Implementation of Fine Sand’s Capillary Force to Filter Polluted Water: A Study on Change of Overflow Media Height to the Debit and Quality of Filtered Tofu Liquid Waste

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Abstract. Four identically designed and constructed Capillary-Gravitational Slow Sand Filter (SSF) with different in its overflow media height were parallelly operated to filtered tofu liquid waste for the purpose to identify responses of debit and quality of permeate with the change of overflow media height. The experiment was conducted following 4x4 LS with the overflow media height as the treatment. Besides the debit for clear and polluted water, samples of the liquid waste and the permeate were taken and analysed for TSS, Turbidity, pH, BOD and COD. Result of analysis showed that debit of SSF was 182.6 -252.1 ml/minute for clear water; 81.3 – 153.5 ml/minute for tofu liquid waste; TSS 7.5 – 20.5 mg/L; Turbidity 0.58 – 3.84 NTU; pH 6.8 – 7.2; BOD 1.7 – 35.4 mg/L; COD 3.8 – 108.0 mg/L with removal efficiency more 96% when overflow media 4 cm or more. In conclusion, the SSF Grapilar reduced when it was used to filter polluted water. In terms of pollutant removal, SSF Grapilar was effective; it was able to remove more than 95% of TSS, Turbidity, BOD, COD and neutralized permeate of tofu liquid waste when the overflow media height was 4 cm or more.

1. Introduction
Slow sand filtration (SSF) is considered the oldest and effective method of water purification but little scientific research have been done into its theoretical and application [1] This technology is effective in removal of turbidity, heavy metals, and microorganism such as protozoa, viruses and bacteria [2,3,4]. This method performs high ability and reliability to bear up fluctuations in water quality, no need for chemicals application, easy to install in rural, semi-urban and remote areas, simple in design and operation[5] that suitable for certain purpose or area.

According to Ref. [6], most serious limitation of an SSF; beside the low flow rate filtration, are low removal of colloid-sized particles; low removal of dissolved organic compounds; large space for installation, and routine effort to clean the filter. If these limitations were solved, SSF could be one of the most suitable future method of water purification, as it is also environmentally friendly.

Some modifications to the SSF standard (down flow SSF) in efforts to improve its performance or to solve the problem have been proposed. A Pipe Slow Sand filter (SSF-Pipe) is an SSF that the sand media is placed in a pipe to have the SFF portable. The sand media inside the pipe is divided into numbers of circling layers by thin plate of aluminium. The water to be filtered enters to the filter through small holes along the length of the main pipe, flows into filter medium following the circling flow guide, and exits through the small holes along the length of the outlet (small) pipe located at the centre of the main pipe [7]. Advantages of SSF Pipes are, in addition to low-cost and simple technology manufacturing, small in size so that it is portable and easy to take care. The inlet could be faced down ward that pollutants filtered do not pill at the inlet, makes the SSF flow relatively free of
disturbance. On the other hand, one disadvantage is that it requires an extra careful in constructing; especially when incorporating fine sand as a filter medium into the pipe [8].

Other type of slow sand filter is a horizontal slow sand filter (HSSF). Ref. [9] have designed an HSSF to have slower filtration flow rate that would produce a better quality of permeate. The HSSF filtration tank is in the form of a box having dimension of 110x40x20 cm. The tank is divided into four equal size boxes, each has dimension of 22x40x20 cm; separated with screen. The first box is for very coarse sand; the second box is for medium sand; the third box is for coarse sand; and last box is for gravels. Above the box containing gavels is a tank box for contaminated water to be filtered. Contaminated water to be filtered flows from the tank box for water to the box containing gravels (fourth box); and then to the box of coarse sand (third box); and then to the box of medium sand (second box) and to the box of very coarse sand (first box); and finally leaving the filtration tank through the outlet at the end of the first box. By this dimension, the researcher concluded that the HSSF could produce save drinking water when the grade of filtration is 5% or 10%; however, the researcher recommended to decrease the filter media from medium sand to fine sand; and to increase the length of filter to have better result.

Capillary-Gravitational Slow Sand Filter (SSF Grapilar), is another type of SSF introduced by [10]. The SSF has both capillary-driven-flow side and gravitationally-driven-flow side, since the inlet and the outlet are located at the bottom of capillary side and gravitational side respectively. The capillary side is also called the inflow side; and the gravitational side is also named as outflow side. These two sides are separated by impermeable-thin wall with at least 30 cm in height. To have the inflow side and the outflow side are connected, there must be sand media layers above the separating wall connecting the two sides that is called as an overflow media. Filtration debit and quality of permeate could probably be depended on the height of overflow media height; as the higher the overflow media there would be bigger cross sectional area of flow; and also higher capillary force on top of the overflow media. The purpose of this research was to identify responses on the debit and the quality of the permeate with change of overflow media height to have the basic operational design of the SSF Grapilar.

2. Materials and Methods

2.1. Material and Apparatus
This research was done by filtering tofu liquid waste using Capillary-Gravitational Slow Sand Filter (SSF-Grapilar) made of wood with dimension of 50x50x40 cm. It has inflow-side and outflow-side of 15 cm wide separated by a thin-impervious wall of 30 cm in height (Figure 1). The sand used as media was fine sand found as the result of wind erosion along Pantai Panjang beach in Bengkulu. The tofu liquid waste to be filtered was fresh tofu liquid waste from one of tofu processing industries in Bengkulu City.

Figure 1. Sketch of the Capillary-Gravitational Slow Sand Filter (SSF Grapilar)
2.2. Experiment Set Up

The experiment was conducted following the 4x4 Latin Square design using four SSF Grapilars similarly designed and constructed with the overflow media height as the treatments. The heights of overflow media to be tested were 2, 4, 6 and 8 cm. The liquid waste was placed in a container; flown to each of the SSF through plastic tube connecting the inflow chamber of the SSF and the container.

Samples of the tofu liquid waste and the permeate from each of SSF were collected at the same time when the filtration process had run for one hour to have the filtration flow relatively constant. Each sample was saved in a 500 ml plastic bottle and directly be sent and analysed for variables observed in the Environment Laboratory, Unit of Technical Service District of Bengkulu City in Bengkulu. Method of variables analysis is as shown in Table 1.

| Table 1. Method of Variables Analysis |
|-------------------------------|---------|------------------|
| Variable | Unit | Method |
| TSS | mg/L | SNI 06-6989.3-2004 |
| Turbidity | NTU | Turbidimeter |
| pH | | pH meter |
| BOD | mg/L | BOD Track |
| COD | mg/L | Method 8000 |

2.3. Data Analysis

The permeate quality data were tabulated and analysed for effectiveness of the SSF in removing the contaminants. Collected debit data were plotted and analysed for its relationship to overflow media height to have a prediction for optimal debit producing the required quality of permeate.

3. Result and Discussion

3.1. Tofu Liquid Waste Sample

Result of analysis of the tofu liquid waste samples is served in Table 2. In general, the values were lower than that of reported by [11] as these samples were taken directly from a tofu processing ditch that had not been mixed with wastewater the days before. It could be seen that the BOD, COD, TSS and pH of the samples were above the standard for tofu industrial wastewater.

| Table 2. Tofu Liquid Waste Sample Analysis |
|-------------------------------------------|---------|------------------|
| Parameters | Value | Indonesia Standard* |
| BOD (mg/L) | 250 - 360 | 150 |
| COD (mg/L) | 752 - 919 | 300 |
| TSS (mg/L) | 508 - 602 | 200 |
| pH | 3.5 - 3.8 | 6 - 9 |
| Turbidity (NTU) | 326 - 418 | - |

*Ministry Environment Republic of Indonesia Regulation No 5 Year 2014

3.2. Permeate Debit

Filtering clear water using the SSF Grapilar with different in flow-outflow height of 25 cm; meaning that the capillary flow height is 5 cm as the height of impermeable wall separating the inflow and the outflow side of the SSF is 30 cm; produced an average debit of 252.1 ml/min. when the overflow media height was 2 cm. The width of the SSF inflow side is 15 cm and its length is 50 cm; so the cross-sectional area of the inflow side SSF is 750 cm2; and therefore the SSF average flow was 0.004 cm/s (0.144 m/h). According to Ref. [12], most of SSF would be effective if it is operated under the flow rate of 0.1 – 0.3 m/h. This value is the same as the hydraulic conductivity of fine sand [13]; indicating that the overflow media was saturated and the presence of capillary-driven flow in the SSF does not significant influence the debit of filtration.
The data of the debit also showed that the higher the overflow media height, the lower the debit of the SSF. As the media height was increased to 4 cm, the average debit decreased to 236.4 ml/min.; and when the media height was 6 cm, the average debit was 226.7 ml/min.; and when the media height was 8 cm, the average debit was 182.6 ml/min. Increase of overflow media height could reduce the stage of saturation from relatively full saturated to less saturated or even to unsaturated that would reduce the free water to flow [14]. Figure 2 is the plot of the SSF filtration debit.

![Figure 2. Plot of the Debits of the SSF Grapilar](image)

Whenever the height of incoming flow was set the same as the height of overflow media; there was no capillary-driven flow in the overflow media; the pressure at some points inside the SSF at the same height of the incoming flow would be the same. If the height of the overflow media is increased, it would generate capillary force acting on the upper side of overflow media, the pressure-driving flow at the same points in side the SSF would decrease or less than that of the incoming flow. Therefore, increase of overflow media height would also increase the height of capillary tube; and the higher the capillary tube (h) the higher the upward capillary pressure (P) as \( P = \rho \cdot g \cdot h \) [15]. The increase of the upward capillary pressure would decrease the pressure flow; as the result the debit reduced.

Data of the debit showed that whenever the overflow media was increased from 2 cm to 4 cm, the debit decreased by 14.1 ml/min.; and if the overflow media was increased from 4 cm to 6 cm, the debit decreased by 26.2 ml/min., and if the overflow media was increased from 6 cm to 8 cm, the debit decreased by 21.0 ml/min. The rate of decrease was not constant, indicating that the relationship was not linear. There would also be no flow when the overflow media height is 0 cm; but there would be certain (finite) value of debit whenever the overflow media height is close to 0. And also, the debit would be constant at certain value whenever the overflow media height has reached the maximum value of height of capillary rise.

Compared to that of the clear water, the debit of tofu liquid waste passing through the SSF was lower. The clear water debit passing through the SSF was 252.1 ml/min.; while the tofu liquid waste debit was 153.5 ml/min. when the overflow media height was 2 cm. There was reduction of debit that was caused by the existence of pollutants in the tofu liquid waste.

In general, tofu liquid waste contains some materials found in beans as the raw material of tofu industry. According to Ref. [11], tofu liquid waste industries in Banda Aceh was having turbidity around 730-920 NTU; COD around 5000-8500 (mg/L). The tofu liquid waste to be filtered having physical characteristics of total suspended solids of 550 mg/l and turbidity 375NTU in average; that mostly higher than that of the clear water. Reduce of the debit of the tofu liquid waste filtration to be compared with that of the clear water could be caused by the existence of those material that could lower value of dynamic velocity (\( \mu \)); higher specific weight (\( \gamma \)); and higher liquid density (\( \rho \)) of the tofu liquid waste.

Increase of overflow media height from 2 cm to 4 cm results in the decrease of debit by 22.1 ml/min.; increase from 4 cm to 6 cm would decrease by 23.6 ml/min.; and increase from 6 cm to 8 cm
would decrease by 26.0 ml/min. Rate of debit change as overflow media height increase was increasing; meaning that the relationship was not linear; as that of the clear water. There also would be no flow when the overflow media height is 0 cm; but there would be certain (finite) value of debit whenever the overflow media height is close to 0 cm. The debit also would be constant at certain value whenever overflow media height reach the maximum height of capillary rise.

Table 3. Results Permeate Analysis

| Replication | Overflow height (cm) | TSS (mgL⁻¹) | Turbidity (NTU) | pH | BOD (mgL⁻¹) | COD (mgL⁻¹) |
|-------------|----------------------|-------------|----------------|----|-------------|-------------|
| 1           | 2                    | 18          | 3.92           | 6.8| 34.4        | 111         |
|             | 4                    | 15          | 2.70           | 6.9| 9.4         | 41          |
|             | 6                    | 11          | 1.25           | 7.0| 2.7         | 10          |
|             | 8                    | 5           | 0.37           | 7.2| 2.1         | 5           |
| 2           | 2                    | 19          | 3.17           | 6.8| 40.3        | 121         |
|             | 4                    | 16          | 2.15           | 6.8| 12.0        | 28          |
|             | 6                    | 13          | 0.76           | 6.9| 2.7         | 9           |
|             | 8                    | 8           | 0.66           | 7.2| 2.1         | 6           |
| 3           | 2                    | 23          | 4.05           | 6.7| 29.7        | 103         |
|             | 4                    | 15          | 2.22           | 6.9| 13.6        | 30          |
|             | 6                    | 12          | 1.21           | 7.0| 3.3         | 8           |
|             | 8                    | 9           | 0.23           | 7.1| 2.4         | 3           |
| 4           | 2                    | 22          | 4.21           | 6.7| 37.0        | 89          |
|             | 4                    | 15          | 2.29           | 6.9| 4.2         | 12          |
|             | 6                    | 14          | 0.94           | 6.9| 2.6         | 7           |
|             | 8                    | 8           | 1.06           | 7.2| 0.3         | 1           |

3.3. Quality of Filtered Water

Result of permeate analysis could be seen in Table 3. It showed that TSS, pH, BOD, and COD concentrations of permeates fulfill the standard for tofu industrial wastewater. It also showed that the turbidity reduced significantly to less than 5 NTU. This turbidity value is higher compared to that of the SSF standard that could produce filtered water with turbidity 1 NTU[6]; or 0.1 – 0.5 NTU whenever nitrification-denitrification occurred during filtration [16].

It could be seen that TSS, Turbidity, COD, BOD concentrations decreased as the overflow media height was increased. This decline was related to the decrease of filtration rate. Table 4 showed the average decrease of the parameters with increase of the overflow media height.

Table 4. Filtration Debit and Permeate Quality of Tofu Liquid Waster Filtered using SSF Grapilar

| Overflow height (cm) | Liquid Waste Debit (ml.min⁻¹) | TSS (mgL⁻¹) | Turbidity (NTU) | pH | BOD (mgL⁻¹) | COD (mgL⁻¹) |
|----------------------|-------------------------------|-------------|----------------|----|-------------|-------------|
| 2                    | 153.5                         | 20.5        | 3.84           | 6.8| 35.4        | 106.0       |
| 4                    | 129.9                         | 15.3        | 2.34           | 6.9| 9.8         | 27.8        |
| 6                    | 107.8                         | 12.5        | 1.04           | 7.0| 2.8         | 8.5         |
| 8                    | 81.8                          | 7.5         | 0.58           | 7.2| 1.7         | 3.8         |

As it is known that the direction of flow filtration in the capillary flow side is upward; in the overflow media is horizontal; and is downward in the gravitational flow side. Decrease of filtration flow would reduce the penetrating force of pollutants entering into capillary tubes as well as increase sedimentation process of pollutant inside the capillary tubes. These would reduce the amount of pollutants passing through the media causing decrease TSS. As the TSS concentration decrease, the turbidity, BOD, and COD concentration would also decrease; while the pH would increase to neutral.
Effectiveness of the SSF Grapilar in removing pollutants is shown in Table 5. It can be seen that removal efficiency of TSS, Turbidity, BOD and COD was more than 95% whenever the overflow media height was 4 cm or more. This removal efficiency was better than that of the SSF Pipe [17], the HSSF [9]. This high removal efficiency of the SSF was believed as the filtration flow is in the opposite direction of the pollutants deposition that help in pollutants separation.

| Overflow (cm) | TSS (%) | Turbidity (%) | pH | BOD (%) | COD (%) |
|--------------|---------|---------------|----|---------|---------|
| 2            | 96.28   | 94.53         | 45.17 | 87.45   | 87.02   |
| 4            | 97.21   | 95.89         | 46.18 | 96.59   | 96.68   |
| 6            | 97.73   | 96.65         | 46.75 | 99.01   | 98.96   |
| 8            | 98.64   | 98.01         | 48.42 | 99.41   | 99.55   |

4. Conclusion
Capillary-Gravitational Slow Sand Filter (SSF Grapilar) could produce debit as much as the standard SSF. The debit was governed by the overflow media height; the higher the overflow media height the lower debit. The debit was lower whenever the liquid being filtered was polluted water (tofu liquid waste). SSF Grapilar was effective in removing water pollutant. It is capable of removing TSS, Turbidity, BOD, COD more than 95% and also neutralizing tofu liquid waste whenever the overflow media height was 4 cm or more. To have permeate fulfilling the standard for tofu industrial wastewater; however, the overflow media height could be set to 2 cm; that would produce higher debit than that of 4 cm.

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