Biochar as bioretention systems for water quality improvement in Malaysia

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Abstract. Rapid urbanization and constant development of infrastructure in the civil engineering community has accelerated in the past decades. However, there has been a reduction of permeable surfaces for rainwater and surface runoff to escape, raising concerns regarding flooding and water quality especially in Malaysia where the tropical climate and heavy rainfall applies pressure on the bioretention systems. To lessen the issue, this paper will be looking into biochar’s benefits in bioretention systems focusing on the type of biochar which will be most suited in improving water quality. In particular, two types of biochar were compared such as rice husk biochar and palm biochar to be tested as bioretention system and different water samples were run through them. Various water quality parameter tests were conducted to evaluate biochar’s performance in reducing pollutants and contaminants from the water samples and thus enable to draw a conclusion on which is the most effective for bioretention use. With a deeper understanding of biochar’s capabilities and limitations, stormwater management strategies can be improved to make the construction industry more sustainable.

1 Introduction

With rapid urbanization in Malaysia, the frequent flash floods experienced over the years is a clear indication that the infrastructure is unable to cope with the volume of surface runoff from impermeable surfaces [1]. This has a butterfly effect as fewer impermeable surfaces leads to greater runoff volume which in-turn means more harmful pollutants are being washed into primary waterways, a great concern for water quality. Bioretention systems are at the forefront of stormwater management as they can tackle most issues brought on by excess runoff, however, with rainfall volume increasing and permeable surfaces decreasing, most bioretention systems are running at full capacity and need further enhancing to improve performance. Biochar is made through a process called pyrolysis which is essentially burning organic biproducts with the absence of oxygen [2]. Biochar structurally has a large surface area making it well versed in capturing heavy metal particles and pollutants, essential for improving water quality in a bioretention system. However, even with these benefits there is

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still a lack of understanding on biochar’s long-term effects and its performance in bioretention systems. A study was conducted on the role of biochar of stormwater management that would promote green infrastructure in major metropolitan areas worldwide [3]. It has been noted that the hydrophobic nature of the biochar and the electrostatic are the primary mechanisms for adsorption of organic containment so the higher the biochar production temperature the more effective its use [4,5]. It has been noted that biochar also supports the growth of plants and improves aesthetic value of the surrounding areas [3]. Another review has been focused on using biochar based bioretention systems focusing of the chemical and microbial pollutants from stormwater [6]. The review has highlighted the key mechanisms of the removal different impurities: of nutrients is biological, adsorption, anion exchange and precipitation, for heavy metals is sorption, cation exchange, complexation, and plant update, for organic compounds is hydrophobic interaction, hydrolysis, oxidation, and biodegradation, for microbial pollutants is filtration, adsorption and hydrophobic interactions. A study conducted on surface modified biochar reported that with modification by H2SO4 excellent results have been obtained with 98% removal efficiency of pollutants [7]. Another study conducted on woodchips and biochar reported that it has effectively removed nitrates, metals and organic contaminants [8].

2 Materials and methods

The biochar samples used in this investigation are rice husk and palm waste. The types of water used are tap water, lake water and sewer treatment water. The water purification system has been conducted within 48 hours. Prior to the experiment the water parameters have been through different tests; BOD (Biological Oxygen Demand), COD (Carbon Oxygen Demand), pH and turbidity. Additionally, the experiment has been repeated twice for reliability of the data obtained. The equipment has been cleaned with distilled water prior to the experiment and the water samples were kept at a constant temperature throughout. Figure 1 shows the experimental set up used for this experiment, a hole was drilled into the top and bottom of plastic jars that are placed on top of the transparent box and a water tube was installed on the top and a valve was installed at the bottom for the water to filter out. Each jar has 6 layers of material; layer 1 is the mesh filter, layer 2 is the plastic netting, layer 3 is the gravel (3cm), layer 4 is the sand (1.5cm), layer 5 is the biochar (5cm) and layer 6 is the sand (1.5cm) mimicking a typical bioretention system [3]. The mesh and the plastic netting are stop the debris from flowing through while the gravel and the sand serve as a drainage and screening layer. The biochar layer is compacted to not allow any presence of air gaps. Each jar was connected to a storage tank inside of the transparent box with a pump (Dophin P200) was used to control the flow rate of the water. A faucet was installed through every storage tank to obtain the water samples. The water samples tap, lake and sewer were all collected from around the University of Nottingham Malaysia campus.

Figure 1. Bioretention experimental system set up.
3 Results and Discussion

3.1 Biochar effect on BOD

The results for each test are given in Table 1, The BOD test measures the quantity of the soluble oxygen required by the microorganisms to decompose organic matter in a certain time frame. This test is important as eutrophication in lakes are contributors to high levels of BOD [1], and combating the BOD levels will have a net positive impact on the ecosystem which inhabits these lakes as they won’t be starved of oxygen, which ultimately leads to a higher water quality. Both biochar's performed similarly in tap water samples with palm biochar averaging a BOD reduction of 29.28% across both tests, against rice husks reduction of 32.60%. This trend continued for both lake water and sewer treatment water with palm biochar reducing BOD content by 23.11% and 25.82% reduction achieved by rice husk biochar. The variation in results between each biochar was minute with percentage variation being under 3.5% for every test with the most important water parameter of sewer treatment water returning a result of 20.14% BOD reduction done by palm biochar and 23.64% by rice husk biochar. According to the Taiwanese EPA river pollution index, all tap water results fell in between the range of 1.05 and 1.55 which classifies as non/mildly polluted water samples, while both river and sewer treatment water fell in the moderately polluted water category; each with a BOD range from 5.11 to 5.41 and 8.24 to 9.48, respectively.

3.2 Biochar effect on BOD

The COD test is a parameter which measures the amount of oxygen required to oxidize a particular specimen (conversion from CO₂ to H₂O). Palm biochar was twice as effective in COD content reduction across both tap water tests versus rice husk biochar, however the inverse result was observed for the lake water and sewer treatment water samples. Palm biochar reduced COD content in tap water by 28.57% while rice husk managed to only achieve a 14.28% reduction in the same 48-hour interval. It is difficult to explain this result as rice husk was able to remove 41.94% of COD content in lake water while palm only managed 24.95%, and 52.06% in sewer treatment water, while palm here only managed to remove 46.11% of COD content. Both water samples with much higher levels of pollutants and contaminants than tap water. A material’s ability to remove COD is highly dependent on its ability to absorb organic pollutants. Rice husk contains a higher silica content than its palm counterpart. Silica is able to bind with heavy metal ions and trap them when in samples of water. Additionally, palm biochar has a greater surface area to volume ratio over palm biochar, resulting in a greater ability to sweep waste particles. These factors can explain rice husks' superior performance in reducing COD levels of lake water and sewer treatment water.

3.3 Biochar effect on Turbidity

The presence of suspended particles, including sediment, mud, organic materials, and other tiny or decomposing creatures, causes turbidity. As for the analysis of the turbidity in a water sample, it will determine the performance of biochar's filtration capabilities, a vital aspect of water filtration and purification. Suspended solids vary in size and can put heavy pressure and in some circumstances even damage water filtration systems. Therefore, removing these particles from runoff before they are treated for municipal use is an important aspect of maximizing efficiency of water treatment.

The results show that over both test runs, rice husk biochar outperformed palm biochar by lowering the TSS values in both samples. In total, rice husk biochar outperformed palm biochar by an average of 4.51% in the initial test run and 5.33% in the second test run. Although this discrepancy may seem rather insignificant, the large volume of water filtered
through the bioretention systems daily means every incremental difference in filtration performance will have significant impacts on efficiency. The average bioretention system filters around 500 L of runoff water per square meter daily, given the average area of Malaysian bioretention system at 48 square meters each bioretention system moves through a volume of roughly 24,000 L/day [9].

This difference can be accounted for by its larger surface area, allowing a greater volume of solids to be absorbed. Another factor for rice husk’s superior ability to absorb comes from its manufacturing process where rice husk is heated at temperatures higher than palm during the pyrolysis process giving it a greater porosity. The pyrolysis of rice husk biochar is typically conducted at a temperature of 550°C to 600°C while palm biochar’s pyrolysis was done at 400-450°C, which accords with the literature [4,5].

Tap water for this test acted as more of a controlled variable as it has a low turbidity value with insoluble suspended particles. The lake water and sewer treatment water on the other hand contained larger particles as they are untreated and exposed to many external contaminants, therefore the turbidity changes in these tests are particularly important. Both biochar's performed exceptionally well in sewer treatment conditions as they lowered turbidity value by over 50%. Rice husk biochar outperformed palm biochar across both tests, a reason for this could be the much greater surface area it has over its palm biochar counterpart. Visually at the end of the test, the lake water and sewer treatment water samples were far less murky to the naked eye at the end of the 48 hours versus before.

3.4 Biochar effect on pH

Based on the results obtained, both biochar's increased the pH levels of all 3 samples rendering them more alkaline at the end of the 48-hour cycle than their initial conditions. Biochar is generally more alkaline by nature due to its rich mineral content which is heated and burned in pyrolysis. When in a bioretention system, through the process of hydrolysis when biochar reacts with the water flowing, it releases OH− by its basic cations (Ca2+, K+, and Mg2+) that increase the soil pH From the results shown, palm biochar was able to increase the alkalinity of each sample more than its rice husk counterpart by an average of 72.03% over both tests. Biochar’s ability to increase the pH level of samples is a great plus point in water filtration especially for bioretention systems as heavy metals and toxins are more soluble in acidic conditions therefore by increasing the alkalinity of water its surrounding environment is more habitable.

The tap water sample was found to have an initial pH value of 9.06, this is relatively high given the average pH levels of tap water in Malaysia are typically in range of pH7-pH8.5. Both biochar's still worked to increase the alkalinity in their respective tap water samples, notably a 5.41% increase in palm while only a 0.77% increase was found in the rice husk sample during the first round of testing. This increase is consistent with both test runs. Palm biochar’s mix contains palm whereas rice biochar’s contains rice husk. This difference in organic material means varying properties; palm biochar has a greater mineral content than rice husk biochar, it is more alkaline as a result. When compared to rice husk, palm in itself has a greater concentration of calcium and potassium minerals which help give palm biochar its alkalinity.

Moreover, both biochar’s were concurrently purifying lake water and sewer treatment samples. These two samples contained a lot more contaminants and impurities and thus the 48-hour results of these tests would show clear indications on which type is more effective. In lake water across both tests, palm biochar increased alkalinity in its sample by 37.23% more than rice husk biochar did. This trend continued along with sewer treatment water as palm biochar outperformed rice biochar by a staggering 48.11%. Alkaline water conditions promote healthy development of aquatic life and plants as well as soil health. In practical
usage, rainwater is more acidic due to the presence of carbon dioxide as well as pollutants which mix into the water. Therefore, biochar's ability to make a sample more alkaline is an important factor to consider when purifying water.

**Table 1.** Results of all the tests conducted in this experiment after 48 hrs. (aPalm waste biochar, bRice husk biochar.)

<table>
<thead>
<tr>
<th>Water Sample</th>
<th>Tap</th>
<th>Lake</th>
<th>Sewer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours</td>
<td>0</td>
<td>48</td>
<td>0</td>
</tr>
<tr>
<td>Biochar</td>
<td>P</td>
<td>R</td>
<td>P</td>
</tr>
<tr>
<td>BOD (mg/L)</td>
<td>1.81</td>
<td>1.28</td>
<td>1.22</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>14</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>Turbidity (mg/L)</td>
<td>22.8</td>
<td>13.95</td>
<td>10.75</td>
</tr>
<tr>
<td>pH</td>
<td>9.06</td>
<td>9.5</td>
<td>9.13</td>
</tr>
</tbody>
</table>

**4 Conclusion**

In conclusion, both biochars were effective at purifying water as they were able to increase alkaline levels, reduce turbidity, suspended solid content as well as BOD and COD levels which are all crucial parameters in determining the quality of a water sample. Palm biochar is more readily available in Malaysia due to the mass palm oil production done locally; however, rice husk biochar was able to outperform palm biochar in most water parameter tests.

**References**


