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The Efficacy of Recycled Concrete Aggregate for Removal Phosphorus in Synthetic Wastewater with Different pH Value

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Abstract: Phosphorus (P) is the main nutrient element for plant growth in the natural water system. However, unnecessary phosphorus loads in water bodies from industrial, agricultural and household wastes may cause the overgrowth of aquatic plants or algae which accelerates the depletion of dissolved oxygen (DO) in water, thereby leading to serious eutrophication problems. Nevertheless, existing conventional wastewater treatment systems for removing phosphorus are expensive and complex. Recycled concrete aggregate (RCA) may be an alternative solution for phosphorus removal. It can reduce pollution and landfill disposal by converting construction waste into valuable products. This study aims to investigate the percentage of phosphorus removal using three different sizes of RCA with different pH of synthetic wastewater. A total of four vertical laboratory-scale RCA filters were designed with four different concentrations of synthetic wastewater which is pH3, pH7, pH9 and distilled water were prepared. The pH and the percentage of phosphorus removal (%) were tested and analysed on both untreated and treated sample. RCA was analysed using Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray spectroscopy (EDX) to determine its chemical composition. The results show that RCA has a high content of aluminium, calcium and magnesium that enhances phosphorus adsorption. The pH values are substantially higher for RCA size 5 mm to 10 mm compared to RCA size 10 mm to 15 mm, and 15 mm to 20 mm. Moreover, it was shown that the higher the pH, which is at pH 9 and the smaller size of RCA, the higher the efficiency of phosphorus removal, which is 96% of removal. In conclusion, RCA has the potential to remove phosphorus, particularly in low concentrations of synthetic wastewater and high pH conditions.

Keywords: column, filter, phosphorus, recycled concrete aggregate, wastewater

1. Introduction

Environmental pollution is a global concern because of the dangerous effects on public health and the environment. The irresponsible disposal of untreated wastewater into waters results in polluted water resources. Moreover, nutrients such as phosphorus has become culprits of concern in accelerating eutrophication. Besides, this issue could cause water poisoning and the degradation of recreational opportunities. Hence, wastewater treatment process should be enhanced to ensure treated wastewater effluent discharged satisfy the consent limits and no longer contribute to water pollution. The removal of phosphorus requires a secondary wastewater treatment process. Enhanced biological phosphorus removal (EBPR) and chemical precipitation are commonly practised nowadays due to its great

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consistency in achieving the removal standards [1]. Unfortunately, such 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 is complex maintenance, it is less practical to be applied for smaller communities which suited more with treatment systems with minimal maintenance. 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. Construction waste materials are increasing due to the rising demand all the new alternative. Unless recycled properly, these large amounts of waste ends up in landfill every year. Nowadays, RCA 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 to 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 reduced 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 thus making the RCA as a medium for water treatment to reduce the waste and save the environment. Also, RCA easily available at construction site, therefore recycling the waste is a better idea towards sustainability. Population growth and urbanization have accelerated consumption of concrete and construction and demolition waste generation, therefore the transformation of this product flow into something valuable nowadays is 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 which is demolition waste. Furthermore, a crush concrete aggregate is one of the alternative treatments for the removal of phosphorus. It is an alternative technology for removing nutrients from wastewater. Some of the advantages of crush concrete are its cost efficiency, high availability and relatively easy installation compared to conventional methods. RCA has a high capability for removing phosphorus. It is also easily available and incurs a low cost. Besides, it is a sustainable method since RCA is a recycled product from the construction site. Thus, the use of RCA is a very economical and promising solution for phosphorus removal from wastewater. There has been previous work on using recycled concrete aggregate (RCA) for water treatment and one of the most researched applications has been as a filter media due to its surface roughness and desirable chemical content (e.g., Mg, Ca, Fe, Al). Therefore, this study was carried out to investigate the removal efficiency of phosphorus using recycled concrete aggregates in different concentrations of pH in an aerated filter.

2. Experimental

2.1 Materials

Recycled concrete aggregate (RCA) was produced from concrete cube waste at the Heavy Structure Laboratory, Universiti Tun Hussein Onn Malaysia (UTHM). Then, the concrete cube waste was crushed using crushing machines (Concrete Crusher A35399) to produce RCA. Next, the aggregates were sieved to obtain the desired sizes ranging between 5 mm to 20 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 mm to 20 mm were accepted for use as adsorbents for the column study. The samples were washed up twice with tap water followed by distilled water before they were dried up in the oven for 24 hours at 105℃. Figure 1 shows the process for crushing concrete cube into recycled concrete aggregate.

Fig. 1 - The process for crushing concrete cube into recycled concrete aggregate

2.2 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, four 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 2 shows the schematic diagram for the arrangement of the filter, while Figure 3 illustrates the dimension of the lab-scale column filter. Table 1 summarise the design parameters of the lab-scale filter. 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 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^{TM} method according to the Standard Methods for the Examination of Water and Wastewater [5]. Three sets of column experiments were carried out for two-month duration of each set. Three lab-scale vertical filters of different pH (3, 7, and 9) system were set up for every set. Each system was accompanied by a control (blank) filter with distilled water as the feed. Sampling was done every week for every sampling point to test for the pH

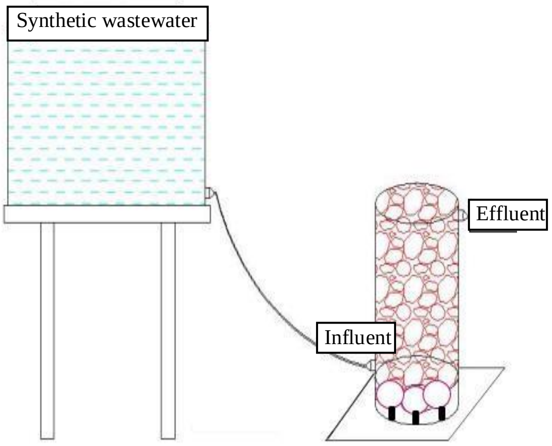

Fig. 2 - The schematic diagram for filter arrangement

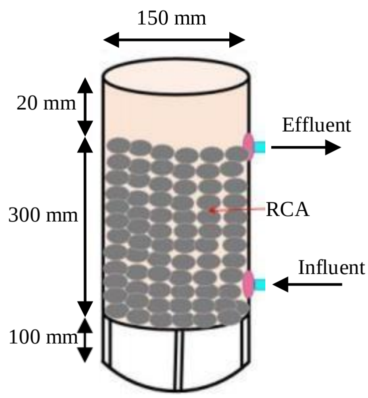

Fig. 3 - The dimension of the lab-scale column filter

Table 1 - Design Parameters of the lab-scale column filter

No	Parameter	Unit	Value
1.	Height	m	0.42
2.	Diameter	m	0.15
3.	Depth of RCA	m	0.30
4.	Hydraulic Loading Rate	$m^3/m^3.d$	0.60
5.	Volume of RCA	m^3	0.007
6.	Flow Rate	ml/min	2.9
7.	Time taken for overflow	Hours	7.6

3. Results and discussion

3.1 Analysis of filter medium surface elements using Scanning Electron Microscopy with Energy Dispersive X-rays (SEM-EDX)

The SEM-EDX test was used in this study 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 4. Moreover, according to the SEM-EDX analysis, the most abundant minerals on a fresh RCA surface were found to be oxygen, calcium, and silica. The result indicated that the highest mineral content in RCA is calcium, which is 23.40%, followed by 11.20% of silica, as summarised in Table 2.

Cement paste contains a high amount of calcium [4]. This is because of the higher calcium content, the higher the phosphorus removal efficiency. Besides, RCA also contains aluminium and magnesium, which enhance phosphorus adsorption [2]. 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 5 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. Table 3 shows the percentage of elements in RCA after treatment. The presence of phosphorus on the surface of RCA is 2.60 %. The findings for BFS and RCA were similar as both media have a high capacity for adsorbing phosphorus from wastewater. RCA contains 36.60% of calcium oxide [4]. 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 the experiments conducted, two samples of RCA obtained were brought for EDX testing to determine their chemical compositions. From all two samples, only one RCA were selected to be used as the filter media in the column study. RCA with the highest amount of amount of CaO were chosen. CaO composition in the RCA were highlighted for the selection of filter media because of their preferences in phosphorus removal mechanism.

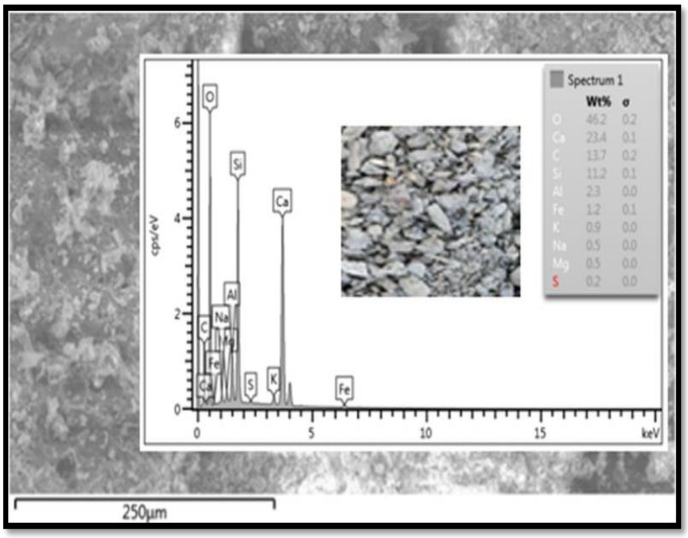

Fig 4 - EDX testing for fresh RCA

Table 2- Percentage of element for fresh RCA

Element	Percentage (%)
O	46.2
Ca	23.4
C	13.7
Si	11.2
Al	2.3
Fe	1.2
Mg	0.5

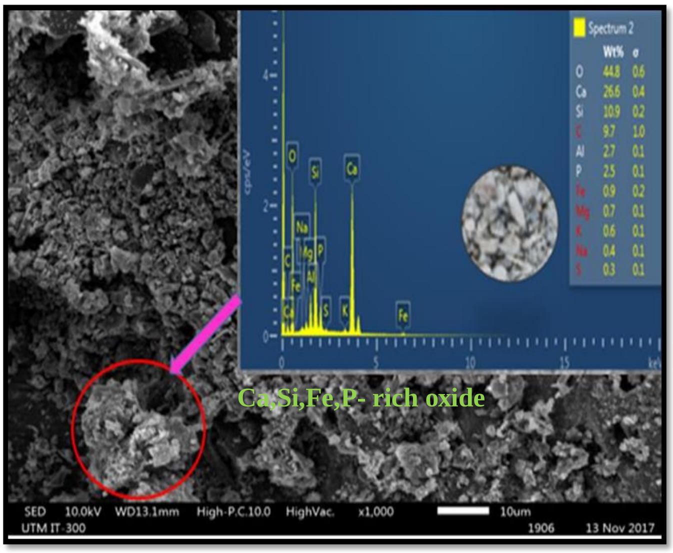

Fig 5 - SEM micrographs and EDX spectra of RCA surface samples of RCA

Table 3- Percentage of element RCA after treatment

Element	Percentage (%)
O	46.2
Ca	23.4
C	13.7
Si	11.2
Al	2.3
Fe	1.2
Mg	0.5

3.2 Percentage Removal of Phosphorus due to pH

Figure 6, 7 and 8 show the percentage graph of phosphorus removal versus pH reading. From the graph, the percentages of phosphorus removal at a pH of 3, 7, 9 for RCA size 5 mm to 10 mm are 88%, 93%, and 96% respectively while percentages of phosphorus removal at a pH of 3, 7 ,9 for RCA size 10 mm to 15 mm are 60%, 70% and 85% and at a pH of 3,7,9 for RCA size 15 mm to 20 mm the percentages of phosphorus removal are 56%, 66%, and 72%. It was shown that the higher the pH, which is at pH 9 and the smaller size of RCA, the greater the efficiency of phosphorus removal. This is similar to the findings by Ahmad *et al*. [2] where the percentage of phosphorus removal is 98% at a pH of 9 in system filter. This is true for systems which allow precipitates to form. Mohan *et al.* [6] stated that the higher the pH value, the higher the calcium content. Thus, the higher the calcium content, the higher the ability of the material to remove phosphorus. Nasir [7] also obtained the optimum pH value for the effective removal of phosphorus. 80% of phosphorus was removed using steel slag at a pH of 9.40. This is because steel slag also has higher calcium content and alkalinity. It shows that an alkaline condition allows precipitation which can influence the removal of phosphorus. Next, the effective removal of phosphorus by using opoka as a filter occurred at a pH of 12.60. The removal of phosphorus using sand was also effective between a pH of 7.8-9.5. In sand, phosphorus is bound to the medium due to adsorption and precipitation reactions with calcium, aluminium and iron. According to Yihuan and Andrew [8], an alkaline pH could also help cement release more Ca^{2+} ions into the solution to react with hydrogen phosphate, causing the precipitation of $Ca_3(PO_4)_2$. The increase in P removal above pH 9 could be due to a similar mechanism due to the formation of OH enriched complexes precipitating calcium phosphate. At pH levels greater than 6, the reactions are a combination of physical adsorption to iron and aluminium oxides and precipitation as sparingly soluble calcium phosphates [10]. From the figure below we can see that the most suitable RCA size for an efficient of phosphorus removal is between 5-10 mm. These results were similar to that of Mohan *et al*. [6] where the sorption capacity of phosphorus was 0.25-0.3 mg/L when the limestones measuring less than 10 mm were used. Meanwhile, the sorption capacity increased to 2.682 mg/L when limestones which were less than 40 mm were used. The uptake capacity of phosphorus was predominantly affected by the size of the medium used. This is because the smaller the size of the medium, the greater the surface available for calcium oxide dissolution [9]. According to Yihuan and Andrew [8], a higher adsorption capacity can be obtained by using particles measuring less than 5 mm. Noted that, distilled water was used as the influents which act as the blank/control system, parallel with the other influents which used 25 mg/L synthetic wastewater as the feed. From the results obtained for Control system, there were no traces of phosphorus found in both the influents and effluents of the Control system. This could be concluded that the presence of phosphorus obtained from the other systems which used synthetic wastewater were all solely contributed from the synthetic wastewater, with no contribution of phosphorus leached out from the filter media.

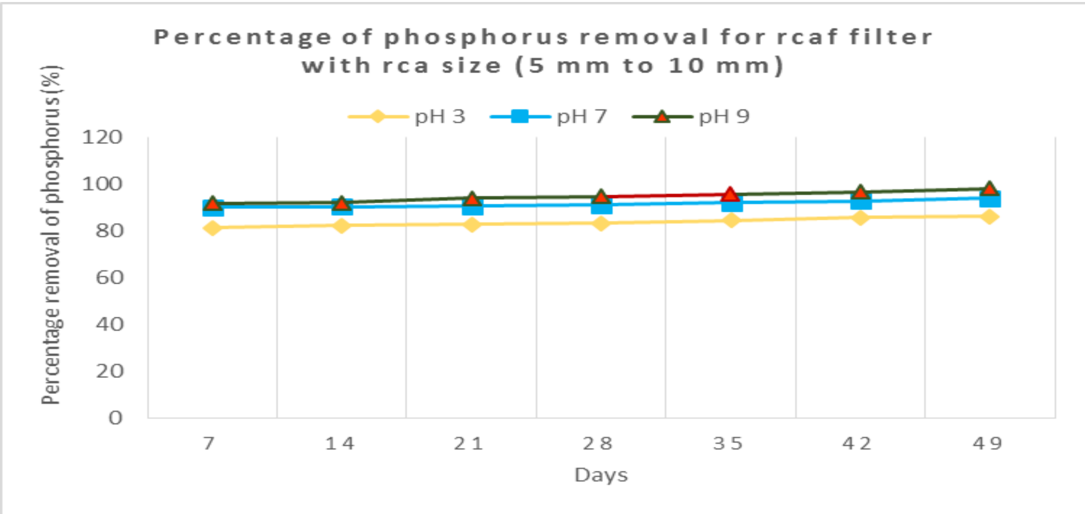

Fig. 6 - Percentage of phosphorus removal for RCAF filter with RCA size (5 mm to 10 mm)

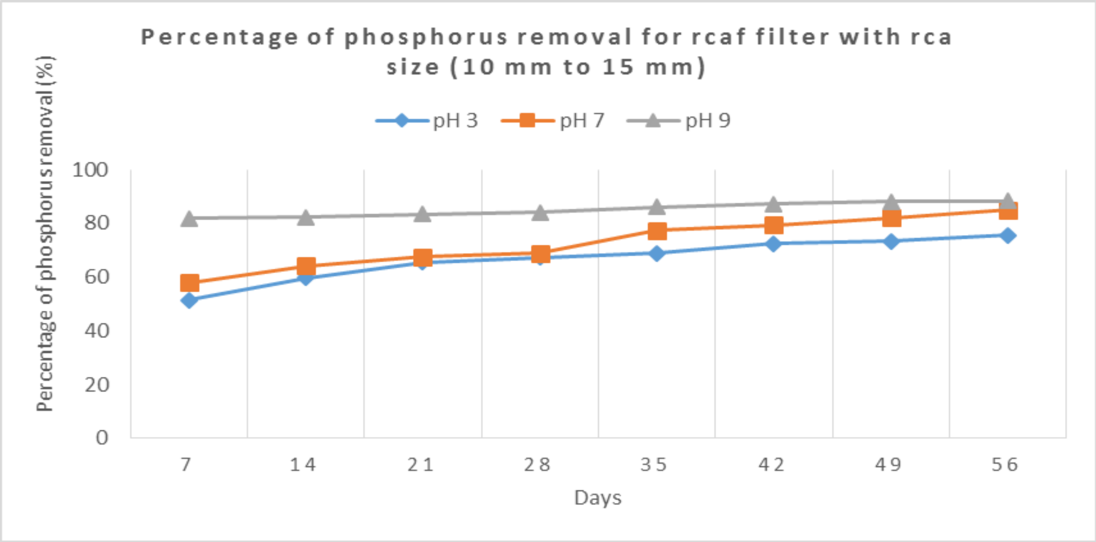

Fig. 7 - Percentage of phosphorus removal for RCAF filter with RCA size (10 mm to 15 mm)

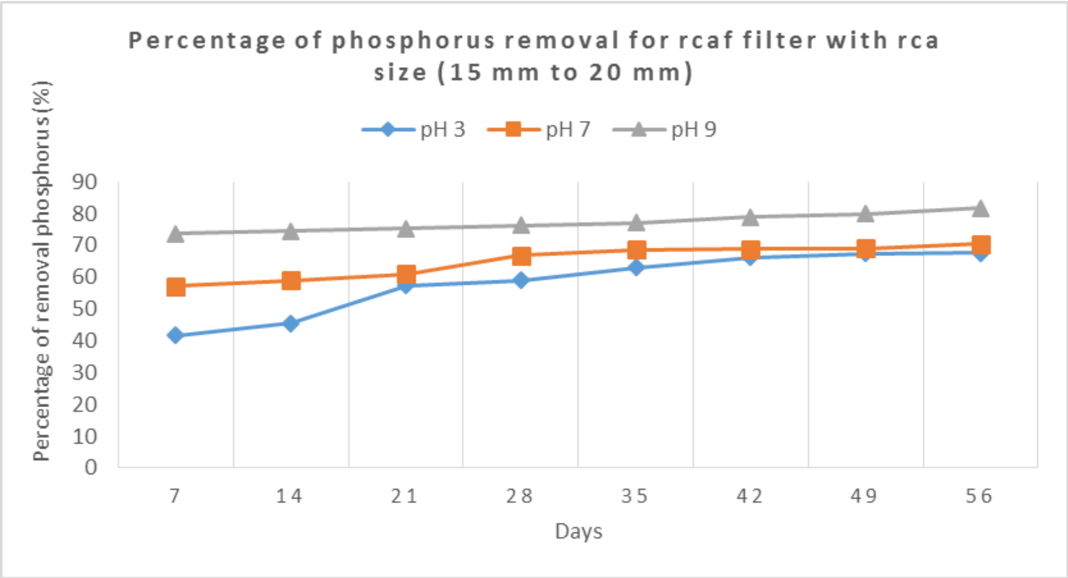

Fig. 8 - Percentage of phosphorus removal for RCAF filter with RCA size (15 mm to 20 mm)

4. Conclusion

The highest pH reading resulted in the highest phosphorus removal efficiency. 96% of phosphorus was removed at a pH of 9. Thus, as a conclusion for this study, RCA 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, production waste at construction sites, pollution, landfill space, and the cost of concrete disposal can also be reduced.

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