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VARIOUS TYPES OF FILTER MEDIA IN TREATING RAINWATER USING THE GREEN WALL FILTRATION SYSTEM

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Abstract

Harvested rainwater frequently has contaminants that need to be removed to obtain clean water. This study investigated a treatment of rainwater by applying a green wall filtration system constructed of a variety of lightweight filter media. This study focuses on finding the best flow rate for effective filtration, determining the right mixture ratio of filter media, and choosing the most suitable combination of media. Three media combinations which were biochar and perlite, cocopeat and perlite, and laterite and perlite, were evaluated based on six water quality parameters, which include total suspended solids (TSS), total nitrogen (TN), total phosphate (TP), chemical oxygen demand (COD), pH, and turbidity. Among the tested configurations, the perlite and biochar combination demonstrated excellent filtration performance. The most significant improvement was observed in pH, where the value increased from 4.95 to 8.0 after filtration, complying with the National Drinking Water Quality (NDWQ) Standard range of 5.5-9.0. Besides, the COD value also showed a significant decrease from 30 mg/l before filtration and 9 mg/l after filtration with the use of biochar-perlite combination filter media. The other parameters tested do not show much difference before and after filtration because rainwater is relatively low in TP, TN, and TSS. The filtration performance was assessed under three different rainwater flow rates: slow (2.153 L/h), medium (2.588 L/h), and high (4.144 L/h). The best filtration performance results were achieved using a fixed 3:1 biochar-to-perlite ratio under a fast flow rate of 4.144 L/h and showed the highest COD removal efficiency, reaching 60%.

Keywords: COD removal, Filtration, Filter media, Green wall system, Rainwater.

1. Introduction

Access to clean water is crucial to all activities of daily life, agriculture, and industries. As a tropical nation, Malaysia records an annual rainfall level of 2000-3000 mm per year, which can be collected at various locations for alternative and/or additional supply of water [1].

However, contamination in rainwater resulting from dissolution of carbon dioxide, sulphur oxides and nitrogen oxides gases is problematic. Untreated rainwater usually contains pathogens such as *Escherichia coli* (*E. coli*), some organic matters and substances of nitrogen and phosphorus, making it slightly acidic with low pH of 4.7 to 5.6 [2]. Despite the level of pollutants in rainwater is comparatively insignificant, a minimal treatment is still considerably necessary for the collected rainwater to be safe for normal usage according to the World Health Organization's (WHO) and National Drinking Water Quality Standards (NDWQS). Specifically, water used for portable purposes should have pH between 5.5 and 9.0, COD of 10 mg/L, total suspended solid of 1000 mg/L and nitrogen level of around 10 mg/L [3]. The conventional filtration method such as a green wall filtration system is considered as a sustainable and cost-effective approach in a well-designed setup with proper choices of filtration media [4, 5].

Selection of the filter media can substantially contribute to the effectiveness of the water filtration system. Using cocopeat produced from dried coconut husk as a filter media was reported for its water retention capability and root-derived nutrient supply during water filtration process. Additionally, cocopeat can improve the rainwater quality by breaking down some organic matters, pathogens, and other pollutants for safe consumption [1, 2]. Another example of filter media is perlite – a lightweight volcanic material having high porosity for good aeration and prevention of clogging [2]. Besides, filtration using biochar showed its removal of microorganisms, decomposition of contaminants, and elimination of heavy metals, pathogens and volatile organic compounds contained in wastewater [1]. As being obtained from the thermal treatment of organic carbon-rich biomass, both biochar and cocopeat can provide an environmentally friendly solution for water management in term of removal of water pollutants. For adsorption in wastewater systems, biochar was found to be more advantageous than other filter materials in term of its reusability and reducibility in levels of organic compounds, heavy metals. However, research in applying biochar in treatment of rainwater to remove pollutants is surprisingly scarce.

Another factor affecting the effectiveness of the water filtration system is the ratios of different filter media. At the cocopeat to perlite ratio of 3:1 (w/w), the COD removal was the highest and led to an overall removal efficiency of 71.0% [1]. Furthermore, removal of nitrogen and COD in lake water was enhanced at the cocopeat to perlite ratio of 2:1 (w/w), although water clogging occurred due to limited aeration [2]. Whereas the lowest level of pollutant removal was recorded at the 1:1 ratio of cocopeat to perlite. These results explained for the reduced treatment efficiency resulting from the increase in proportion of filter media [2]. Retention time relating to flow rate can directly affect the system efficiency. A study tested a water filtration system having a medium flowrate of 13 L/h which resulted in an increase in COD and nutrient removal efficiency by 80%. Whereas operation at a higher flowrate of 22 L/h considerably reduced the efficiency to 65% due to the short retention time.

Interaction between the filter media and pollutants which can be expressed in the adsorption isotherms was studied using biochar [6]. The study showed that the adsorption of pollutant by biochar was due to its porous structure and the obtained results gave the best fits for both Langmuir and Freundlich models. In addition, a combination of biochar and perlite was capable for COD adsorption in agreement with Langmuir characteristics. The study also suggested to application of Langmuir model could exhibit multiple layers of adsorption and give better prediction of the adsorption capacity for optimisation of the designed filtration system.

Aiming at improving the efficacy of pollutant removal, the objective of this study was to investigate three different filter media used in the green wall water filtration system.

2. Research Method

2.1. Materials

Water quality was determined in terms of chemical oxygen demand (COD), pH, total suspended solids (TSS), total nitrogen (TN), and total phosphorus (TP) in this study. For COD, the Spectroquant COD cell tests were used in the range of 25-1500 mg/L (1145410001, Merck, Germany) with a spectrophotometer (Spectroquant Prove 300, Merck, Germany). For TP and TN, the cell test kits for phosphate (detection range 0.5-25.0 mg/L) and total nitrogen (detection range 0.5-15 mg/L) were used respectively (Merck, Germany).

In the green wall filtration system, this study tested five filter media i.e., cocopeat, biochar, perlite, laterite, and a plant, which were shown in Fig. 1. Cocopeat was a powder obtained from processing dried coconut husk fibre. Biochar was an organic substance made of compost, manure, bone meal, fish emulsion, and seaweed extract. Perlite was rock with highly porous structure usually used in aquarium to enhance water retention and prevent blockage. Laterite was used as a natural way of absorbing heavy metal and enhancing water retention. For the green wall, *Epipremnum aureum* plant was used as a natural absorbent of heavy metals. This plant was selected due to its adaptability to temperature variation in the tropical weather with minimal needs for fertilisation, water, or sunlight within two months [2].

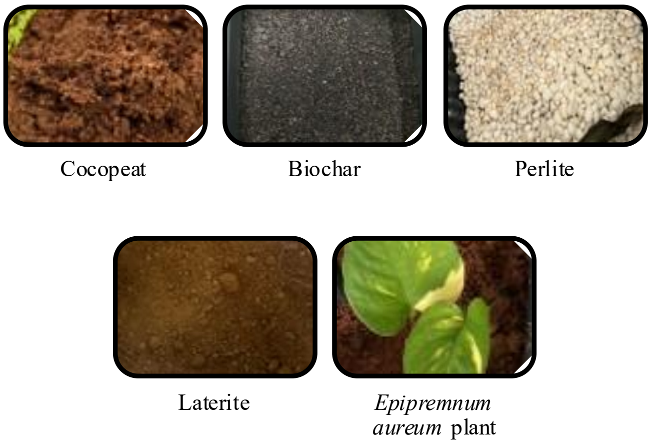

Fig. 1. Four filter media used for filtration of rainwater.

2.2. Preparation of filter media

Prior to water filtration experiment, the filter media such as cocopeat and perlite were pre-washed with water thoroughly to remove impurities.

At a ratio of 3:1 (w/w), the cocopeat and the perlite were weighed. The filter media was then transferred to the containers (plastic pots) and hang in the green wall. Combination of cocopeat and perlite was tested in the first experiment.

By following the same preparation step and ratio, the second experiment tested with two other combinations which were biochar combined perlite and laterite combined perlite.

2.3. Rainwater harvesting

Rainwater was harvested in an urban farm located at the open car park of block E, Taylor's University, Malaysia. An amount of 50 L rainwater was collected in each experiment and stored in the storage tank.

2.4. Green wall setup

The green wall system used for filtration of rainwater was constructed by a metal frame where the plant containers (pots) were arranged in a total of three layers as shown in Fig. 2. Height of the system was kept at 3 m for easy handling and maintenance. Each layer consisted of six containers, making a green wall of eighteen containers. Size of each container was (13 × 11) cm with a volume of 1.23 L. Inside each container, a plastic mesh was placed at the bottom to prevent loss of filter media during watering. The green wall system was equipped with a 50 L storage tank placed on ground, a water pump, and valves.

Rainwater was pumped from the lower storage tank to the upper tank and distributed through pipelines where filtration was placed. Flow rate of rainwater was adjusted via the pump. At the top of the green wall, rainwater was pumped and evenly supplied to each container through the different layers of filter media. After flowing through the filtration, the filtered water was recollected at the reservoir where samples were taken. The filtered water subsequently flowing back to the lower storage tank was then transferred to the upper storage tank via a submersible pump in order to continue a new cycle. Rainwater samples of 100 ml were collected in the beakers for further analysis.

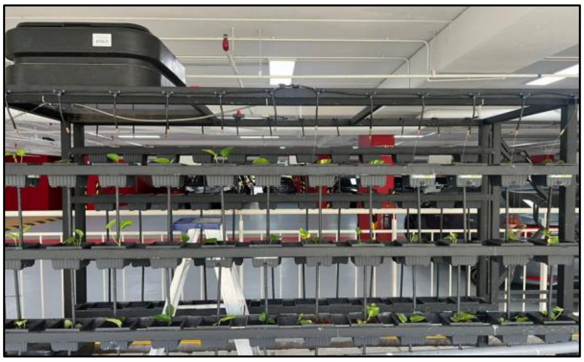

Fig. 2. The green wall setup used for rainwater filtration.

2.5. Flow rates of rainwater

Three different flow rates ranged from low to high were applied for the rainwater used in the green wall system as mentioned in Table 1. Flow rates were measured determined manually by measuring the amount of water (100 mL) exiting the opening pipe and the corresponding time taken by a stopwatch.

Table 1. Flow rates of rainwater in the green wall system.

Level of flow	Average flow rate (L/h)
Low	2.153
Medium	2.588
High	4.144

2.6. Sample collection and analysis

Samples of rainwater collected from the storage tank were analysed instantly for COD, TSS, TN, TP, and turbidity before any treatment. Characteristics of the rainwater are presented in Table 2. After the filtration using different filter media, water discharged at the effluent of the containers was collected. Samples were taken for three different combinations of filter media, which were cocopeat – perlite, biochar – perlite, and laterite – perlite. Each combination was tested at three flow rates (low, medium, and high).

In order to identify contaminants, including hydrocarbons, decomposed plant matter, and other biodegradable materials in rainwater, the COD test is used to determine the quantity of oxygen required to oxidize organic pollutants. The COD test followed procedures of the COD cell test kits. Basically, a 3 ml sample of rainwater was pipetted into the cell test and shook well to start the reaction. The COD cells were subsequently placed in a digestor at a preheated temperature of 150 °C for 120 minutes. Once the reaction stopped, the cell tests were cooled to room temperature in the digestor, followed by measurement of COD levels in the spectrophotometer [7]. Relative purity of the water sample was measured via the turbidity to determine the amount of colloidal particles present in rainwater [2].

Table 2. Characteristics of rainwater.

Parameter	Unit	Value	Recommended criteria for water by NDWQS and WHO
pH	-	4.95	5.5 – 9.0
TSS	mg/l	< 0.5	< 0.5
COD	mg/l	30	10
TN	mg/l	< 0.5	10
TP	mg/l	< 0.5	0.05
Turbidity	NTU	10	1000

2.7. Calculation

2.7.1. Adsorption efficiency

Performance of the treated rainwater was evaluated based on the NDWQS and WHO standards. Tests were conducted to find the combination of filter media, flow rate that resulted in the highest removal efficiency. The test mainly focused on pH, COD, whereas other parameters such as TSS, TN, TP and turbidity showed no significant changes after treatment [2]. Calculation of the removal efficiency of the filter media in the green wall system used Eq. (1).

$$Removal\ efficiency\ (\%) = \frac{C_o - C_f}{C_o} \times 100\% \quad (1)$$

where C_0 and C_f denoted as the initial and final concentrations of COD of the collected rainwater sample.

2.7.2. Adsorption isotherm

With three combinations of filter media at the 3:1 (w/w) ratio, effectiveness of COD removal was compared and evaluated with changes in pH. Freundlich and Langmuir models were applied to obtain the best fit line that exhibits the efficiency of COD removal. Equations (2) and (3) express the adsorption in the two models.

$$q_e\ (\%) = \frac{a\ b\ C_e}{1 + b\ C_e} \times 100\% \quad (2)$$

where, q_e is the adsorbate quantity per unit mass of solid, a is the highest possible amount of adsorbate that the solid can take in, b is the Langmuir adsorption constant, which is connected to the energy needed for adsorption, and C_e is the concentration of the adsorbate in the solution when equilibrium is reached [2].

$$q_e\ (\%) = K_f\ C_e^{\frac{1}{n}} \quad (3)$$

where K_f: the Freundlich constant, and n: the empirical constant.

The best-fit line equations for Langmuir and Freundlich models are shown in Eqs. (4) and (5) mentioned in Table 3.

Table 3. The best-fit line equations for Langmuir model and Freundlich models.

Model	Best fit line equation	
Langmuir	$\frac{1}{qe} = C_1(\frac{1}{Se}) + C_2$	Eq. (4)
Freundlich	$\frac{1}{qe} = C_1(\frac{1}{Se}) + C_2$	Eq. (5)

where, q_e: concentration of pollutant adsorption, S_e: concentration of pollutants at equilibrium, C_i: constant

3. Results and Discussion

3.1. COD removal efficiency of filter media

All three combinations of filter media, namely perlite and biochar, perlite and cocopeat, perlite and laterite were tested for their COD removal in the green wall filtration system. The obtained results were shown in Fig. 3.

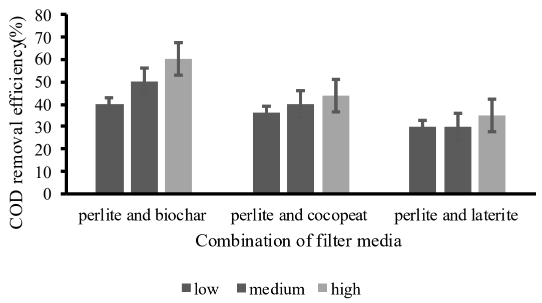

Fig. 3. The overall COD removal efficiency.

Among the three, the combination of perlite and biochar resulted in the highest COD removal efficiencies at 40.0% 50.4% and 60.0% for the low, medium, and high flow rates, respectively. On the other hand, the combination of perlite and cocopeat was found to be less efficient in removal of COD which ranged from 36.0% to 44.0% as can be seen in Fig. 3. It was also noticed the combined filter media combined between perlite and laterite was the least efficient in COD removal at below 40% found in all levels of flow rates.

The presence of perlite in all three combinations was to enhance permeability and aeration of the filter bed as it was combined with other filter media [8]. In comparison with laterite having lesser surface area and porosity structure, this led to its limitations in effective adsorption of contaminants/pollutants [7]. In regard of adsorbing organic matters contained in the rainwater, biochar was more capable than cocopeat.

3.2. Changes of pH in filtration

Beside the measurement of COD to evaluate removal efficiency, pH was another important parameter that needed to study. Results of pH were shown in Fig. 4. As the flow rates varied from low to high, changes in pH were insignificant as found in case of combining perlite with cocopeat or laterite. In these two combinations, neutral pH was recorded at around 7.0. The level of pH remained almost unchanged in case of applying the combination of laterite and perlite for the filtration. However, pH levels of the perlite and biochar combination rose from 6.6 to 8.0 as the flow rate increased.

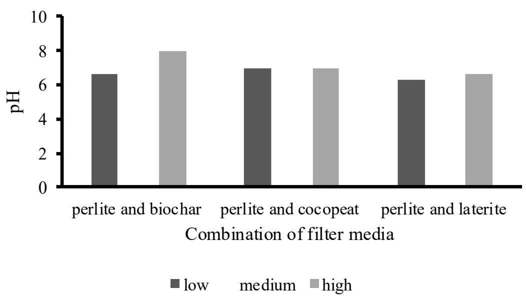

Fig. 4. pH of rainwater after filtration using combinations of filter media at different flow rates.

According to some studies, the cation exchange capacity (CEC) of each filter material accounted for the hydrogen ion concentration in the media which could affect the pH changes [9]. A slight effect of pH change in the combination having perlite as it was chemically inert, neutral with low CEC. Unlike perlite, constituents contained in biochar were alkaline with high CEC level, thus making it able to raise pH by neutralising the acidity in the water [9]. As reported in a study, pH obtained after filtration of wastewater using biochar material increased substantially from 5 to 8, which made the treated wastewater less acidic [10]. Among the three combinations of filter media, the combined perlite with biochar was the most efficient to apply for the green wall system in rainwater filtration.

Figures 5 and 6 show the fitness to the Langmuir and Freundlich models for the filtration media applied in the green wall filtration system of this study.

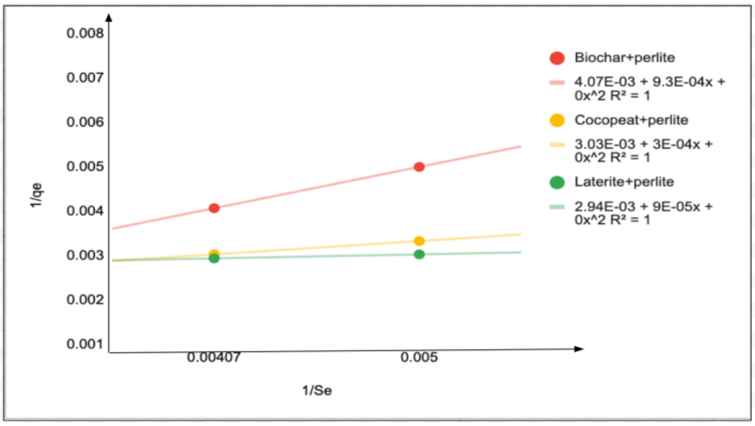

Fig. 5. Fitness to the Langmuir model applied for each combination of filter media.

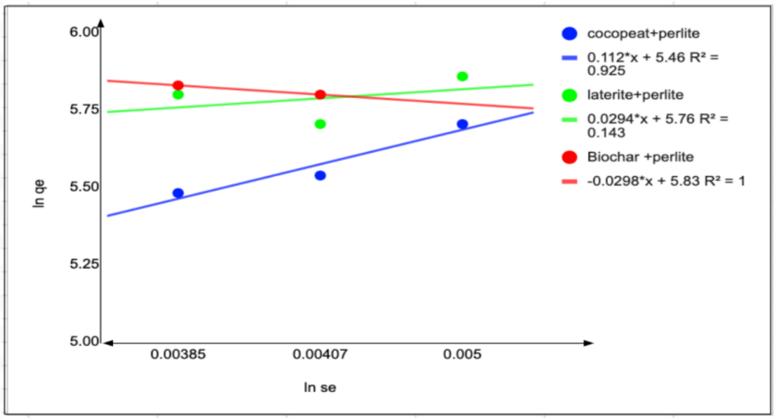

Fig. 6. Fitness to the Freundlich model applied for each combination of filter media.

As can be seen in Figs. 5 and 6, the regression coefficients of all combinations of filter media were obtained at 1 when applying the Langmuir model. However, level of fitness reduced to 0.925, 0.143 in case of applying the Freundlich model for the two combinations of perlite and biochar as well as perlite and cocopeat. Due to such differences between two models, the Langmuir isotherm outperformed that of Freundlich. Thus, prediction of adsorption capacity by Langmuir model was better, thus able to optimise the design of filter media in enhancing the filtration system.

Adsorbent and adsorbate were the two parts of the adsorption mechanism [10]. The contaminants in the rainwater measured in COD, served as the adsorbate, while the combined filter medium acted as the absorbent. Pollutants flew through the macro-pore system of the combined filter media, which was called macro transport. Subsequently, they moved through the meso-pore and micro-pore structures of the filter media [11]. Ultimately, the organic material will attach to the filter medium via micro- and mesopores [11]. However, the degree of affinity could vary for each filter material, thus the adsorption rate varies [11]. With biochar, the surface area and porous structure, which improved adsorption of the dissolved organic matter, were the reasons why the biochar-perlite combination demonstrated the maximum COD reduction. A study reported that biochar is a carbon-rich substance that has a strong affinity for organic materials and improves pollutant retention. By increasing porosity, aeration and water retention, perlite on the other hand can enhance the contact time between rainwater and the filter surface, thus making it suitable to combine with biochar [2].

4. Conclusions

The focus of this study was to examine the adsorption kinetics and treatment efficacy of the three different filter media combinations in the green wall filtration system for rainwater. With a fixed ratio of 3:1 applied for all combinations of filter media, COD and pH were primarily selected to investigate the effectiveness of pollutant removal for rainwater at three levels of flow rates (low, medium, and high). Based on the obtained results, the combination of perlite and biochar was the most effective for COD removal at the high low rate of 4.144 L/h. The resultant pH after filtration increased to 8.0, which met the standard of drinking water suggested by WHO. With the high coefficient (R^2=1), the Langmuir isotherm model was well-fitted to the adsorption process in this study as compared to the Freundlich one. Thus, a further study is recommended to investigate variation in the ratio of filter media impacts of other plant species, pore size of filter media on efficiency of water treatment in the green wall system.

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