Blackwater Filtration

SMTP Research Paper

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Abstract

According to the PUBs mission statement, it seeks to ensure an efficient, adequate & sustainable supply of water. Recycled wastewater, or NEWater, is one important aspect of Singapore's water supply, since NEWater is expected to meet up to 55% of Singapore's future water demand.

In recent years, Singapore's expenditure on waste water filtration has been in steep incline due to the exorbitant prices of the non-reusable filter membranes which must be replaced regularly, resulting in the current 2.3 billion SGD wastewater system operating cost. Without cheaper alternatives, a large amount of Singapore's annual budget is being wasted in needless water sanitation costs.

In response to this problem, our study proposes to investigate vermifiltration as a viable method for cost-effective and efficient wastewater filtration. Vermifiltration, using biological filter medias and organisms, is cheaper, cleaner and as effective at filtering waste water than conventional membrane-based methods.

We have enacted an all-inclusive investigation into the various plausible filter medias as well as their thickness and positioning and have found a 1:1 ratio of a 3.5cm deep layer of sawdust atop a 3.5cm deep layer of activated carbon below a 2cm layer of sand and 3cm layer of soil containing *Lumbricus terrestris* has the best removal of soluble ammonia, solid and nitrogen compounds, adequately meeting all of PUBs water quality requirements. As such, vermifiltration is a viable and cheaper wastewater filtration technique for Singapore to employ.

Introduction

Currently, Singapore's current water filtration system requires a high cost of resource and infrastructure development to support new water management strategies, and requires the constant changing of water filter membranes, which is extremely inconvenient and costly as the membranes foul easily. Also, wastewater needs to be transported to and from the centralised reclamation plants through a tunnel sewerage system, which is extremely costly. As such, we can conclude that current system is incapable of attaining maximum efficiency, as the changing of filters is inefficient. Also, the sludge generated through conventional BW filtration cannot be completely incinerated and takes up valuable landfill area. Overall, as mentioned, there is high starting capital and maintenance costs involved in the filtration system due to filter membrane changes. As such, our project aims to improve upon the current vermifiltration system to meet the water demands of Singapore by obtaining the highest filter efficiency through experimentation.

Literature Review

Recently, vermiculture technology is emerging as an environmentally sustainable and economically viable technology all over the world, commonly used in developing countries. Water scarcity is worldwide problem, and greywater reuse is an attractive option as a potential solution for water deprived region world-wide (Kharwade, et al., 2011). Currently, by using vermifiltration technology with earthworms, this biofilter is able to remove high biochemical oxygen demand (BOD) and chemical oxygen demand (COD) loadings, as well as suspended solids from greywater (Sinha, et al., 2007). Vermifiltration is one of the simple, low cost, eco friendly, chemical free technique used to treat the wastewater using the Eisenia fetida earthworm species (Misal, 2017).The resulting vermi-filtered water is clean and disinfected enough to be reused for farms irrigation, in parks and gardens. During vermifiltration, there is no sludge formation in the reactor which requires additional expenditure on landfill disposal; instead a vermicompost which is a bio-fertilizer is formed (Kharwade, 2011).

The conventional setup contains of 4 layers: earthworms at the topmost layer, followed by sand, an aggregate, and then gravel as the bottommost layer (Sinha, et al., 2007). Earthworms, as a crucial part of a vermifilter system, is able to promote growth of 'beneficial decomposer bacteria' in wastewater and acts as an aerator, grinder, crusher, chemical degrader and biological simulator (Dash, 1978). The layers are meant to sieve out and absorb impurities from the water passing through, and soil, sand and gravel provide ideal sites for colonization by decomposer microbes which work to reduce BOD, COD, TDSS and the turbidity from the wastewater (Manyuchi, 2013). Specifically, The earthworm degrades the wastewater organic by 'enzymatic action' (which work as biological bringing the pace and rapidity in biochemical reaction) and that is the reason for BOD removal in vermifilter. Also, COD reduction is greatly affected by detention time, higher the detention time lower will be COD (Kharwade, et al., 2011). As such,vermifiltration is a viable solution to water problems all over the world.

However, currently in Singapore, more costly and inefficient treatment methods are implemented for water treatment, with the high costs due to transporting water to centralised reclamation plants, and the constant need to change water filter membranes. This is reflected from the huge increase in cost, doubling from 2000 to 2015 (The Straits Times, 2015). Also, Energy issues in Singapore water and wastewater operations include: Design, Operation and Costs of Large Wastewater Treatment Plants (Jacobson, 2008). However, while vermifiltration is less costly and allowed for decentralised water treatment, there is a need for this system to be as efficient as the current system, and to meet up to the water parameters at the same time.

In improving the efficiency of the vermifiltration system, there are a few factors to consider, namely: types of filter media, depth of filter medias, positioning of filter medias, hydraulic loading rate, hydraulic retention time and earthworm density. While there has been research on hydraulic retention time, hydraulic loading rate and earthworm density, whereby the highest percentage of COD and TSS reductions were at HLR of 10 rpm and worm density of 400 individuals per area (Malek, et al., 2013), little research has been done on the bottom layers of the system. As such, our project aims to research on the types and depth of filter medias, to obtain maximum efficiency, while maintaining acceptable water quality.

Proposed Solution

Materials

- Sawdust
- Sand
- Coffee grounds
- Acrylic Sheets
- Manganese (II) sulfate
- Potassium dihydrogen phosphate
- Ammonium Chloride
- Zinc Sulfate
- Activated carbon
- Soil
- Earthworms
- Calcium Chloride
- Dextrose/Glucose
- Potassium hydrogen phosphate
- Magnesium Sulfate
- Iron (II) Sulfate

Apparatus

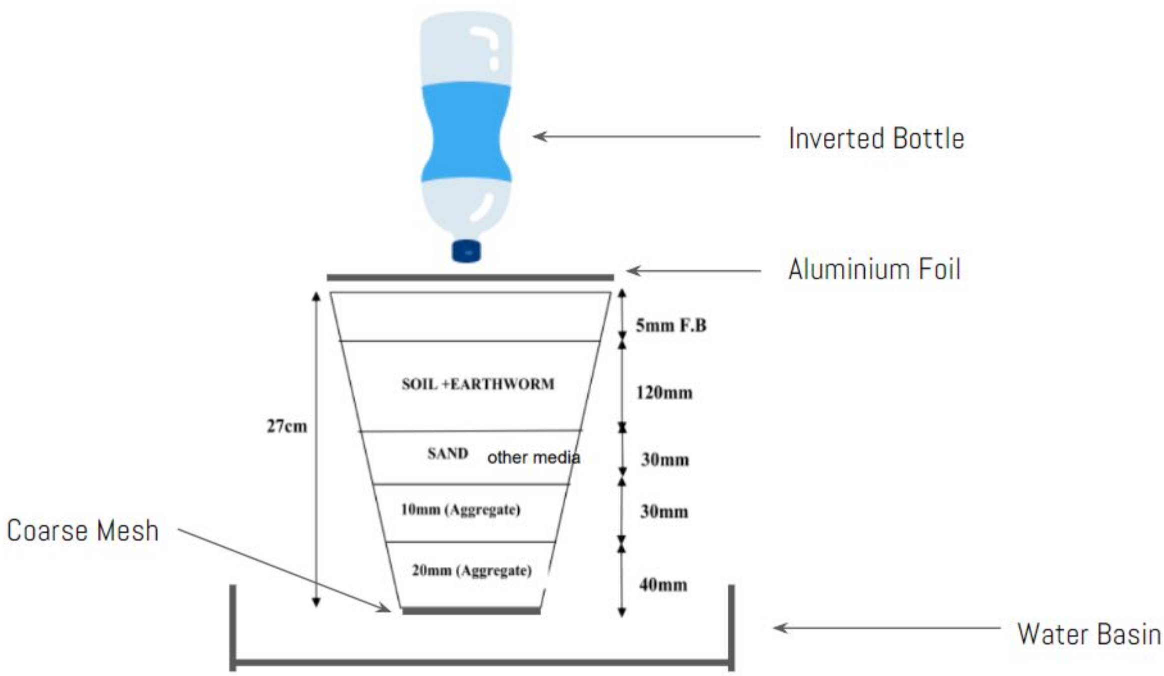
1. 8, 1.5 Litre plastic bottles
2. Scroll Saw
3. Measuring Cylinder
4. Colorimeter (HACH Kit)
5. Basin
6. Pipette & Micropipette

Variables

Independent variables	• Depth of biomedias • Types of biomedias • Positioning of media layers
Dependent variables	• NH3-N

	• Turbidity • Retention Volume • pH
Controlled variables	• Width of the setup • Temperature • Earthworm density

The Setup Structure is as followed:



- Sloping, Funnel set-up design is to Funnel more blackwater poured from the top through a smaller area of biomedia, thus reducing material required, making the setup more cost effective.
- Inverted bottle is meant to drip the synthetic blackwater into the setup
- The aluminium foil at the top is to prevent earthworms from escaping the setup
- The coarse mesh at the bottom is to hold the biomedias within the setup, only allowing water to exit the bottom of the setup

- Water would be dropped through the setup with a combination of different biomedias for the bottom 2 layers, and water is collected at the basin.

The different combinations of the biomedia is as follows:

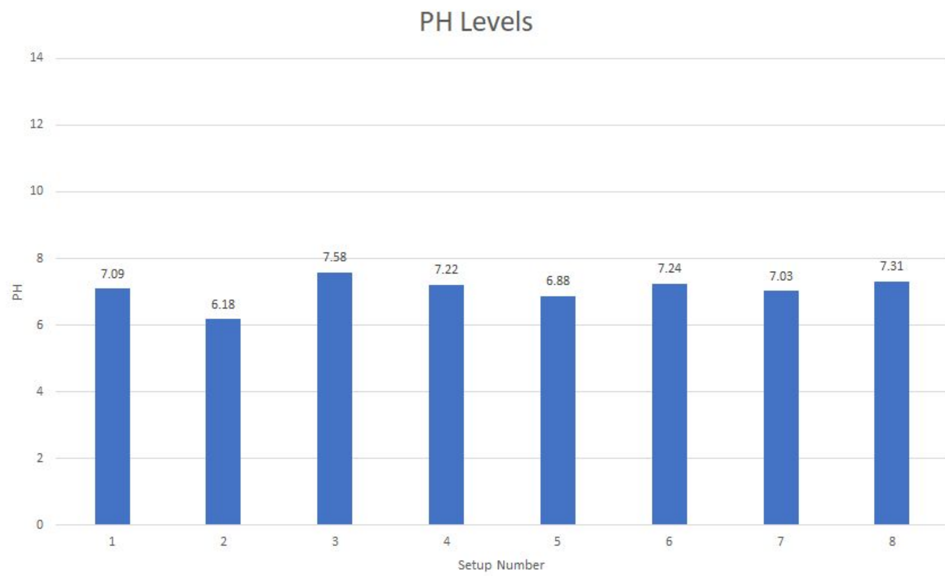
<table>
<tr><th></th><th>Set-up 1</th><th>Set-up 2</th><th>Set-up 3</th><th>Set-up 4</th><th>Set-up 5</th><th>Set-up 6</th><th>Set-up 7</th><th>Set-up 8</th></tr>
<tr><td>Top Layer</td><td colspan="8">5mm F.B.</td></tr>
<tr><td>2nd Layer</td><td colspan="8">120mm Soil + Earthworm</td></tr>
<tr><td>3rd Layer</td><td colspan="8">30mm Sand</td></tr>
<tr><td>4th Layer</td><td rowspan="2">70mm Activated Carbon</td><td rowspan="2">70mm Sawdust</td><td>50mm Activated Carbon</td><td>20mm Sawdust</td><td>50mm Sawdust</td><td>20mm Activated Carbon</td><td>35mm Activated Carbon</td><td>35mm Sawdust</td></tr>
<tr><td>Bottom Layer</td><td>20mm Sawdust</td><td>50mm Activated Carbon</td><td>20mm Activated Carbon</td><td>50mm Sawdust</td><td>35 Sawdust</td><td>35mm Activated Carbon</td></tr>
</table>

The synthetic blackwater is made by the combination of the following chemicals:

Ingredients	Quantity
Dextrose/Glucose	480 mg/L
K2HPO4	1.28 g/L
KH2PO4	0.64 g/L
NH4Cl	0.48 g/L
MgSO4·7H2O	0.60 g/L
FeSO4·7H2O	0.02 g/L
ZnSO4·7H2O	0.02 g/L
MnSO4·7H2O	0.02 g/L
CaCl2	0.08 g/L

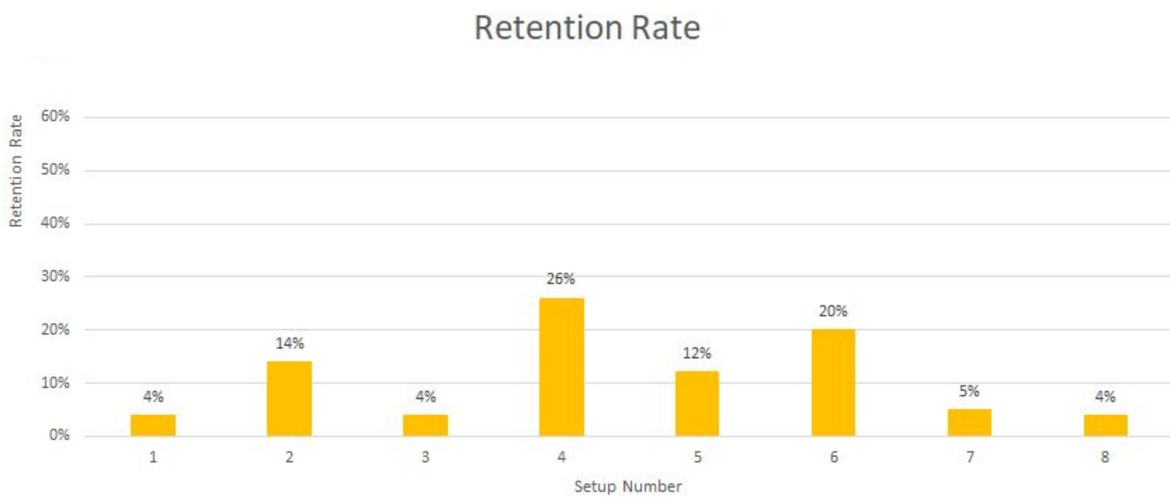
Results and Discussion

Referring to the order of the setups as shown above, the following table graphs display the results for the respective variables.



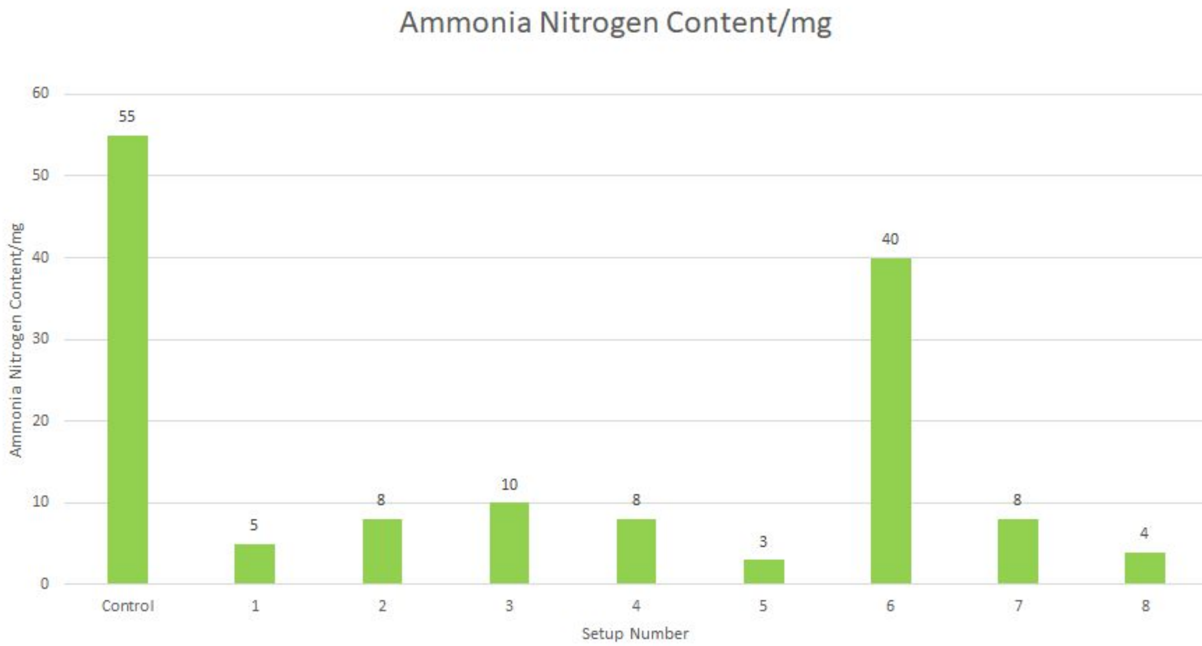
A water ph of 6-8 is mandated by the PUB water cleanliness requirements. This is to ensure, recycled wastewater is not harmful to citizens or other organisms due to overly high or low ph levels.

As seen in the graph above, all 7 setups are within the stipulated ph levels and fluctuate between 6 and 7. As such it is apparent that our vermifilter is able to filter out alkali or acidic substances within the water to ensure a fairly neutral ph.



A lower retention rate indicates that the setup would be not retain as much water within the setup, thus ensuring that almost the total amount of water poured in would be collected in the end.

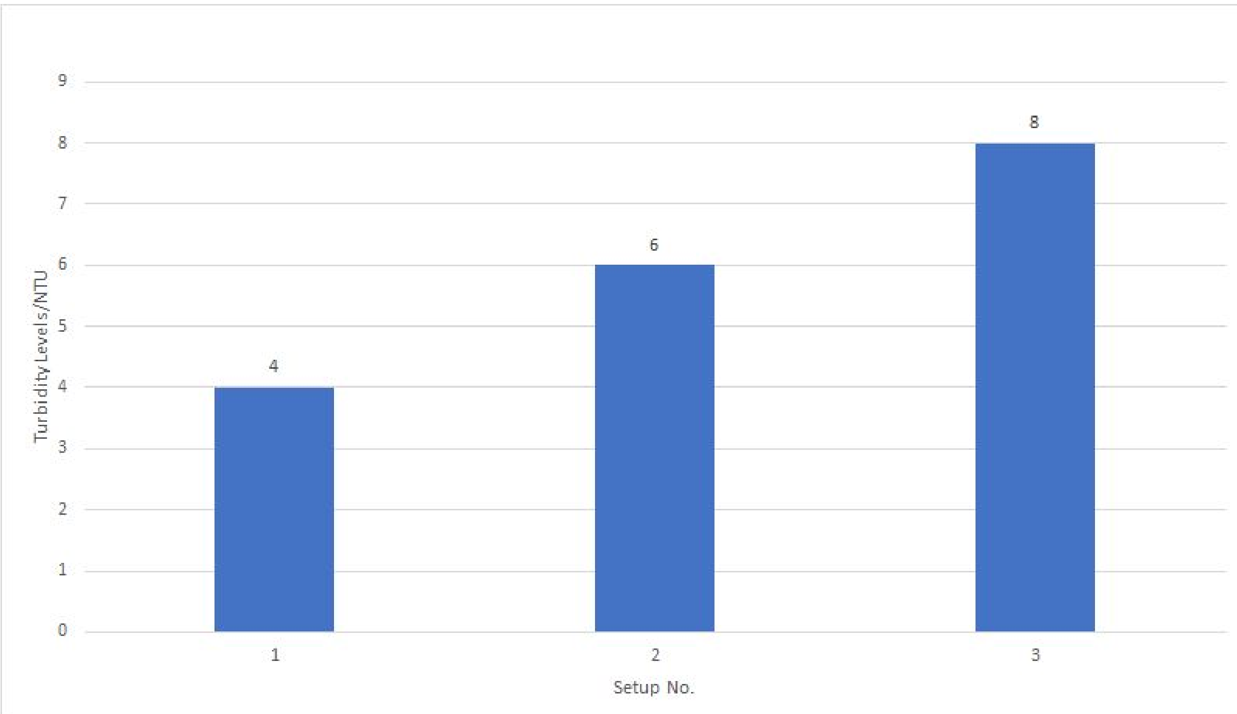
The graph shows that most of the setups mainly have a low retention rate, inclusive of 7cm activated carbon, 5cm activated carbon and 2cm sawdust, 3.5cm activated carbon and 3.5cm sawdust, as well as 3.5cm sawdust and 3.5cm activated carbon. As the rest of the setups have a high retention rate, it may not be as efficient and thus would result in a loss of water while put through the filter. As such, the setups with high retention rates (exceeding 10%) would be ruled out.



The ammonia nitrogen content test indicates amount of ammonia nitrogen left in the filtered water. The blackwater itself had hit the limit of the Hach Kit test of more than 55mg per sample. As observed in the table, only the 2cm activated carbon 5cm sawdust has an exceptionally high ammonia nitrogen content of 40mg. On the other hand, the acceptable ammonia nitrogen content required by PUB standards is below 6mg. Only 3 setups meet the PUB water quality requirements, namely 7cm activated carbon with 5mg ammonia nitrogen content, 5cm sawdust and 2cm activated carbon with 3mg ammonia nitrogen content, as well as 3.5cm sawdust and 3.5cm activated carbon with 4mg.

Upon observing the results, we can observe a trend, whereby the ammonia nitrogen content is significantly lowered when activated carbon is placed as the bottom most layer. This indicates that the positioning of the biomedias does matter, more than the depth of the individual biomedias. The reason behind this trend is due to the fact that activated carbon has a porous structure that absorbs polar alkaline adsorbates like ammonia. With the sawdust placed at the top, the sawdust would be able to slow down the speed at which the water flows through the setup, allowing for more water to be exposed to activated carbon in a larger amount of time. This allows activated carbon to be able to better filter out more ammonia nitrogen from the blackwater with the sawdust placed at the top. On the flipside, the activated carbon placed at the top would cause the water to flow through the activated carbon at a much quicker pace, thus resulting in less ammonia nitrogen content being absorbed by the activated carbon.

After eliminating the unfeasible setups, the turbidity of the filtered water was tested for the remaining setups, and the results for the 7cm activated carbon, 3.5cm sawdust and 3.5cm activated carbon, as well as the 5cm sawdust and 2cm activated carbon setups are as followed.



As the requirements for drinking water for turbidity is below 5 NTU, we can conclude that only one of the setups, which is the 3.5cm sawdust and 3.5cm activated carbon setup, meets the World Health Organisation's requirement, with 4 NTU. On the other hand, the 7cm activated carbon and 5cm sawdust and 2cm activated carbon has 6 NTU and 8 NTU respectively. Thus, the turbidity rules out the rest of the setups, and proves the 3.5cm sawdust and 3.5cm activated carbon setup to be the most efficient and viable option.

In conclusion, after considering all 8 setups through all 4 indicators, we have concluded that 3.5cm sawdust and 3.5cm activated carbon is the best setup as it has an acceptable NH3-N value as well as a low retention rate, with a neutral pH and low turbidity. As this vermifilter setup is easy to make, sludge- and odour- free, does not require the change of filters, and is environmentally friendly, along medias that are easily accessible, the vermifilter is a viable replacement for the current water filtration system in Singapore, with the right depth, positioning and types of biomedias that allow it to effectively filter wastewater for industrial purposes.

Conclusion

Based on the stipulated PUB water quality parameters concerning ammonium nitrogen content (5mg/L), Ph (Ph 6-8) and turbidity (5NTU), as well as a comparison between the relative water retention rates of the various setups, we have concluded that the setup composing of 3.5cm sawdust and 3.5 activated carbon is the best setup. This setup has an acceptable NH3-N value of 4mg/L, a low retention rate of 4% and a neutral pH.

This vermifiltration setup is easy to make, sludge- and odour-free, doesn't require change of filters (which increases cost), and is environmentally friendly. Furthermore, the medias are easily accessible in Singapore, while still being able to effectively filter wastewater. Thus making vermifiltration a viable method of wastewater filtration in Singapore which will significantly reduce blackwater filtration costs from their current 2.3 billion SGD.

<u>References</u>

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