wastewater can reduce TDS by 79%, TSS by 75%, COD by 67%, oil and fat by 69% (Rustum et al., 2020), and BOD by 90.43% (Samal et al., 2018a). Domestic waste treatment can reduce COD by 80%, Nitrate by 80% and turbidity by 90% (Ghasemi et al., 2020).

The success of vermicomposting is affected by several factors, including earthworm density, Hydraulic Retention Time (HRT), and filter material (Adugna et al., 2019). Filter materials serve to separate pollutants and create a conducive environment, thus, worms and microbes can live well (Adugna et al., 2019). The top layer (vermibed) functions as a place for worms to live (Samal et al., 2018a). The vermibed material should be organic materials because it is food for worms and microbes to grow well (Samal et al., 2018a; Singh et al., 2018). Materials vermibed used are sawdust, cow dung (Adugna et al., 2019), domestic organic waste, garden soil, and vermicompost (Samal et al., 2018a). The layer of vermicomposting media functions as a place to live for microbial colonies, as an adsorbent, and as a filtration unit, the material can be used river stones (Adugna et al., 2019; Singh et al., 2019b), sand, gravel (Samal et al., 2018a; Singh et al., 2018).

Only a few studies discussed the effect of vermibed material (top layer) on vermicomposting performance. This research aims to examine the effect of vermibed material on vermicomposting performance in treating greywater waste, especially on the concentration of BOD, NH₃-N, and Dissolved Oxygen (DO).

2. Methodology

2.1 Materials

The materials used in this research were domestic wastewater, gravel, rough sand, coconut fiber, mustard greens, cabbage, garden soil, sawdust, banana stalk, cow dung, and earthworms *L. rubellus*. The materials used for the analysis of COD parameters are K₂Cr₂O₇ pro analysis (Merck), Ag₂SO₄ pro analysis (Merck), HgSO₄ pro analysis (Merck), NH₄)₂Fe(SO₄)₂·6H₂O pro analysis (Merck), and feroin. BOD analysis using MnSO₄ pro analysis (Merck), Kalki-lodida-Azida, Na₂S₂O₃ pro analysis (Merck), H₂SO₄ pro analysis (Merck), amilum, buffer fosfat, MgSO₄ pro analysis (Merck), KCl pro analysis (Merck), and inoculum from PT. SIER. NH₃-N analysis using CuH₂OH pro analysis (Merck), CsFeN₂O₂ pro analysis (Merck), CuH₂NaO₄ pro analysis (Merck), NaClO pro analysis (Merck). The equipment used in this research were reactor vermicomposter, pH meter, and spectrophotometer.

2.2 Design of Vermicomposter

The vermicomposting reactor design is shown in Figure 1. This research is on a laboratory scale with four reactors with three replications. The reactor used a plastic box 59 cm, long 38 cm wide, and 29 cm high. Media with the composition is presented in Table 1. The porosity of rough sand, gravel, and coconut fiber media was 47.73%. Each vermibed in the vermibed layer was inoculated with 30 Lumbricus rubellus (L. rubellus) worms. The treated greywater came from dense settlements in Surabaya City, Indonesia. Before using it as a vermibed, the sap in sawdust was removed (Mahogany and Dutch teak) by soaking it for 24 hours. Remove NH₃-N in cow dung by drying it in the sun for seven days (Anggada et al., 2019). The mustard greens and cabbage were fermented for three weeks, and banana stalks *Musa paradisiaca* for seven days (Nurdiansyah et al., 2018). When it was used as vermibed, the material with garden soil was mixed in a ratio of 1:3, so that the porosity of the vermibed was higher and that the worms were easy to move (Samal et al., 2018a; Singh et al., 2018). Coconut coir contains lignin (35%-45%) and cellulose (23%-43%). Carboxyl groups in cellulose and phenolic acids in lignin function as biosorbents (Ganing dan Mappau, 2019). Coconut coir filter media can reduce BOD 98.58% and TSS 83.51% liquid waste from fast food restaurants (Utomo et al., 2018).

2.3 Water Sample

The domestic wastewater used in this study was taken from domestic waste disposal in Dukuh Menanggal Village, Gayungan District, Surabaya, East Java. The collection was carried out at three locations. Sampling was conducted during the dry season so that it was not mixed with rainwater. Wastewater sampling was carried out at around 08.00 with the assumption that the community at that time was carrying out activities that produced domestic wastewater. The wastewater before...
being treated is mixed in the reactor to make it homogeneous. Gravel, rough sand, coconut fiber, mustard greens, cabbage, garden soil, sawdust, banana stalk, cow dung, and earthworms *L. rubellus* were obtained from around Surabaya.

### 2.4. Seeding and Acclimitation

Seeding and acclimating gravel, rough sand, and coconut fiber needed seven days using greywater (Rahmadyanti et al., 2020; Singh et al., 2021). Acclimatizing worms in vermibed needed three days (Fadilah et al., 2017; Nurdiansyah et al., 2018). The greywater flew from the influent tank through perforated pipes that extend above the reactor so that it dripped evenly over the vermibed surface. Greywater passed through the vermibed and filtration media, then came out as an effluent through a pipe under the reactor. Maintain Hydraulic Retention Time (HRT) of about 3.1 days and the Hydraulic Loading Rate (HLR) BOD of about 0.1 kg BOD m\(^{-3}\) day\(^{-1}\). Analysis of BOD, NH\(_3\)-N, and DO, on days 0, 3, 6, 9, 12, and 15 with three replications.

<table>
<thead>
<tr>
<th>Table 1. Vermifilter Media Composition.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layer to Aggregate</td>
</tr>
<tr>
<td>size (cm)</td>
</tr>
<tr>
<td>1(^{st}) (Top layer/vermibed)</td>
</tr>
<tr>
<td>2(^{nd})</td>
</tr>
<tr>
<td>3(^{rd})</td>
</tr>
<tr>
<td>4(^{th})</td>
</tr>
<tr>
<td>5(^{th}) (Bottom layer)</td>
</tr>
</tbody>
</table>

![Figure 1. Vermifilter Reactor](image)

### Table 2. The Initial Characteristics of Greywater.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Quality standards*</th>
<th>Influent</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD concentration</td>
<td>mg/L</td>
<td>30</td>
<td>310.00±8.16</td>
</tr>
<tr>
<td>COD concentration</td>
<td>mg/L</td>
<td>100</td>
<td>590.00±10.00</td>
</tr>
<tr>
<td>NH(_3)-N concentration</td>
<td>mg/L</td>
<td>10</td>
<td>13.17±0.29</td>
</tr>
<tr>
<td>pH value</td>
<td>-</td>
<td>6 - 9</td>
<td>4.77±0.03</td>
</tr>
<tr>
<td>Temperature value</td>
<td>°C</td>
<td>-</td>
<td>27.00±0.00</td>
</tr>
<tr>
<td>DO concentration</td>
<td>mg/L</td>
<td>-</td>
<td>2.15±0.01</td>
</tr>
</tbody>
</table>

* (Minister of Environment and Forestry of the Republic of Indonesia, 2016)
2.5. Analysis

BOD analysis was performed by analyzing DO on day 5 minus DO on day 0. DO analysis using the Winkler method is to fill the Winkler bottle completely and close it, then add 1 ml of MnSO₄ and 1 ml of Alkal-Iodide-Azide solution and close it again. Wait 5-10 minutes until it clumps and settles. Added 1 ml of H₂SO₄ inverted until the precipitate disappears. Then titrated with Na₂SO₃ and starch indicator. Ammonia analysis using a spectrophotometer with a wavelength of 640 nm. Before measuring the absorption, 50 ml of the sample was added with 1 ml of phenol and 1 ml of sodium nitroprusside, 2.5 ml of oxidizing solution (C₆H₅Na₃O₇ and NaClO solutions) then closed and left for 1 hour to form a color. pH analysis using a pH meter. Temperature analysis with a thermometer. COD analysis was carried out by closed reflux method using K₂Cr₂O₇ and added a mixed solution of H₂SO₄ and Ag₂SO₄. Oxidation was carried out at high temperature for 2 hours. Then titrated with (NH₄)₂Fe(SO₄)₂·6H₂O and ferroin indicator. COD analysis (Agency, 2004a), BOD₅ (Agency, 2009), NH₃-N (Agency, 2005), DO (Agency, 2004b), pH SNI 6989.11:2019, temperature SNI 06-6989.23-2005. Concentration difference test by analysis of varian (ANOVA) and parameter concentrations in mean ± standard deviation.

3. Results and Discussion

3.1. Greywater Characteristics

Greywater’s effect is cloudy and black. Table 2 presents the chemical characteristics of greywater. Referring to the (Minister of Environment and Forestry of the Republic of Indonesia, 2016) for parameters BOD, NH₃-N has not met the quality standard. The BOD/COD concentration ratio of 0.53 was in the range of 0.30-0.80. It indicates that wastewater is biodegradable, and untreated (Nurhayati et al., 2019; Ratnavati dan Sugito, 2021). The low DO concentration was due to the high concentration of organic substances (Singh et al., 2019b; Sugito et al., 2021). The high concentration of NH₃-N in greywater came from urine, feces, and the degradation of organic nitrogen by bacteria into NH₃-N (McCarty et al., 2020). High NH₃-N concentrations can cause poisoning in aquatic biota (Singh et al., 2019b).

3.2. BOD Concentration

Figure 2, shows all reactors experienced removal of BOD from day 3 to day 15. The removal of BOD increased in all reactors, VF1 reactor on day 3 removal BOD by 64.73% and at the end of the experiment by 89.89%. VF2 was from 66.66% to 92.36%. VF3 was 68.49% to 94.51%. VF4 was from 62.25% to 92.90%. The decrease in BOD occurred because earthworms have a symbiosis with microbes in degrading organic substances (Singh et al., 2019b; Sugito et al., 2021). Complex organic substances were degraded by being eaten, absorbed through the skin, digested, and excreted by worms so that they became soluble organic substances that are easily broken down by microbes (Samal et al., 2017a; Singh et al., 2021, 2019b).

Mucus worms can increase aerobic microbes and the degradation of organic substances (Samal et al., 2018a; Singh et al., 2019b). The movement of worms in vermibed can increase oxygen, the number of microbes, and the degradation of organic substances(Singh et al., 2019b). Microbes in the intestines of worms help digest organic substances (Kumar dan Ghosh, 2019). Sand and gravel media function as adsorbents, filtration media, and as a place for microbial colonies to grow (Kumar dan Ghosh, 2019; Singh et al., 2019a). Coconut fiber is also an adsorbent of organic substances (Carvalho Costa et al., 2020). Carboxyl groups in cellulose and phenolic acids in lignin act as adsorbents. Domestic wastewater treatment with aerobic-anerobic infiltration wells can reduce BOD 92.69% and COD 85.72% (Ganing dan Mappau, 2019)
the same as research on greywater treatment with vermifilter, with BOD concentrations removal of 97.6% (Adugna et al., 2019). Blackwater processing with vermifilter reduces organic matter was 99% (Koslengar et al., 2020). Table 3 shows that ANOVA test on the concentrations of BOD of all reactors showed that the four vermibeds did not give a significant difference (P-value > α, α = 0.05).

3.3. \( \text{NH}_3\text{-N} \) Concentration

Figure 3 shows that the \( \text{NH}_3\text{-N} \) concentration in all vermifilter has decreased. Influent greywater contained 13.17 ± 0.29 mg/L \( \text{NH}_3\text{-N} \). The high concentration of \( \text{NH}_3\text{-N} \) in greywater showed that microbes degrade organic and inorganic nitrogen in wastewater into \( \text{NH}_3\text{-N} \) (Singh et al., 2019b). The removal of \( \text{NH}_3\text{-N} \) increased in all reactors. VF1 reactor on day 3rd removal \( \text{NH}_3\text{-N} \) was 71.39% and at the end of the experiment was 97.84%. VF2 from 69.62% to 98.08%. VF3 was from 76.65% to 98.46%. VF4 was from 71.62% to 98.89%.

The removal of \( \text{NH}_3\text{-N} \) occurred due to the nitrification process by Nitrosomonas sp bacteria oxidizing \( \text{NH}_3\text{-N} \) to nitrite (Ratnawati dan Sugito, 2021). Nitrobacter bacteria oxidize nitrite to nitrate (Nurhayati et al., 2019; Singh et al., 2019b). Bacteria need oxygen to reduce \( \text{NH}_3\text{-N} \). The higher the oxygen level, the higher the reduction of \( \text{NH}_3\text{-N} \) (Samal et al., 2018a). The decrease in \( \text{NH}_3\text{-N} \) in the vermifilter occurred due to the symbiosis of worms with microbes. The intestines of earthworms contained nitrifying and denitrifying bacteria. The movement of worms in vermibed will increase oxygen and increase \( \text{NH}_3\text{-N} \) degradation (Samal et al., 2017b). The mucus in the skin of worms contains microbes that can increase the degradation of \( \text{NH}_3\text{-N} \). Ammonification and nitrification processes occur in vermibed and biofilter media (Samal et al., 2018a; Singh et al., 2019b). The decrease in \( \text{NH}_3\text{-N} \) was also due to the adsorption process on sawdust. Sawdust was an excellent adsorbent for removing \( \text{NH}_3\text{-N} \) from aqueous solutions (Adugna et al., 2019). Table 4 shows that ANOVA test on the concentrations of \( \text{NH}_3\text{-N} \) of all reactors indicated that the four vermibeds did not give a significant difference (P-value > α, α = 0.05).

The removal of \( \text{NH}_3\text{-N} \) increased because of an increase in the number of microbial colonies and DO in the wastewater. This research was almost in line with research on black water processing that vermifilter can reduce \( \text{NH}_4^+ \) 99% (Koslengar et al., 2020). Feedlot runoff processing with vermifilter removal total nitrogen got higher, and the average reduction was 34.4-38.8% (Singh et al., 2021).

3.4. DO Concentration

The oxygen concentration in the vermifilter affected the symbiosis process of earthworms with microbes. DO assisted oxidizing pollutants in wastewater. Figure 4 shows the DO concentration during the study.

All vermifilter reactors with DO concentrations increased from day 3 to day 15. The results also showed an increased DO in all reactors. VF1 reactor on day 3 increased DO by 23.43% and at the end of the experiment was 167.18%. VF2 was 29.68% to 187.03%. VF3 was from 50.00% to 259.37%. VF4 was from 35.94% to 273.44%.
Table 3. ANOVA Analysis in BOD Concentration.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>149.7535</td>
<td>3</td>
<td>49.917824</td>
<td>0.0043711</td>
<td>0.999588</td>
<td>3.098391</td>
</tr>
<tr>
<td>Within Groups</td>
<td>228396.9</td>
<td>20</td>
<td>11419.847</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>228546.7</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4. ANOVA Analysis in NH$_3$-N Concentration.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>1.298622</td>
<td>3</td>
<td>0.432874</td>
<td>0.017148</td>
<td>0.996838</td>
<td>3.098391</td>
</tr>
<tr>
<td>Within Groups</td>
<td>504.8544</td>
<td>20</td>
<td>25.24272</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>506.1531</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. ANOVA Analysis in DO Concentration.

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
<th>F crit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>5.983857</td>
<td>3</td>
<td>1.994619</td>
<td>0.517608</td>
<td>0.674931</td>
<td>3.098391</td>
</tr>
<tr>
<td>Within Groups</td>
<td>77.0707</td>
<td>20</td>
<td>3.853535</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>83.05455</td>
<td>23</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Table 6. The BOD, NH$_3$-N, and DO Final Concentration.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Quality standards*</th>
<th>Effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>VF1</td>
</tr>
<tr>
<td>BOD concentration</td>
<td>mg/L</td>
<td>30</td>
<td>29.66±4.49</td>
</tr>
<tr>
<td>NH$_3$-N concentration</td>
<td>mg/L</td>
<td>10</td>
<td>0.28±0.029</td>
</tr>
<tr>
<td>DO concentration</td>
<td>mg/L</td>
<td>1</td>
<td>5.70±0.00</td>
</tr>
</tbody>
</table>

*(Minister of Environment and Forestry of the Republic of Indonesia, 2016)

Before being treated with greywater, the DO concentration was low because it contained high organic substances. During treatment, the concentration of organic substances decreased so that the DO concentration increased (Samal et al., 2017a; Singh et al., 2019b). The movement of earthworms in vermibed also caused an increase in DO concentration (Singh et al., 2019b). The results of this research were almost in line with research on pig waste treatment with vermicompost (Manyuchi et al., 2019). Table 5 shows that the ANOVA test on the concentrations of DO of all reactors indicated that the four vermibeds did not give a significant difference (P-value>α, α = 0.05).

3.4. The Effect of Vermibed on the BOD, NH$_3$-N, and DO Concentration

Vermibed is the top layer of the vermicompost and it is an active site for worms to live (Singh et al., 2019b). Earthworms and microbes can grow and develop well if vermibed contains organic substances and has high porosity. Vermibed plays a role in the degradation of organic matter because it is a habitat for worms and aerobic microbes (Samal et al., 2018b). Vermibed with high porosity can increase the removal of organic substances and nutrients (Samal et al., 2018a). Compost is vermibed. It is good for earthworms and microbes (Singh et al., 2018). Table 6 shows that all vermicompost reactors at the end of the study had decreased concentrations of BOD, NH$_3$-N, and increased DO. At the end of the study, BOD concentrations were between 22.00-31.00 mg/L, NH$_3$-N concentrations between 0.14-0.28 mg/L, and DO 5.70 – 7.96 mg/L.

A literature review found the content of organic substances. Nitrogen in cow dung is higher than in another livestock manure. So, worms prefer such manure (Dani et al., 2017). Cabbage and mustard greens are organic waste that worms like because they
are odorless. They also have high protein content (Nirigi et al., 2019). The protein content in cabbage is around 1.5%, and water is between 65-80% (Rusad dan Santosa, 2016). The humidity preferred by worms is between 60 -75% (Manyuchi et al., 2019). Supporting research was urban waste treatment using vermibed organic waste. It can reduce BOD 98.5%, COD 74.3%, TSS 96.6%, and NH₄ + 99.1% (Lourenço dan Nunes, 2017).

4. Conclusion

The research shows that vermifilter technology was effective to reduce BOD concentration and NH₃-N concentration. It applied various process condition, material vermibed used mixture of mustard greens and cabbage, sawdust, banana stalk, and cow dung, duration of research of 3, 6, 9, 12 and 15 days. The longer research process, lower the concentration of BOD concentration and NH₃-N, and the higher the DO concentration and pH value. The percentage of BOD concentration was 94.52%, NH₃-N concentration was 98.99%, increase DO concentration was 278.13 % and pH value of 5.70-7.96. Vermibed materials (mixture of mustard greens and cabbage, sawdust, banana stalk, and cow dung) did not give a significant difference in BOD concentration, NH₃-N, DO, and pH value (p > 0.05). Vermifilter combined with plant is also recommended to be further research.

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