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The Physical and Chemical Characteristic of Recycled Concrete Aggregate for Removal Phosphorus as a Filter System

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Abstract: The removal of phosphorus from wastewater is a common procedure. Improving water quality is the aim of wastewater treatment. There are many types of conventional methods that have been used for the removal of phosphorus. Phosphorus reaction with chemicals can be removed immediately from water. However, the use of chemicals often increases the cost of wastewater treatment. This study aims to investigate the physical and chemical characteristics of RCA that influence the removal of phosphorus, as well as the percentage of phosphorus removal using RCA of two different sizes namely, 5 mm to 10 mm and 25 mm to 30 mm. The samples taken from the influent and effluent filters were tested and analysed in terms of the uptake capacity of phosphorus (q) and the percentage of phosphorus removal (%). The highest percentage of phosphorus removal achieved was 99.54% in the initial concentration of 10 mg/L by RCA measuring between 5 mm to 10 mm while the lowest percentage of phosphorus removal was 66.25% in the initial concentration of 50 mg/L for RCAs measuring between 25 mm to 30 mm. Furthermore, RCA achieved the highest uptake capacity (q) of 3.45 mg/L in the initial wastewater concentration of 50 mg/L. 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

Phosphorus (P) is a main nutrient element for plant growth in the natural water system. However, excessive 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. In developing countries, approximately 75% of domestic wastewater is released into the environment without treatment (Rozari *et al*. 2016). Ayaz *et al*. (2012) reported that eutrophication in receiving water bodies may occur when the concentration of phosphorus is 6 mg/L. Therefore, proper treatment for removing phosphorus from domestic wastewater to achieve the admissible level for natural systems is needed. According to Nasir (2016), an important factor that needs to be considered in designing a filter includes the selection of the filter material itself. The utilisation of easily available and low-cost materials has been widely demonstrated by previous studies for the removal of phosphorus including limestone, fly ash, iron oxide, steel slag and blast furnace slag (Johansson, 2013). Therefore, a detailed study of filter media capabilities for the removal of phosphorus is essential.

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The removal performance of phosphorus is influenced by temperature, pH, and concentration of metallic salt. pH value has a significant effect on the removal of phosphorus. Generally, adsorption will occur at a low pH while calcium will precipitate during the removal of phosphorus at a high pH (Ahmad *et al*., 2017).

Unaerated systems and aerated systems vary in the admission of oxygen into the systems throughout the aeration process. Under aerated conditions, calcium and aluminium adsorb on the surface of adsorbents to become the adsorption site for the removal of phosphorus. However, phosphate is precipitated together with Ferum ions. Besides that, highly dissolved oxygen in aerated conditions cause much more carbon dioxide to be exposed to the atmosphere, thereby producing carbonic acid. This results in the increase of pH levels in the system (Hamdan & Mara, 2013). In this study, the aerated system and unaerated system was chosen to investigate which is better performance compared to the both system. Besides that, the size of recycled concrete aggregates (RCA) also influences the removal of phosphorus. Yassin *et al*., (2016) stated that smaller-sized RCA acts as the best filter medium. 66-99% of phosphorus can be removed by RCA measuring between 5-35 mm. The initial concentration of synthetic wastewater was between 10-50 mg/L. Although the total volume of aggregates used as a filter medium was relatively small, filters nevertheless play important and diverse roles in many projects. However, filter materials for water and effluent treatment are often used in relatively small quantities as high quality aggregates are not readily provided by commercial production processing which may be designed to yield a satisfactory general purpose aggregate at the lowest cost. RCA was choose to be filter media in this study due to it easily available at construction site. There is abundance of waste that has been thrown away at construction site. Thus, this RCA can be made as alternative filter materials and may be made to be something valuable.

2. Experimental

3. 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) 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 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 C.

2.2 Physical and chemical testing of RCA

In this study, the physical and chemical characteristics of RCA were determined. Several tests were conducted to analyse the characteristics of RCA to determine its ability and strength as a filter for phosphorus removal. Physical and chemical breakdown in service may seriously impair the design grading of a filter and adversely affect its performance. The strength, shape, surface structure and composition of the individual particles will have an important influence on the above properties, the abrasion resistance and the crushing strength of the aggregates during placing and compaction. Three physical characteristics tests carried out on RCA in this study were the bulk density test, water absorption test and the aggregate impact value test and two chemical characteristics tests were conducted on recycled concrete aggregates in this study namely, point zero charge and pH.

2.3 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. 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 (2005).

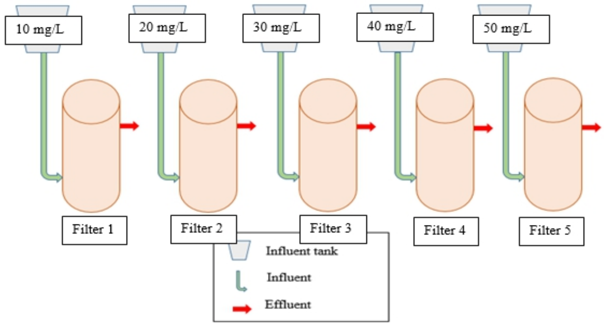

Fig. 1 - The layout of the lab-scale vertical unaerated recycled concrete aggregate filter system

4. Results and discussion

3.1 Physical Characteristics Tests on Recycled Concrete Aggregate

There were three main physical characteristics tests conducted on RCA in this study namely the bulk density test, water absorption test and aggregate impact value test. These tests were done to investigate the efficiency of RCA as a medium for the removal of phosphorus in synthetic wastewater. Table 1 shows the readings for the physical characteristics of RCA.

Table 1 - Physical characteristics of RCA

Parameter	Value
Bulk density	1680 kg/ m^3
Water absorption	1.27%
Aggregate impact value (AIV)	28.75%

The bulk density of an aggregate, or its unit mass, reflects in part its void content at a given degree of compaction and is therefore an indirect measure of grading and shape. The value of the bulk density of the aggregate depends on the amount used to fill up the container, size distribution, shape and specific gravity.

Angular and flaky materials can reduce bulk density. It can be seen that the highest bulk density of RCA is 1680 kg/ m^3. This is because this RCA consists mostly of mortar and has a narrow size distribution. In contrast, Faiz Uddin (2016) found that the bulk density for RCA is 1247 kg/m^3. RCA is generally sourced from crushed concrete structures. Therefore, residues may adhere to RCA. Meanwhile, Larbi *et al.*, (2015) determined that the bulk density for RCA is 1148 kg/ m^3. This is due to the effect of superplastizers on density. The test clearly showed that compacted aggregate which has a bigger bulk density provides better strength. It was also found that a filter medium with higher bulk density provides better adsorption efficiency. Therefore, a filter medium with better adsorption efficiency would result in more effective phosphorus removal.

This water absorption test helps to determine the water absorption of RCA according to IS: 2386 (Part III) – 1963. According to Anchor *(1998)*, the water absorption of aggregates should not exceed 3%. In this study, the water absorption for RCA was 1.27%. Hence, the results showed that it did not exceed the maximum 3% absorption. Water absorption represents the porosity of aggregates. Ayaz *et al.*, (2012) reported that the higher the porosity, the larger the specific surface area where the adsorption mechanism can take place.

The aggregate impact value (AIV) test was conducted in accordance with IS: 2386 (Part IV) – 1963. The strength of aggregates is evaluated by aggregate impact value. The aggregate impact value test delivers a relative measure of resistance under a progressively applied compressive load. To achieve high quality strength, aggregates should retain a low aggregate impact value. The AIV test based on IS: 2386 (Part IV) – 1963 states that the aggregate impact value should not exceed 45%.

Adnan *et al.*, (2010) found that the AIV for RCA was 20.80 %. This was due to the mortar attached to recycled aggregates (RA) which probably influenced the amount of broken particle size smaller than 2.36 mm size after the blasting process. All the results showed that the AIV of RCA did not exceed 45% thus proving that RCA has achieved its required strength. Zhilong *et al.*, (2014) claimed that RCA with high aggregation strength displayed relatively compact structures which are effective for removing phosphorus. Generally, the destabilised particles interrelate with each other and aggregate to form compact micro flocs. When the process continues, the formation of aggregates is dominated by adsorption.

3.2 Chemical Characteristics Tests on Recycled Concrete Aggregate

Three chemical characteristics tests were performed on RCA namely, the point zero charge (PZC) test, pH test and the analysis of filter medium surface elements using Scanning Electron Microscopy with Energy Dispersive X-ray (SEM-EDX). These tests were done to examine the efficiency of RCA as a medium for phosphorus removal in synthetic wastewater. Table 2 shows the results of the chemical characteristics of RCA.

Table 2 - Chemical characteristics of RCA

Parameter	Value
Point zero charge of RCA	8.60
pH of RCA	9.30

The point of zero charge (PZC), defined as the pH value at which the net proton charge equals to zero, is a significant parameter for understanding the aggregation of recycled concrete aggregates (RCA). When bare RCA is detached in solutions at pH_{PZC}, the surface charge of RCA approaches zero and the electrostatic force is reduced, followed by the formation of aggregation between RCA. To discover the pH_{PZC} of each RCA, the surface charge of the RCA visible in pH 1–10. pH_{PZC} offers information concerning more efficient stabilisation (Nee and Kim, 2013). This test was conducted at 170 rpm for 24 hours.

The reading point zero charge of RCA is 8.60. Figure 2 displays the Point Zero Charge graph. This result was similar to that by Nasir (2016) where the pH_{PZC} for steel slag is 9.2. This is because the surface charge has zero value near pH_{PZC}, followed by less coagulation or flocculation between each particle.

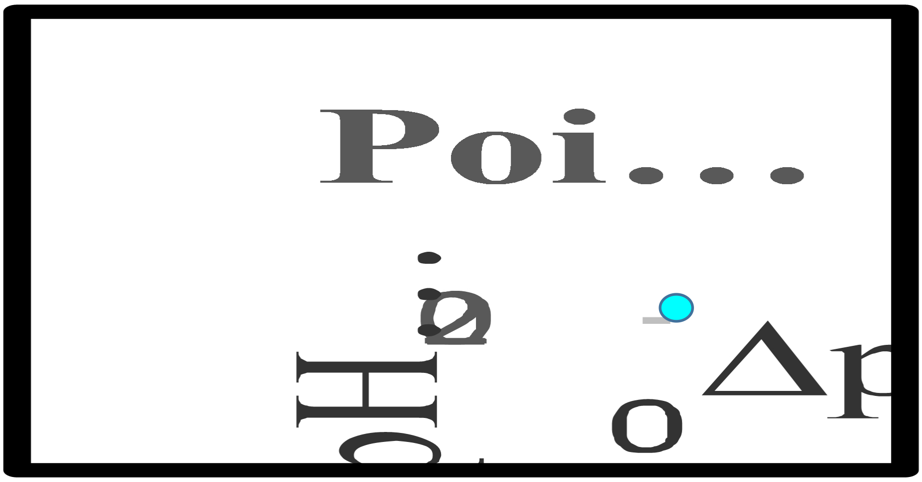

Fig. 3: Point Zero Charge

The pH value of RCA is 9.30 which is alkaline. Thus, RCA has high alkalinity content. The removal of phosphorus is related to pH level. Regarding to Xiong *et al*., (2011). This is due to the mechanisms endorsed by the double layer outcome whereby 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%).

Nasir (2016) obtained a pH value of 10.19 for steel slag. Although steel slag is the product of different processes and different chemical compositions, it shares similar characteristics with RCA such as high calcium content and alkalinity which influence phosphorus removal (Zuo *et al*., 2015). On the other hand, Ahmad *et al*., (2017) found that the effective pH for phosphorus removal lies between pH 9 to pH 11. The phosphate removal efficiencies were between 51-71% and 55-80%. This might be due to the vibration produced during aeration which causes the reaction to proceed faster.

3.4 Percentage of Phosphorus Removal Efficiency

This section discusses the data and analysis on the percentage of phosphorus removal by RCA. Figure 3 shows the percentage graph of phosphorus removal using RCA of different sizes (5-10 mm and 25-30 mm) in five different concentrations of synthetic wastewater. For RCAs measuring 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 measuring 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 measuring between 5 mm to 10 mm while the lowest percentage of phosphorus removal was 66.25% in the initial concentration of 50 mg/L for RCAs measuring between 25 mm to 30 mm. It can be seen that the percentage of phosphorus removal decreases as the concentration of synthetic wastewater increases. From the graph, the percentage of phosphorus removal decreases as the initial concentration of synthetic wastewater increases. It was similar due to the outcomes by Wood and Atamney (2016) where 80-90% of initial phosphorus was absorbed by Laterite in concentrations of 10-25 mg/L while 60% of initial phosphorus was absorbed when higher concentrations were applied. According to Yihuan and Andrew (2018), 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.

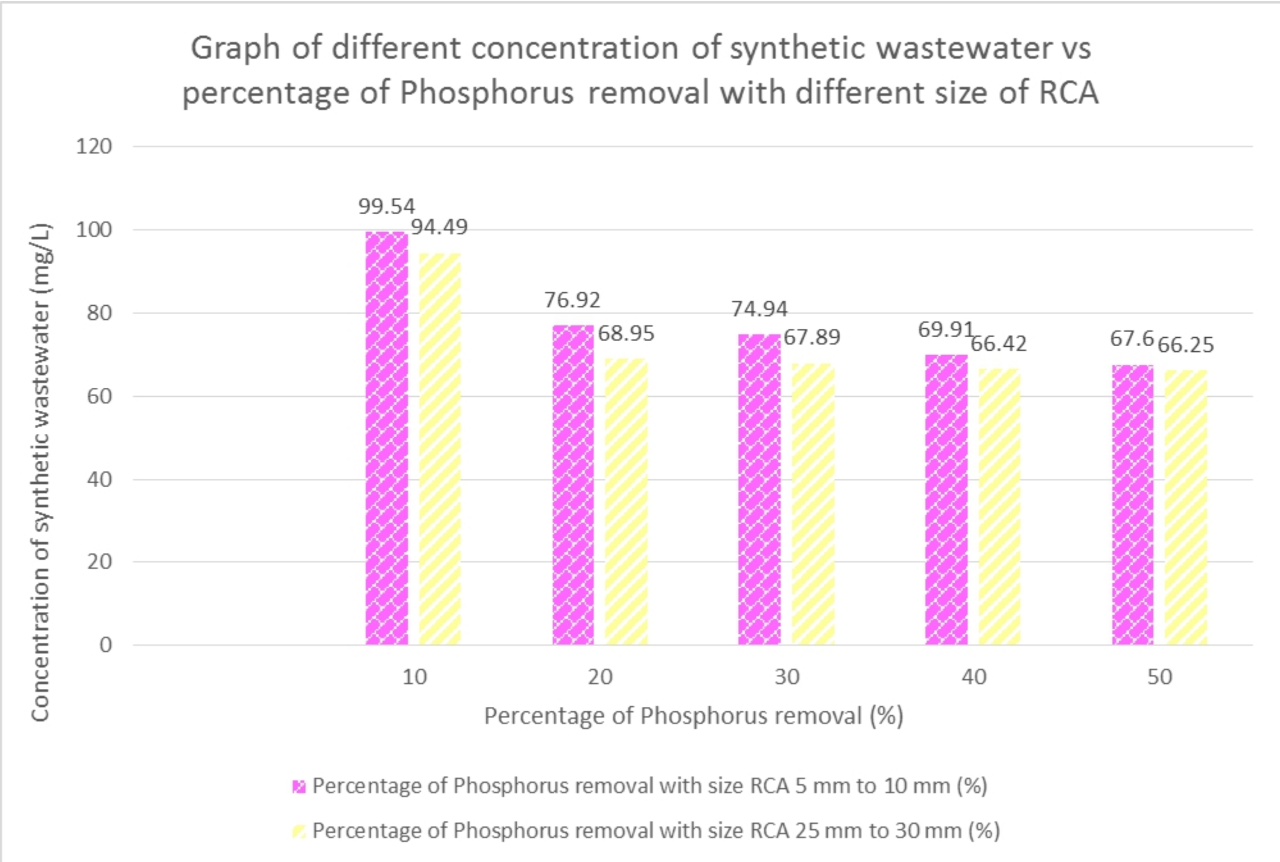

Fig. 3 - Percentage of Phosphorus removal with different size of RCA versus different concentration of synthetic wastewater

5. Conclusion

Based on physical and chemical characteristic of RCA, it shows that RCA could be an efficient new types of filter for removal of phosphorus.

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References

[1] Adnan, S. H., Hamdan, R., & Mohd Yassin, N. I. (2016). Removal of phosphorus from synthetic wastewater using recycled concrete aggregates as filter media. 2nd International Conference on Science, Technology and Social Science

[2] Ahmad, S. Z. N., Hamdan, R., & Wan Mohamed, W. A. (2017). Comparisons Study of Phosphate Removal In Unaerated And Aerated Steel Slag Filter System. Jurnal Teknologi

[3] Ayaz, S. C., Aktas, O., Findik, N., & Akca, L. (2012). Phosphorus removal and effect of Adsorbent type in a constructed wetland system. Desalin. Journal of Environmental Engineering, 37

[4] Faiz, U., (2016). Mechanical and durability properties of fly ash geopolymer concrete containing recycled coarse aggregates. International Journal of Sustainable Built Environment

[5] Hamdan, R., & Mara, D. (2013). Study of in-filter phosphorus removal mechanisms in an aerated blast furnace slag. International Journal of Research in Engineering and Technology, 2000

[6] Johansson,L. (2013). Substrates for phosphorus removal potential benefit for wastewater treatment. Water resources.40:23-36

[7] Larbi, B., Abdelaziz, M., & Miloud, B. (2015). Study of the physico-mechanical properties of a recycled concrete incorporating admixtures by the means of NDT methods. Scientific-Technical Conference Material Problems in Civil Engineering, 12

[8] Nasir, N. N. (2016). Effect Of pH and Density Metal Oxide on Removal of Phosphorus Using The Filter System Vertical Steel Slag. Journal of Environmental Engineering

[9] Nee, K., and Kim, Z., (2013). Sensitivity of nanoparticles stability at point zero charge. Journal of industrial and engineering chemistry

[10] Rozari, P. De, Greenway, M., & Hanandeh, A. (2016). Phosphorus removal from secondary sewage and septage using sand media amended with biochar in constructed wetland mesocosms. Science of Total Environment, 3, 123–133

[11] Xiong, J., He, Z., Mahmood, Q., Liu, D., Yang, X., & Islam, E. (2011). Phosphate removal from solution using steel slag through magnetic separation. Journal of Hazardous Materials, 152(1), 211–5

[12] Yihuan, D and Andrew, W., (2018). Mechanism of phosphorus by recycled crush aggregate. International Journal of Environmental Research and Public Health

[13] Zhilong, A., Stanford, R., Wu, S., (2014). Phosphorus recovery from wastewater by suite crystallization property of aggregate. International Journal of Environmental Research and Public Health

[14] Zuo, M., Renman, G., & Gustafson, J. P. (2015). Phosphorus removal performance and speciation in virgin and modified argon oxygen decarburisation slag designed for wastewater treatment. Journal of Water Research, 12(3)