Tofu’s Liquid waste treatment by continuous vermibiofilter column-type reactor

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Abstract. The demands of tofu as food constantly increase in Indonesia, a large amount of clean water for production process of this food enhance significantly and resulting amount of liquid waste discharging goes to the sewer system increase and finally arrive into the streams or rivers in almost all big cities in Indonesia. Currently, only view of tofu makers which have waste water treatment plant however far from the standard which is expected for treating this liquid waste. Sampling of this liquid waste from centre of tofu maker were not comply the ministry of environment and forestry regulation (PerMenLH No.5 Tahun 2014). Therefore, in this study we have used vermibiofilter column-type reactor for treating Tofu’s liquid waste for reducing the concentration of pollutant. Vermibiofilter has chosen since this technique is regarded as simply way for treating the tofu’s liquid waste and also will provide a benefit for earthworm farmer in which this tofu’s liquid waste is food stuff for earthworm. The Species of earthworm we have used was Lumbricus rubellus that is an endemic earthworm in Indonesia. Usage of earthworm in biofilter column-type reactor shown that the removal efficiency of turbidity, TSS, COD, and BOD are 99.2 %, 66.19 %, 80.77 % and 81.05 % respectively and for column-type reactor without having earthworm (biofilter) as a control, the removal efficiency for Turbidity, TSS, COD and BOD are 98.4 %, 41.93 %, 66.77 % and 66.7 % respectively. This result showed that earthworm Lumbricus rubellus plays significant role for degrading organic matter, producing the microorganism decomposer and also absorbing organic matter.

Keywords: column-type reactor; earthworm; tofu’s liquid waste; vermibiofilter

1. Introduction

Tofu is one of many favorite foods in Indonesia however for making this tofu needs large amount of clean water. One kilogram of soybean needs 45 litres clean water to produce tofu [1] and liquid waste released was around 15-20 liters [2]. Clean water needs for every tofu production process for 3 kg of soybean is described in Table 1 [3]. According to data we collected that there are 60 tofu makers in Warung Muncang village which famous place as Centra of tofu Cibuntu at Bandung City, West Java. Each of these tofu makers spent approximately 2-9 tones soybean per day to produce tofu. Therefore, for every ton of soybean to make Tofu needs around 45 m³ of clean water and approximately equals to 20 tons of liquid waste produced. Solid waste which is resulted from tofu production can be used for cattle feds; however currently the liquid waste cannot be used for other benefit. This liquid waste

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contains of protein 40-60%, carbohydrate 25-50 %, oil and grease around 10 % and apparently as a thick liquid (whey) physically [4]. Concentration of this liquid waste for BOD around 7.800 mg/L, COD around 9.256 mg/L, Total suspended solid around 330 mg/L and pH 4.19 [5]. The content of organic carbon varies between one tofu productions with another. Because the recipe for tofu production depends on how much clean water is used to clean soybeans and the process steps that occur. Sometimes after the manufacturing process ends, the liquid waste is discharged directly into the sewer system where the temperature of the liquid waste is between 40-46 ºC. This affects the ecosystem of water bodies where dissolved oxygen will suddenly drop; Total nitrogen will increase and create anaerobic conditions because complex organic decomposition occurs through streams and rivers.

Because large effluent comes from tofu production is not usable and a problem come from earthworm farmers due to scarcity of cow dung as feeding stuff for earthworm culture, therefore we did a study to find out whether the *Lumbricus rubellus* earthworm can reduce pollutant of tofu’s liquid waste and also this tofu’s liquid waste could be a food source for *Lumbricus rubellus* earthworm. Earthworm is known has high economic values for cosmetics, medicine, fishery aqua culture and livestock [6,7]. Many studies relate to these earthworms (*Eisenia fetida*) for reducing liquid waste have been done with low cost bio-safe technique and most suitable for waste water and sludge treatment of WWTPs in developing countries. Several type-reactors also have been introduced for growing earthworm for removing the pollutant such as BOD, COD, TSS, Turbidity and colour [8–10]. *Lumbricus rubellus* has been chosen since rarely used for removing pollutant and become our concern in this study.

2. Materials and Methods

2.1. Raw Tofu’s liquid waste

Tofu’s liquid waste effluent was collected from centre of Tofu Cibuntu at Bandung City, West Java where tofu makers produced tofu. 15 litres of tofu’s liquid waste was taken and put into the plastic drum and taken to Laboratory and then transferred to 7 litter of yellow plastic bucket which was equipped with small capacity aerator to blow air into this tofu’s liquid waste in order to avoid fault odour. Temperature for this study in laboratory was around 25-27 ºC. Collecting sample was done twice a week for observing the fluctuation of effluent during one month and the characteristic of this tofu’s liquid waste was showed in Table 1.

There was fluctuation of pollutant content occurred in effluent taken from that sampling sources. We also did interview regarding to amount of raw material (soybean) that tofu maker used. Surprisingly, the fluctuation is related to the capacity of production which also depend on the order from customers. Table 2 shows the standard effluent allowable for discharging to water bodies.

| Parameter | unit | Concentration |
|-----------|------|---------------|
| pH        | -    | 4.3 – 4.79    |
| Turbidity | NTU  | 1,206 – 1,663 |
| TSS       | mg/L | 85.16 – 205.29 |
| COD       | mg/L | 5,000 – 8,000 |
| BOD5      | mg/L | 5,394 – 7,704 |
Table 2. Standard effluent allowable for soybean industrial process according to PerMenLH No. 5 year 2014

| Parameter               | Soybean process | Soy Sauce | Tofu | Temphei |
|-------------------------|-----------------|-----------|------|---------|
|                         | Content (mg/L)  | Load (kg/ton) | Content (mg/L) | Load (kg/ton) | Content (mg/L) | Load (kg/ton) |
| BOD                     | 150             | 1.5       | 150  | 3       | 150  | 1.5       |
| COD                     | 300             | 3         | 300  | 6       | 300  | 3         |
| TSS                     | 100             | 1         | 200  | 4       | 100  | 1         |
| pH                      |                 |           | 6-9  |        |      |           |
| Maximum waste water     |                 |           | 10   | 20      | 10   |
| quantity (m³/ton)       |                 |           |      |        |      |           |

Source: PerMenLH No.5, 2014

2.2. Setting-up vermibiofilter column-type reactor

Two identical column-type reactors made of transparent acrylic and equipped with four drain valves (sampling points) of each reactor, with rectangular shape of 10 × 10 × 100 cm were used (Figure 1) and consisted of 4 layers of bio-filter. Figure 2 shows the earthworm was used in this study and sampling from this farming. To protect worms from predators (ants and rats) and to avoid a direct contact with sunlight, the reactors were monitored every day. The plastic net was installed below top layer and above sampling port SP4 for protecting worms borrowing deeply into this layer. In this topmost layer of 10 cm × 10 cm × 20 cm was the bed material contained soil mixed with fewer amounts of cow dung and earthworms which were released in reactor (A) and without earthworm in reactor (B) as control. Two sprinkler systems were used for trickling tofu’s liquid waste that allowed a uniform distribution on bed material of both reactors (A and B) from the top. Tofu’s liquid waste from the drums flowed through flexible plastic hose by gravity. Tofu’s liquid waste percolated down through various layers in these two reactors passing through bed material (A and B). Every valve was closed when tofu’s liquid waste flows into both reactor until this liquid waste goes up to third layer or below the soil-cow dung bed.

![Figure 1. Two identical column-type reactors](image-url)
Furthermore, the valve of bottommost layer (sampling points P1 and P1’) act as effluent controls to keep the rate of influent and effluent flow in these two reactors constant without letting the flooding of cow-ground dung with tofu wastewater. From P1, P1 ‘and P4, P4’ is the lowest and highest sampling port, tofu liquid waste treated is collected and analysed for BOD, COD, pH, turbidity, and TSS. The analytical techniques established by the standard methods were followed during the study described in Table 3.

### Table 3. Analysis method for determining pH, Turbidity, TSS, COD and BOD₅

| Parameter | Methods           | Standards                  |
|-----------|-------------------|----------------------------|
| pH        | Potentiometry     | SNI 06-6989.11-2004        |
| Turbidity | Turbidimetry      | SNI 06-6989.25-2005        |
| TSS       | Gravimetry        | SNI 06-6989.3-2004         |
| COD       | Closed reflux     | SNI 6989.73:2009           |
| BOD₅      | Winkler Titration | SNI 6989.72:2009           |

HRT is very important because this is the actual time spent by earthworms with liquid waste to take organic material from it as food. HRT of vermibiofilter system can be calculated using equation (1):

\[
HRT = \frac{(\rho \times V_s)}{Q_{\text{liquid waste}}} 
\]

where HRT = Theoretical hydraulic retention time (hours); V_s = volume of the soil-cow dung profile (vermibiofilter bed), through which the liquid waste flows and which have live earthworms (cum); \( \rho \) = porosity of entire media (aggregate gravel, sand and soil) through which liquid waste flows; \( Q_{\text{liquid waste}} \) = flow rate of liquid waste through vermibiofilter bed (cum/h). In this study, tofu liquid waste was channelled into reactors A and B, each 4 mL / minute with porosity of all media was 18% and HRT for each reactor was 1 hour and 30 minutes.

HLR is defined as the volume of liquid waste applied, per unit area of the ground-cow dung profile (bed vermibiofilter) per unit time. It really depends on the number of live adult earthworms that function per unit area in the vermibiofilter bed. HLR of vermibiofilter system can be calculated using equation (2):
HLR = \frac{V_{\text{liquid waste}}}{(A \times t)} \quad (2)

where HLR = hydraulic loading rate (m/h); \(V_{\text{liquid waste}}\) = volume flow rate of liquid waste (cum); \(A\) = area of soil-cow dung profile exposed (sqm); \(t\) = time taken by liquid waste to flow through soil-cow dung profile (h). HLR will vary from soil to soil. The infiltration rate depends on the soil characteristic. In this study, HLR was 0.024 m³/m² hour.

2.4. Earthworm culture and inoculating with eartworms
Earthworms were collected from the local vermiculture farmer namely redworm (\textit{Lumbricus rubellus}). Then the worms were fed with cow dung in a controlled temperature (temperature and moisture content) prior to transferring to Laboratory. Reports says about 8-10.000 numbers of worms per cubic meter of worm bed and of 10 kg media or biomass (soil and vermicast) is effective in term of optimum production and healthy earthworms [9]. However, in this study 40 adult earthworms (approx. 20 grams) was used in 0.002 m³ of soil-cow dung mixture bed exist in the reactor A, as by means of Shinha and his co-worker has done [11]. These earthworms are given 5 days for acclimatization in a new environment while dripping tofu liquid waste through the entire layer of media slowly for acclimatization before the waste is collected for analysis.

3. Results and discussion

3.1. pH value of treated tofu’s liquid waste
Results indicate that the pH value of treated tofu’s liquid waste was improved by earthworms during the treatment process in reactor A (SP1) to become neutral; however in reactor B (SP1’) without earthworm, pH was improved but not consistent as showed during the study (Table 4). Sampling ports (SP4, SP4’) underneath’s soil-dung bed for both reactors were not showing difference but increase of pH value occurred in both reactors.

Differences between SP1, SP4 and SP1’, SP4’ of two reactors shows that there are many factors that influence pH value such as dissolved gas, organic acid, humic substances, and inorganic salts in two reactors. The organic matter decomposition by microbes in liquid waste yields the organic mineral such as \(\text{CO}_2\), \(\text{NO}_3\) and organic acids. That might play an important role in changing the pH value during the study. Reducing of \(\text{NH}_4\) and \(\text{NO}_3\) caused pH value to change [10]. Earthworms can be a trigger to accelerate microbial activity by increasing the population of soil microorganisms. This will cause the bio-film to decompose microbial growth on the gravel aggregate surface to maintain pH at level 7 in reactor A, unlike reactor B. SP4 is a sampling port under the inhabitants of earthworms. This shows that the earthworm itself does not shift towards a neutral pH even though there is a slight increase in pH to neutral. SP1 reactor A clearly shows that biological processes occur and the time when liquid waste passes through the reactor is sufficient to affect the pH in this system. Many studies also mention that after processing using earthworms the pH of treated wastewater becomes neutral [9–11].

Table 4. pH value of treated tofu’s liquid waste in both reactors

| Week | pH value before treating | pH value of treated tofu’s liquid waste |
|------|-------------------------|----------------------------------------|
|      |                         | Reactor A | Reactor B |
|      |                         | SP1  | SP4  | SP1’ | SP4’ |
| 0    | 4.79                    | 7.8  | 6.7  | 7.2  | 5.8  |
| 1st  | 4.49                    | 7.1  | 5.6  | 5.7  | 6.6  |
| 2nd  | 4.88                    | 7.4  | 6.2  | 5.7  | 6.6  |
| 3rd  | 4.3                     | 7.6  | 5.1  | 7.3  | 5.0  |

Note: SP1, SP4; SP1’, SP4’ are sampling ports (drain valve) of both reactors
3.2. Turbidity removal

Turbidity refers to turbidity of wastewater due to the presence of macroscopic and microscopic suspended solids, such as clay, silt and organic matter. The results showed that there was a significant reduction in turbidity of wastewater by earthworms in reactor A (SP1) and reactor B (SP1'), especially in the third week of the study and reached around 99%. For the sampling points P4, P4' from reactors A and B, there is a clear difference between reactors A and B. Reactor A shows the highest displacement compared to reactor B and it seems that the earthworm effect appears in the third week of the study (see Table 5). It seems that earthworms are involved to reduce turbidity by releasing large numbers of bacteria through excretion and creating colony microorganisms on the gravel aggregate surface. These microorganisms eat organic material for their food and there are ionic interactions and chemical bonds between several organic compounds and aggregate gravel minerals, soil and sand.

Table 5. Turbidity value of treated tofu’s liquid waste

| Week | Turbidity of untreated liquid waste (NTU) | Turbidity of treated liquid waste (NTU) |
|------|------------------------------------------|----------------------------------------|
|      | Reactor A | Reactor B |
|      | SP1 | SP4 | SP1’ | SP4’ |
| 0    | 1284 | 635 | 642 | 618 | 698 |
| 1st  | 1663 | 14  | 793 | 641 | 1226 |
| 2nd  | 1206 | 13  | 13  | 638 | 831 |
| 3rd  | 1347 | 9   | 11  | 22  | 729 |

3.3. Removal of TSS

Total Suspended Solid (TSS) is suspended material with a particle diameter> 1 um when filtered these small particles are held on the surface of paper 0.45 um millipores. TSS affects the turbidity value by blocking the penetration of light into the base of the water body. Phytoplankton photosynthesis in water bodies is the worst and affects the ecosystem food chain in general. Turbidity values cannot be converted to TSS values because turbidity is the optical property of liquids. TSS inconsistencies can be found at the SP1 sampling port, SP1’ starting from the previous sample taken until the second week as also shown at the sampling points P4, P4’, and there is no difference between reactors A and B. However, TSS values indicate that different turns out to occur in the third week as indicated by the decreased TSS value.

Table 6. TSS value of treated tofu’s liquid waste of reactor A and B

| Week | TSS of untreated liquid waste (mg/L) | TSS value of treated liquid waste (mg/L) |
|------|-------------------------------------|----------------------------------------|
|      | Reactor A | Reactor B |
|      | SP1 | SP4 | SP1’ | SP4’ |
| 0    | 205 | 184 | 162 | 172 | 175 |
| 1st  | 179 | 171 | 159 | 171 | 137 |
| 2nd  | 185 | 173 | 164 | 222 | 202 |
| 3rd  | 85  | 29  | 5   | 50  | 32  |
3.4. COD removal
The value of Chemical Oxygen Demand (COD) indicates the charge of organic pollutants which naturally can be oxidized through chemical processes, and causes a lack of dissolved oxygen in water [9]. The efficiency of COD removal in reactor A shows quite better than in reactor B without earthworms especially in the third week of the study (Figure 2) Significant differences between reactors A and B indicate that earthworms play an important role to remove COD pollutants. The activity of earthworms and aerobic microorganisms in reactor A, symbiosis accelerates the decomposition of organic matter [11].

| Week | COD of untreated Tofu’s liquid waste (mg/L) | COD of treated Tofu’s liquid waste (mg/L) |
|------|-------------------------------------------|-----------------------------------------|
|      | COD of untreated Tofu’s liquid waste       | COD of treated Tofu’s liquid waste       |
|      | (mg/L)                                    | (mg/L)                                  |
|      | SP1                                       | SP1'                                    |
| 0    | 5385                                      | 2307                                    |
| 1st  | 6538                                      | 1538                                    |
| 2nd  | 8000                                      | 800                                     |
| 3rd  | 5200                                      | 200                                     |

Table 7. COD values of treated Tofu’s liquid waste
In the first week the sampling showed an increase in transfer efficiency but in the second week the samplings decreased the transfer efficiency at SP4, SP1 and SP4’ sampling points but were still higher than the first sampling of all sampling points. In general, interactions of all bio-filters and earthworms occur in each reactor. Both reactors work properly to remove COD.

3.5. BOD removal
Biochemical Oxygen Demand (BOD) values indicate inconsistent values every week in reactors A and B as explained for the COD values as well (Table 8). However, in general this system works very well where there is a decrease in BOD on SP4 reactor A.

The removal efficiency occurred in the first week of study for reactors A and B. The highest transfer efficiency at the SP1 sampling point (76.65%) was followed by SP4 (65.27%), SP1’ (46.09 %) and SP4’ (44.06 %), respectively. Significant BOD transfer efficiency was observed in the third week in the range of 61 – 97%. These results indicate that not only earthworms but dirt-soil mixtures, gravel aggregate also play an important role in reducing BOD content in bio-filter column type reactors (Figure 5).

Table 8. BOD value of treated tofu’s liquid waste

| Week | BOD of untreated liquid waste (mg/L) | BOD of treated Tofu’s liquid waste (mg/L) |
|------|-------------------------------------|------------------------------------------|
|      | SP1 | SP4 | SP1’ | SP4’ | Reactor A | Reactor B |
| 0    | 5255 | 2438 | 4440 | 4994 | 6267 |
| 1st  | 6359 | 1485 | 2208 | 3428 | 3557 |
| 2nd  | 7704 | 677  | 3286 | 5734 | 4016 |
| 3rd  | 5394 | 1022 | 174  | 1793 | 2099 |
Figure 5. BOD Removal efficiency of treated tofu’s liquid waste

4. Conclusion
The results show that *Lumbricus rubellus* earthworm grows better with tofu’s liquid waste and also there were young earthworms born in the reactor. The removal of TSS, COD, BOD and turbidity occurred with a significant percentage. The pH becomes neutral in the presence of earthworms in the reactor. Column type reactors are only used on a laboratory scale and have shown that the results for removing pollutants are good and can be implemented as part of the entire process at the industrial scale wastewater treatment plant.

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