The vertical recycled concrete aggregate filter for removal of phosphorus in wastewater

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Abstract. The irresponsible disposal of untreated wastewater into waters, soil and groundwater results in polluted water resources. Moreover, nutrients such as phosphorus have become culprits of concern in accelerating eutrophication. Besides, this issue could cause water poisoning and the degradation of recreational opportunities. Therefore, for justifying this problem, it is important to understand the quantity of phosphorus (P) flows by using recycled concrete aggregate (RCA) as filter materials. RCA used as a filter system has emerged as an alternative technology for phosphorus removal. This can overcome the problem of construction site waste by converting the waste into valuable products. Thus, this study aims to investigate the physical and chemical characteristics of RCA that influenced adsorption of P and the percentage of phosphorus removal from synthetic wastewater by using two different sizes of RCA. A total of five vertical recycled concrete aggregate filter was designed. The samples taken from influent and effluent were tested once a week and analyzed to determine pH and percentage removal phosphorus. RCA was analyzed using Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDX) testing to determine chemical composition. The results show that RCA primarily contained aluminium, calcium, and magnesium that could enhanced the phosphorus adsorption. The RCA with size 5 to 10 mm is shown to have high potential to remove phosphorus up to 99.57%. The higher the size of RCA, the higher percentage of phosphorus removal. In conclusion, RCA has the potential to remove phosphorus from wastewater.

1. Introduction
Environmental pollution is a global concern because of the dangerous effects on public health and the environment. The reckless disposal of untreated wastewater results in polluted water resources. Moreover, nutrients such as phosphorus have become culprits of concern in accelerating eutrophication. Besides, this issue could cause water poisoning and the degradation of recreational opportunities. Hence, the wastewater treatment process should be enhanced to ensure treated wastewater effluent discharged satisfies the limits and no longer contribute to water pollution. Besides, the removal of phosphorus in wastewater has become among the most significant issues and indicators in defining the efficiency and reliability of the treatment system of wastewater. The removal of phosphorus requires a secondary wastewater treatment process. Enhanced biological phosphorus removal (EBPR) and chemical precipitation are commonly practiced nowadays due to its great consistency in achieving the removal standards [1]. Yet, these conventional technologies require advanced cost, constant maintenance by experts and high energy consumption. By itself, chemical precipitation desires an abundance of chemicals and EBPR consumes a lot of energy to maintain its tank performance. Meanwhile
conventional treatment technology mostly has complex maintenance; thus, less practical to be applied in smaller communities. Opportunely, natural wastewater treatment process such as waste stabilization ponds (WSP), constructed wetlands (CW) and rock filters (RF) are very outstanding alternatives for phosphorus removal where it can be practical for smaller communities due to its lower maintenance. Natural wastewater treatment technology has become a positive alternative to replace the conventional method since they are more economical [2].

The growing quantities and types of waste materials, shortage of landfill spaces, and lack of natural sources all indicate the urgency of finding innovative ways of recycling and reusing waste materials. Unless recycled properly, these large amounts of waste end up in landfill every year. Nowadays, RCA was obtained from construction and demolition waste to become a valuable resource as an alternative solution [3]. Consequently, RCA was used as an alternative filter media for the removal of phosphorus in this study. This was done to reduce the uncontrolled disposal of waste at construction sites. If the situation is not controlled, it will cause problems for the environment as there will be a decrease in space in urban areas due to waste demolition. On the other hand, RCA can help to save the environment as no excavation of natural resources is needed. Less transportation as well as less land is required, thus it will reduce greenhouse gas emissions. Moreover, the use of RCA can also save time as it is readily available. Besides, RCA has a higher calcium content which translates to a higher ability for removing phosphorus [4]. Thus, RCA possesses high potential to be used as a filter medium for removing phosphorus. In Malaysia, making the RCA as a medium for water treatment is an alternative to reduce the waste and save the environment. Rock filters (RF) have become an encouraging alternative technology for removing nutrients from wastewater. The advantages of RF due to its comparatively easy to be installed and great quantity availability as compared to the conventional method. Modifications were done on the rock filters, by replacing the filter media to develop their performances in nutrient removal. A few significant factors also need to be calculated while choosing the best filter media such as saturation time, availability at a local level, and the recyclability of filter materials. Also, RCA is easily available at construction site, therefore recycling the waste is a better idea towards sustainability. Population growth and urbanization have accelerated the consumption of concrete and construction and demolition waste generation, therefore the transformation of this product into something valuable has become very significant for us.

In the present study, RCA was chosen as a filter media which are high calcium and can be easily obtained from old construction work as demolition waste. Furthermore, a crushed concrete aggregate is one of the alternative treatments for the removal of phosphorus from wastewater. Some of the advantages of crushed concrete are cost efficiency, high availability and relatively easy installation compared to conventional methods. RCA has a high capability for removing phosphorus. Therefore, this study was carried out to investigate the removal of phosphorus from synthetic wastewater using recycled concrete aggregates as a filter at different pH in an aerated filter.

2. Experimental

2.1 Material

2.1.1 Recycled concrete aggregate (RCA). Recycled concrete aggregate (RCA) was produced from concrete cube waste at the Heavy Structure Laboratory, Universiti Tun Hussein Onn Malaysia (UTHM). The concrete cube waste was crushed using crushing machines (Concrete Crusher A35399) in order to produce RCA. Next, the aggregates were sieved to obtain the desired sizes ranging between 5 mm to 30 mm (British Standard sieve BS410/1986) using a shaker (Endecotts Lombard Rd. London, model SW193BR, England). RCA samples in the range of sizes of 5 to 20 mm were accepted for use as adsorbents for the column study. The RCAs were washed twice with tap water followed by distilled water before they were dried up in the oven for 24 hours at 105°C.

2.1.2 Synthetic phosphorus solution. Synthetic wastewater was prepared from potassium dihydrogen phosphate, KH₂PO₄. The concentration of synthetic wastewater chosen was 25 mg/L, based on the
typical range of total phosphorus concentration in Malaysia [4]. Synthetic wastewater was chosen in this study in order to study the efficiencies of phosphorus removal without any influence from other impurities or contaminants in the wastewater. Theoretically, to make 25 mg/L, 1000 mg/L KH$_2$PO$_4$ stock solution was prepared and diluted. 4.394 g KH$_2$PO$_4$ salt was weighed and dissolved in 1 L volumetric flask using distilled water to obtain 1000 mg/L KH$_2$PO$_4$ stock solution. Subsequently, 25 mL of 1000 mg/L KH$_2$PO$_4$ stock solution was pipette into 1L volumetric flask and distilled water was added to make 25 mg/L. These preparations were based on equation (1):

$$M_1V_1 = M_2V_2$$

Where $M_1$ is the concentration of orthophosphate stock solution, $V_1$ is the volume of stock solution to be taken for dilution, $M_2$ is the concentration of desired orthophosphate to be prepared and $V_2$ is the desired volume of the diluted orthophosphate to be prepared. Then, the pH of synthetic wastewater was adjusted to desired pH values (3, 9, and 11) using 0.1 M HCl and 0.1 M NaOH solution.

### 2.2 Test parameter

Sampling of the wastewater was done once a week for a duration of two months. All of the influents and the effluents of the columns were sampled. The parameters tested in the laboratory include pH and concentration of phosphorus. The tests would be done in triplicate to monitor the reproducibility of the results thus ensuring reliable results obtained. Table 1 shows the analysed parameters and the instrument used.

| Parameters | Instrument/method used               |
|------------|-------------------------------------|
| pH         | HANNA HI 991301 pH meter            |
| Phosphorus | 4500-P F using Smartchem 200 WESTCO Discrete Analyzer |

### 2.3 Analysis of phosphorus

The analysis of the phosphorus in synthetic solution was done by measuring only the reactive organic phosphorus. This is due to the lack of organic matter or any other contaminants, which are prone to react with phosphorus to form other phosphorus related species since the synthetic wastewater was prepared from distilled water. The analysis was carried out using DR6000™ method according to the Standard Methods for the Examination of Water and Wastewater [5]. This method could analyse phosphorus within the range of 0.3 to 30.0 mg (PO$_4^{3-}$/L. The procedure was started by preparing the samples and reagents before analysis was conducted. Then, DRB 200 Reactor was started and preheated to 150 °C. The DR6000 programme was set to 536 Total/AH PV TNT.

After that, 5.0 ml of sample was added to the Total Phosphorus Test Vial. The reagent, which consisted of one Potassium Persulfate Powder Pillow also added in Phosphonate to the vial. The capped vial was shaken carefully to dissolved the powder before being inserted into the reactor. The instrument timer was started for 30 minutes. When the timer expires, the vial was carefully removed from the reactor. The vial then was put on the test tube rack and let to cool at room temperature. After being cooled, 2 mL of 1.54 sodium hydroxide standard solution was added to the vial and the vial was capped, the solution was shaken to mix well. The vial was cleaned after finish shaking, and inserted into the 16 mm cell holder. The reading was zeroed to 0.00 mg/L. Next, the vial was removed from DR6000 and PhosVer 3 Powder Pillow was added to the vial and the solution was shaken well to mix for 20-30 seconds to dissolve the powder. The DR6000 instrument timer was restarted and set to 2 minutes reaction time. Then, the samples were measured within 8 minutes after the timer was expired.
2.4 Column Study
Lab-scale vertical RCA filters were developed to investigate the removal of phosphorus from synthetic wastewater in this study. This filter was cylindrical in shape. In this study, five filters were designed and placed at the Wastewater Engineering Laboratory, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia (UTHM). The perspex filter was designed with an inner diameter of 150 mm, a thickness of 5 mm and a total height of 420 mm. Figure 1 shows the schematic diagram for the arrangement of the filter. The analysis of the phosphorus in synthetic solution was done by measuring only the reactive organic phosphorus due to the lack of organic matter or any other contaminants which are prone to react with phosphorus to form other phosphorus related species since synthetic wastewater was prepared from distilled water. The analysis was carried out using DR6000™ method according to the Standard Methods for the Examination of Water and Wastewater [5].

![Figure 1. The layout of the lab-scale vertical recycled concrete aggregate filter system.](image)

3. Results and discussion

3.1 Characterization of RCA
3.1.1 pH test. This test was done to examine the efficiency of RCA as a medium for phosphorus removal in synthetic wastewater. The pH value of RCA is 9.30, which is alkaline indicating that RCA has high alkalinity content. The removal of phosphorus depends on the pH level [6]. This is due to the mechanisms of the double layer produced when acidic H⁺ is attracted to the concrete surface by calcium, aluminium, and magnesium hydroxide content, which generates a secondary positive layer to bind the negative phosphate. Most materials with high pH also have higher calcium content which is >15%. A previous work [6] obtained a pH value of 10.19 for steel slag. Although steel slag is the product of different processes with different chemical compositions, it shares similar characteristics with RCA such as high calcium content and alkalinity, which influenced the phosphorus removal [7]. On the other hand, another study [8] found that the effective pH for phosphorus removal lies between pH 9 to pH 11.

3.1.2 The analysis of filter medium surface elements using Scanning Electron Microscopy with Energy Dispersive X-ray (SEM-EDX). The SEM-EDX test was used in this study in order to examine phosphorus distribution on the RCA surface and sediment samples. The SEM-EDX test on the fresh surface of RCA samples is shown in figure 2. Moreover, according to the SEM-EDX analysis, the most abundant element on a fresh RCA surface were found to be oxygen, calcium and silica. The result indicated that the highest element content in RCA is calcium which is 23.40%, followed by 11.20% of
silica. Cement paste contains a high amount of calcium [4]. This is because the higher calcium content, the higher the phosphorus removal efficiency. Besides, RCA also contains aluminium and magnesium, which enhance phosphorus adsorption. After two months in the filter system, phosphorus can be seen on the surface of the RCA samples after being examined using SEM-EDX.

Figure 3 shows the presence of phosphorus on the surface of RCA through EDX mapping and the spectrum analysis of the RCA surface after a two-month treatment. The presence of phosphorus on the surface of RCA is 2.60%. This is similar to the results by a previous work [2] using the BFS sample which contained 2.20% of phosphorus. The study [2] also stated that phosphorus rich oxides formed after the effluent from the primary facultative pond underwent further treatment in the BFS filter. The findings for BFS and RCA are comparable as both media have high capacity for adsorbing phosphorus from wastewater. RCA contains 36.60% of calcium oxide [1], while BFS contains 39.97% of calcium oxide [2].

Therefore, the adsorption of phosphorus to calcium oxide could have been the key removal mechanism for phosphorus in the RCA filter and the BFS filter. To choose the most suitable filter media for further experiments, two RCA samples obtained were brought to EDX analysis to determine their elemental compositions as shown in table 2. From the two samples, only one RCA was selected to be used as the filter media in the column study. RCA with the highest amount of CaO was chosen as the filter media because of its preference for phosphorus removal.

![EDX testing for fresh RCA.](image)

**Figure 2.** EDX testing for fresh RCA.
3.2 Percentage of phosphorus due to different concentration of synthetic wastewater

This section discusses the data and analysis on the percentage of phosphorus removal by RCA. Figure 4 shows the percentage of phosphorus removal using RCA of different sizes (5-10 mm and 25-30 mm) in five different concentrations of synthetic wastewater. For RCA between 5-10 mm, the percentages of phosphorus removal were 99.54%, 76.92%, 74.94%, 69.91% and 67.60% for the initial concentrations of 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L and 50 mg/L, respectively. Next, for RCAs between 25-30 mm, the percentages of phosphorus removal were 94.49%, 68.95%, 67.89%, 66.42% and 66.25% for the initial concentrations of 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L and 50 mg/L, respectively. The highest percentage of phosphorus removal achieved was 99.54% in the initial concentration of 10 mg/L by RCAs between 5 to 10 mm. The lowest percentage of phosphorus removal was 66.25% at the initial concentration of 50 mg/L for RCAs measuring between 25 mm to 30 mm.

It can also be seen that the percentage of phosphorus removal decreases as the concentration of synthetic wastewater increases. This is similar to the outcomes reported by a previous work [9] where 80-90% of initial phosphorus was adsorbed by laterite at concentrations of 10-25 mg/L while 60% of the initial phosphorus was adsorbed when higher concentrations were used. According to another work [10], the adsorption capacity increases linearly for the initial concentrations between 5 to 30 mg/L, but the percentage of phosphorus removed reached its maximum at the initial concentration of 15 mg/L. This suggests that the removal of phosphorus is not suitable at higher initial concentrations.

### Table 2. EDX testing for the two RCA samples.

| Percentage (%) | RCA 1 | RCA 2 |
|----------------|-------|-------|
| CaO            | 56.2  | 50.8  |
| O              | 46.2  | 40.2  |
| Ca             | 23.4  | 21.3  |
| C              | 13.7  | 12.9  |
| Si             | 11.2  | 11.0  |
| Al             | 8.9   | 8.8   |
| Fe             | 4.8   | 3.9   |
| Mg             | 6.7   | 5.2   |
Figure 4. Percentage of phosphorus removal with different size of RCA versus different concentration of synthetic wastewater.

4. Conclusion
As a conclusion, RCA sized between 5 to 10 mm has the potential to be used as a filter medium for phosphorus removal in synthetic wastewater. This finding could benefit the environment by reducing the discharge of phosphorus from wastewater to water bodies, which could further lead to eutrophication. Other than this, the use of RCA as a filter medium seems to be a promising contribution towards the sustainability of the construction industry. By using RCA, waste production at construction sites, pollution, landfill space and the cost of concrete disposal can also be reduced.

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