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THE UTILIZATION OF RECYCLED CONCRETE AGGREGATE FROM CONSTRUCTION WASTE AS VERTICAL FILTER

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Abstract

The eutrophication in surface water is one of the problem cause by the higher amount of phosphorus (P). Nevertheless, the existing conventional wastewater treatment system to remove phosphorus is require a complex process. Hence, a system using environmental friendly should be adept to overcome this problem. Recycled concrete aggregate (RCA) used as a filter system issue as an alternative technology for phosphorus removal. This can overcome the problem of construction site waste by converting the waste into something valuable products. Thus, this study aim to investigate the physical and chemical characteristic of RCA that influenced adsorption of P and to determine the percentage of P removal by using two different size of RCA which is (5 mm to 10 mm) and (25 mm to 30 mm). A total of five vertical recycled concrete aggregate filter laboratory scale was design using recycled concrete aggregate and five different concentration of synthetic wastewater which is 10 – 50 mg/L was prepared. Samples were taken from the influent and effluent filters to be tested once a week, and analyzed to determine the amount of pH, the uptake capacity of Phosphorus (q) and the percentage of Phosphorus removal (%).RCA was analyzed using Scanning Electron Microscopy (SEM) and Energy-dispersive X-ray spectroscopy(EDX) testing to determine chemical composition. Results shows that RCA is highly contained with Aluminium, Calcium and Magnesium elements that enhanced the Phosphorus adsorption. The RCA with size 5 mm to 10 mm and synthetic wastewater 10 mg/L display high potential in removing P with 99.54% removal at pH 9.77. Furthermore, this RCA also shows the highest uptake capacity (q) of 3.45 at concentration of synthetic wastewater 50 mg/L. The lower concentration of synthetic wastewater, smaller size of RCA and higher pH have slightly better Phosphorus removal efficiency. In conclusion. RCA has a potential in removing P from synthetic wastewater.

Keywords--Phosphorus, Recycled concrete aggregate, synthetic wastewater

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INTRODUCTION

Phosphorus (P) is a primary nutrient element plants growth in natural water system. However, excessive P loads to water bodies from industrial, agricultural, household wastes may cause the overgrowth of aquatic plants or algae which accelerate the depletion of dissolved oxygen (DO) in waters, and leading to serious eutrophication problems. In developing countries, approximately 75% of domestic wastewater is discharged to the environment without treatment (Rozari*et al*. 2016& Othman et al., 2016). Ayaz *et al*. (2012) reported that eutrophication in receiving water bodies may occur when concentration of phosphorus was 6 mg/L.

Therefore, becoming treatment to remove phosphorus from domestic wastewater for natural systems is needed. Present, construction and demolition (C&D) activities shows a growing trend for several years. The pollution will happen if the management of solid waste in construction not disposed in a proper method. Thus, to support sustainable of natural resources and reduced disposal of demolition waste, recycling of concrete is a momentous alternative method. Recycled concrete aggregate that has been crushed for selected size was used in this study to investigate its performance as an effective filter for removal of P.

The aim for wastewater treatment is improving water quality. There are numerous types of conventional methods that have been used for removing of P. Phosphate reaction with chemicals can be separate instantly from water. Yet, the use of chemicals increase the cost of wastewater treatment (Zuo*et al*. 2015). Therefore, this study was conducted to find the proper method of obviate phosphorus in a filter system using recycled concrete aggregate as it is environmentally friendly.

According to (Nasir, 2016) the selection of the filter material itself is the important factors that need to be considered in designing a filter. The utilization of easily accessible has been widely incontestable by previous study in removing 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 necessary. The performance removal of phosphorus influenced by temperature, pH, concentration of metallic salt and many more. The significant effect on removal of phosphorus is by pH value. Mostly, at low pH adsorption will occur while at high pH value Calcium will precipitate for removal of Phosphorus (Ahmad *et al*., 2017). Unaerated system and aerated system vary in the starter of oxygen into the systems throughout the aeration process. Below aerobic conditions, Calcium and Aluminium adsorb on the surface of adsorbent which be able to be the adsorption site for removal of phosphorus however phosphate are precipitated out with Fe ions. Besides that, high dissolved oxygen in aerated conditions effects much more carbon dioxide to be exposed to the atmosphere therefore produce slight carbonic acid. This outcomes in the increase in pH levels in the system (Hamdan & Mara, 2013). In this study, unaerated system has been chosen due to its performance were slightly better compared to aerated system which is the system can removed 76- 98% of P while for aerated system the removing of Phosphorus is (66-95%). It is evidently seen that unaerated system perform better at removing of phosphorus (Ahmad *et al*., 2017& Hussain et al., 2016). Hence, unaerated system chosen in this study. Then again, the size of RCA also influenced on the removal of phosphorus. Yassin *et al*., (2016) stated that for different size of RCA, it shows that smaller size of RCA act as the best filter media in removing Phosphorus which is for (66-99%)

percentage removal of Phosphorus between sizes of RCA (5-35 mm). The initial concentration of synthetic wastewater chosen from (10-50 mg/L).

Rock filters (RF) have turn an encouraging alternative technology for removing nutrients from wastewater. The advantages of RF due to its relatively 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. Recycled concrete aggregate (RCA) attracts more attention as the filter media due to high capability in removing phosphorus (Suraya *et al*., 2019). Also, RCA easily available at construction site, therefore recycling the waste is a better idea towards sustainability. Population growth and urbanization have speeded up consumption of concrete and construction and demolition waste generation, therefore the transmutation of this product flow into something valuable nowadays is become very significant for us. In the present study, RCA was choosen 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. Some of the advantages of crush concrete are its cost efficiency, high availability and relatively easy installation compared to conventional methods.

According to previous studies, one of the alternative filter media for the removal of phosphorus is recycled concrete aggregate (RCA). 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. Furthermore, Yassin *et al*., (2016) reported that RCA can remove nearly 100% of phosphorus due to specific phosphorus adsorption onto metal hydroxides and the precipitation of hydroxyapatite. Thus, the use of RCA is a 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). Li *et al*., (2017), for example, used fly ash aerated crushed concrete at laboratory scale to achieve 95.6% total nitrogen removal from sewage and landfill leachate. Guo *et al*., (2019) also used RCA as a wastewater filter and show edit could remove 37% of COD and 55% of total P. The mechanism has been reported to be based on the calcium, aluminium, and iron content which can bind with phosphate. Phosphorus (P) is needed for optimum crop production and mineral phosphorus reserves are thought to be limited with no substitutes. Furthermore, removal of P from wastewater to meet environmental quality standards is now a significant in chemicals and power.

EXPERIMENTAL STUDY

Materials

Recycled concrete aggregate

In this study, Recycled Concrete Aggregates (RCA) was collected from concrete cube waste at Heavy Structure Laboratory, UniversitiTun Hussein Onn Malaysia (UTHM). Then the concrete cube waste were crushed by using the crushing machines (Concrete Crusher A35399), Malaysia in order to produce Recycled Concrete Aggregates (RCA). Next aggregates were being sieves with size (5 mm to 30 mm) by test sieve (British Standard sieve BS410/1986) using a shaker, Endecotts Lombard Rd. London, model Sw193BR, England. Figures 1 and 2 shows the step from concrete cube waste becomes the recycled concrete aggregates.

Figure 1 & 2. Process of crushing the waste cube into recycled concreteaggregate

Preparation of synthetic wastewater

In general there are two types of wastewater that can be used which is raw wastewater and synthetic wastewater. Synthetic wastewater is prepared in Wastewater Engineering Laboratory, UTHM and it was prepared before the treatment process. The synthetic wastewater was prepared by using Potassium Dihydrogen Phosphate (KH_2PO_4). For the preparation of synthetic wastewater, 4.391g of KH_2PO_4 was weighed and filled into 1L of volumetric flask. Then, distilled water was added into volumetric flask up to 1L volume to produce 1000 mg/L of phosphorus concentration. Then, the mixture was mixed thoroughly. The synthetic wastewater was prepared into five different initial concentrations which are 10 mg/L, 20 mg/L, 30 mg/L, 40 mg/L, 50 mg/L. In order to produce different initial concentration of phosphorus in synthetic wastewater, the stock solution were diluted distilled water according for the design concentration.

Filter column study

Lab scale the vertical Recycled Concrete Aggregates Filter (VARCAF) was developed to investigate the removing of phosphorus from synthetic wastewater in this study. This VARCAF was design in cylindrical shape. In this study, there are five VARCAF was design and placed at Wastewater Engineering Laboratory, Faculty of Civil and Environmental Engineering, UniversitiTun Hussein Onn Malaysia (UTHM). The VARCAF designed with the inner diameter of 150 mm, 5 mm of thickness and total height is 420 mm made from Perspex material. Figure 3 shows illustrates schematic diagram of the layout of the lab-scale vertical unaerated recycled concrete aggregate filter system. The VARCAF designed based on Hydraulic Loading Rate. Based on the study by Williamson and Swanson (2013) HLR starts from range of 0.06 to 0.34 day-1. For the warm climates like Malaysia, HLR range is lower compared to another country which are calmer climates. Based on this situation, this study takes 0.06 for the value range of HLR as the initial trial. The equation in appendix shows the calculation to determine the flow rate of synthetic wastewater the parameter design for VARCAF.

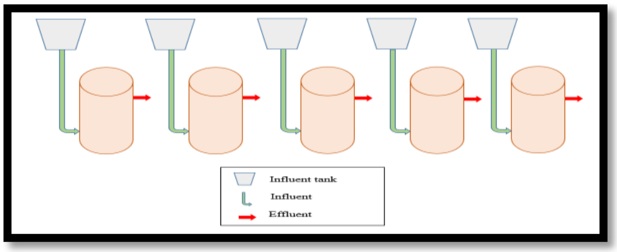

Figure 3. Schematic diagram of the layout of the lab-scale vertical unaerated recycled concrete aggregate filter system

RESULTS AND DISCUSSION

Physical Characteristics

There are three main physical characteristic testing of RCA in this study which is bulk density, water absorption and aggregate impact value. These test was doneto investigate the efficiency characteristic of RCA as a medium for removal of Phosphorus (P) in synthetic wastewater. Table 1 shows the reading for physical characteristic testing of RCA.

Table 1. Physical characteristic testing of RCA

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

Themain parameter for determining the mass/volume ratio of absorbent is the bulk density. Value of the bulk density of the aggregate depends upon the amount of used to fill the container as possible, size distribution, shape and specific gravity.

Angular and flaky shape of the material reduce the bulk density. It can be seen that the highest bulk density is 1680 kg/ m^3. It is significantly higher than those of researcher. This is because this RCA is mostly composed by mortar, and it presents a narrow size distribution. Different with FaizUddin (2016), the bulk density test for RCA is 1247 kg/m^3. The RCA is generally sourced from crushed concrete structures, therefore, old mortars adhered to the RCA. Meanwhile, Larbi *et al.*,(2015) determine that bulk density for RCA is 1148 kg/ m^3. This is because the effect of the superplastizier on the density. Test clearly shows that compacted aggregate which has bigger bulk density provides better strength. Generally, Nhat (2015) define the bulk density for biochar is 1590 kg/m^3 and describe that high bulk density of a medium filter provide much better adsorption efficiency. Therefore, better adsorption efficiency of medium deliver the effectiveness for removal of Phosphorus.

Next is water absorption test. This test helps to determine the water absorption of Recycled Concrete Aggregate as per IS: 2386 (Part III) – 1963. According to Anchor *(1998)*, the water absorption of aggregates should not exceed 3% of absorption. In this study, water absorption for RCA was 1.27. Hence the result shows it not exceed the maximum of 3% absorption. Water absorption signify the high porosity strength of aggregates. RCA which is having less water absorption are more porous in nature and are generally considered suitable medium filter for removal of Phosphorus. Ayaz *et al.*, (2012) reported that larger the porosity, larger the specific surface area where adsorption of mechanism can take place. For the aggregate impact value, the test is accordance to IS: 2386 (Part IV) – 1963. The strength of aggregates is evaluated by aggregates impact value. The aggregates impact value test deliver a relative measure of resistance under a progressively applied compressive load. To achieve high quality strength, aggregate should retained low aggregate impact value. The AIV test based on IS: 2386 (Part IV) – 1963, states that the aggregates impact value shall not exceed 45%. Other researcher, Adnan *et al.*, (2010) examined the AIV test for RCA was 20.80 %. This is due to the mortar attached to recycled aggregate (RA) could most probably influence the amount of broken particles size smaller than 2.36 mm size after the blasting. Shahiron*et al.*, (2017) show that the AIV Test for RCA was 12.7 % which is the lowest percentage. This is due that the recycled aggregates were treated first with 25% epoxy resin. All the results shows that AIV test not exceed 45% thus proof that the RCA has achieve its strength. Regarding to Zhilong*et al.*, (2014) high aggregation strength displayed relatively compact structures formed relatively higher removing phosphorus. Generally, in the AIV process, the destabilized particles interrelate with each other and aggregate to form compact micro flocs. When the process continues, the formation of aggregates is dominated by adsorption.

Chemical Characteristics of RCA

There are two kind of chemical characteristic testing of RCA in this study which is point zero charge testing and pH of RCA. These test was doneto examine the efficiency characteristic of RCA as a medium for removal of Phosphorus (P) in synthetic wastewater. Table 2 shows the reading for chemical characteristic testing of RCA.

Table 2. Chemical characteristic testing 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 zero, is an significant parameter for understanding the aggregation of recycled concrete aggregate (RCA). When bare RCA are 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 solutions was analyzed by DLS. pH_{PZC} offers info concerning more efficient stabilization (Nee and Kim, 2013). This test conducted at 170 rpm for 24 hours.

The reading point zero charge of RCA is 8.60. Then, H_20 contributes H^+ is more than OH^-, therefore the surface absorption was negative charge. Figure 4 displays graph of Point Zero Charge. This result similar to Nasir (2016), the pH_{PZC} for steel slag is 9.2. This is due to near pH_{PZC}, the surface charge had zero value, followed by less coagulation or flocculation between each single particle.The pH value of RCA is 9.30 which is alkaline thus RCA gives high alkalinity content. Thus, based on the determination of pH that has been conducted, its demonstration that RCA was alkaline. The influence removal of Phosphorus related to pH level and Calcium content of filter material. As a calcium ions can form stable and insoluble products with phosphate, calcium-based materials are considered to be one of the potential sorbent of phosphorus removal. This is due to the mechanisms endorsed to the double layer outcome whereby acidic H+ was attracted to the concrete surface by Calcium, Aluminium, and Magnesium hydroxide content generating a secondary positive layer to bind the negative phosphate. The most of materials with high pH also have higher Calcium content which is (>15%) (Xiangling*et al.*, 2016).

Nasir (2016) also get pH value for steel slag as an alkali which is 10.19. Although steel slag is the product of different processes and different chemical compositions, but they share similar characteristics such as high calcium content and alkalinity, which influence for phosphorus removal (Zuo*et al.*, 2015). On the other hand, Ahmad *et al.*, (2017) also get the effective pH for removal of Phosphorus at pH 9 to pH 11. Their phosphate removal efficiencies were 51-71% and 55-80%. This is might be due to the vibration produced during aeration which causes reaction to proceed faster.

Scanning Electron Microscopy (SEM) and Energy dispersive X-ray spectroscopy (EDX) of RCA

SEM and EDX testing were used in this study in order to study phosphorus distribution on the RCA surface and in sediment samples. SEM and EDX testing for fresh surfaces of the RCA samples are shown in figure 4 and figure 5 SEM and EDX testing after treatment. The surface of the RCA sample is covered by loosely bonded cement paste and considerably amount of porous fine particles. Moreover, as has been assembled from the SEM/EDX analysis, the most abundant minerals on a fresh RCA surface were found to be oxygen, calcium and silica. The result indicated the highest element in RCA is oxygen which is 46.20% follows by calcium which is 23.40% and 11.20% of silica. Cementpaste contains high amount of Calcium (Yassin *et al*,. 2016). This is due to the higher calcium content, the higher the ability for removing phosphorus. Besides the RCA also contain aluminium and magnesium whereas this element enhance phosphorus adsorption. After two months in the filter system, phosphorus can be seen on the surface of RCA samples after being examined by SEM/EDX testing Hamdan and Mara, (2013) state that phosphorus rich oxides formed after the effluent from primary facultative pond underwent further treatment in the BFS filter. These findings demonstrate that BFS and RCA has a high capacity for adsorbing phosphorus from wastewater which same took place on the BFS surface and RCA surface. The RCA was encompassed of 36.60% of calcium oxide that was state from previous study by Adnan *et al*., (2016) while Hamdan and Mara, (2013) state that the BFS was comprised of 39.97 % of calcium oxide. Therefore, the adsorption of phosphorus to calcium oxide could have been the key removal mechanism for phosphorus in the RCA filter and BFS filter.

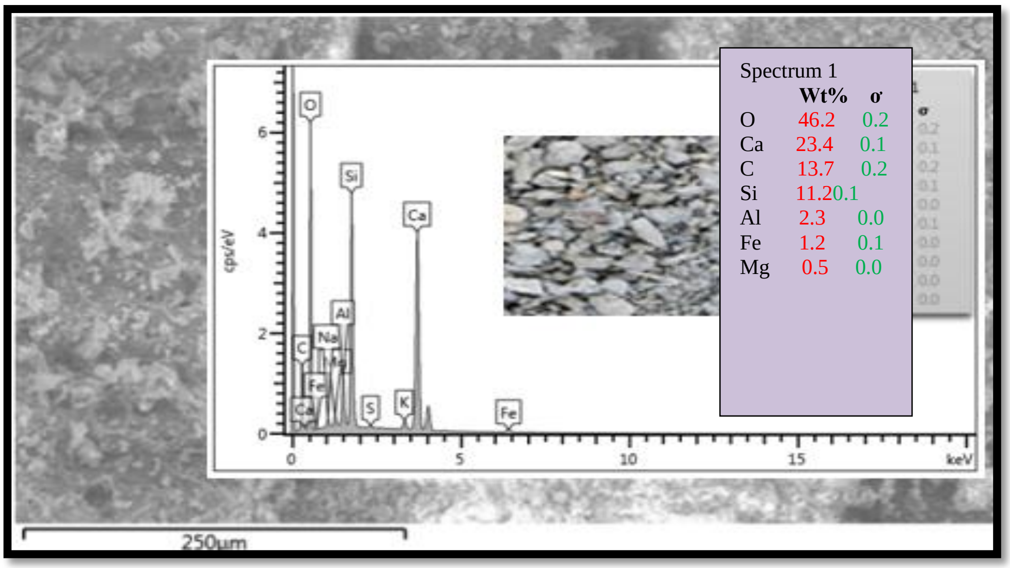

Figure 4. EDX testing for fresh Recycled concrete aggregate

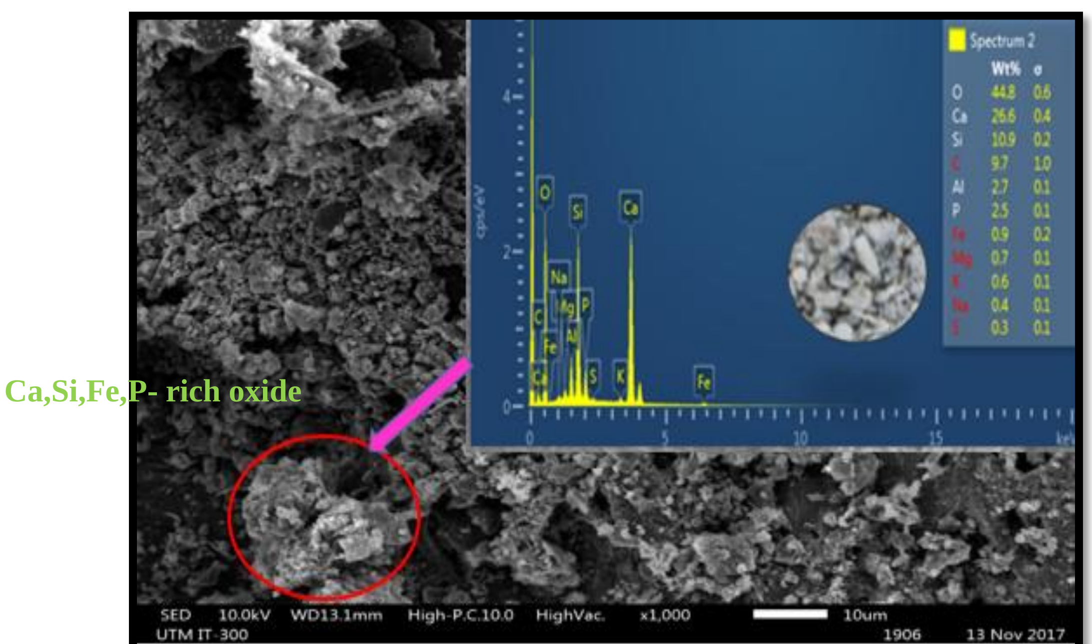

Figure 5. SEM micrographs and EDX spectra of RCA surface samples over treatment period in the vertical Recycled Concrete Aggregate filter

Percentage of phosphorus removal

This section deliberated on data and analysis on percentage of Phosphorus removal. Figure 6 shows graph of percentage of Phosphorus removal with different concentration of synthetic wastewater for RCA size (5-10 mm) and (25-30 mm) with five different concentration of synthetic wastewater. For RCA size (5-10 mm), the percentage of Phosphorus removal in initial concentration 10 mg/L is 99.54%, then 76.92% for initial concentration 20 mg/L while 74.94% for initial concentration 30 mg/L, 69.91% for initial concentration 40 mg/L and lastly 67.60% for initial concentration 50 mg/L. Next, for RCA size (25-30 mm), the percentage of Phosphorus removal in initial concentration 10 mg/L is 94.49%, then 68.95% for initial concentration 20 mg/L while 67.89% for initial concentration 30 mg/L, 66.42% for initial concentration 40 mg/L and lastly 66.25% for initial concentration 50 mg/L.

The highest percentage of Phosphorus removal is 99.54% which is in concentration 10 mg/L for RCA size 5 mm to 10 mm while the lowest percentage of Phosphorus removal is 66.25% which is in concentration 50 mg/L for RCA size 25 mm to 30 mm. Commonly it can be seen that the percentage of Phosphorus removal decreasing as concentration of synthetic wastewater increasing. From the graph, it defined that the percentage of phosphorus removal decreasing as initial concentration of synthetic wastewater increasing. It was similar due to the outcomes from Wood and Atamney (2016) where (80-90%) of initial Phosphorus where absorbed by Laterite when applying concentrations (10-25 mg/L) and 60% of initial Phosphorus absorbed when higher concentration applied. Regarding to Yihuan and Andrew (2018), the adsorption capacity increased linearly with the initial concentration from (5-30 mg/L), but the amount of Phosphorus detached reach maximum at an initial concentration of 15 mg/L. This suggest that removal of Phosphorus not suitable at higher initial concentration.

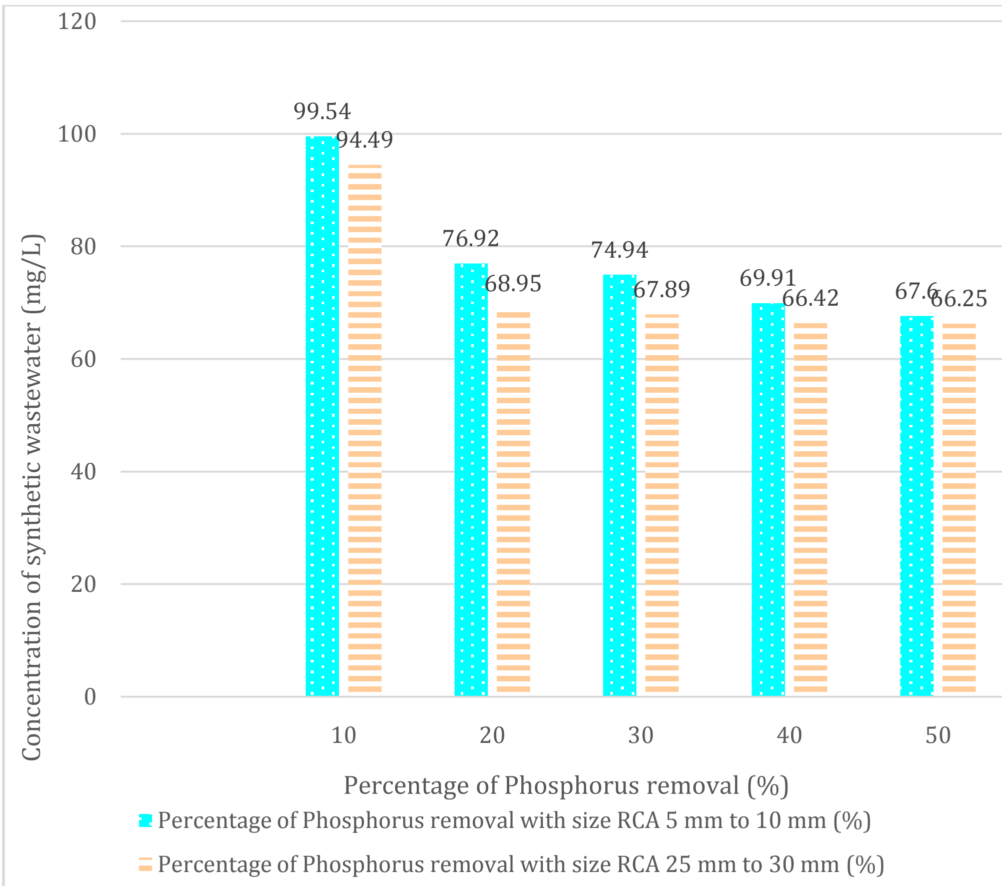

Figure 6. Graph of percentage of Phosphorus removal with different size of RCA versus different concentration of synthetic wastewater

The correlation between the uptake capacity of RCA of different sizes versus the initial concentration of synthetic wastewater

Figure 7 shows the linear correlation between the uptake capacity coefficients of RCA of different sizes versus the initial concentrations of synthetic wastewater. The linear correlation coefficient measures the strength and the direction of a linear relationship between two variables.

From the graph, the R^2 between the uptake capacities of phosphorus is near 1.00 namely, 0.9916 for RCAs measuring between 5 mm to 10 mm and 0.9929 for RCAs measuring between 25 mm to 30 mm. Thus, the correlation coefficient for the uptake capacity of RCA of different sizes have a strong positive linear correlation as R^2 is close to +1.

It clearly shows that the relationship between the uptake capacities and RCA of different sizes is a positive linear correlation relationship. In contrast, Maung, (2006) found that the R^2 between the uptake capacities of P using limestone was about 0.7865 for limestones measuring between 10 mm to 20 mm and 0.8654 for limestones measuring between 20 mm to 30 mm.

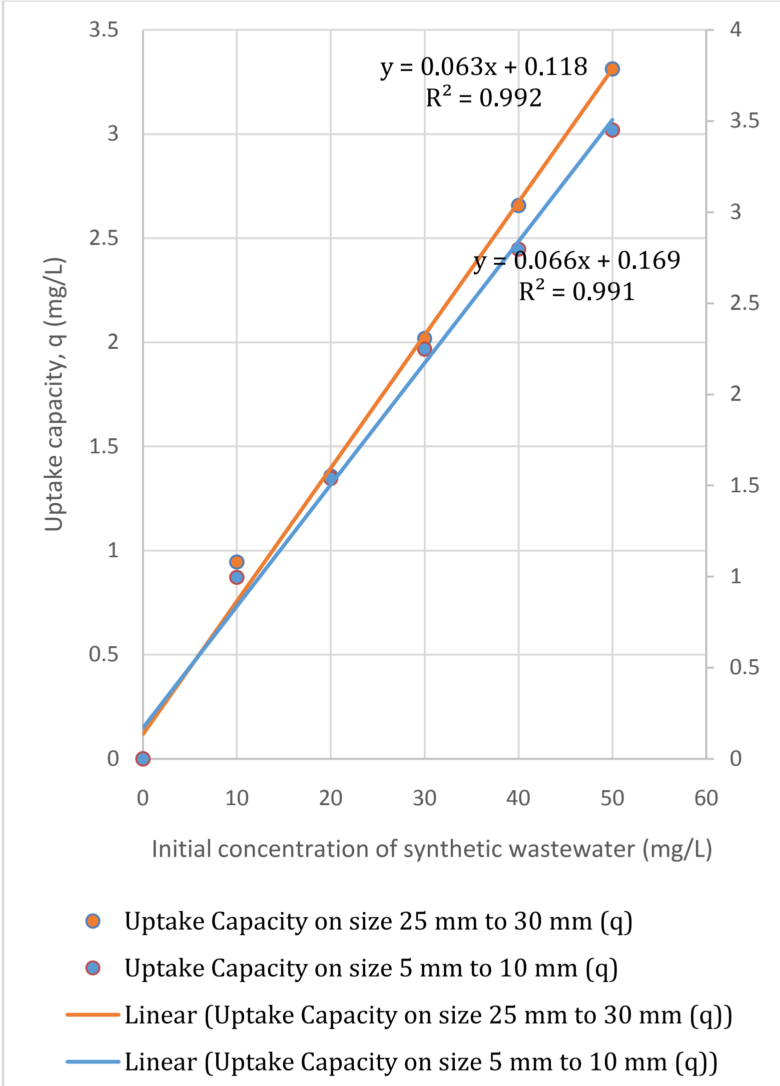

Figure 7. The correlation between the uptake capacity of RCA of different sizes versus the initial concentrations of synthetic wastewate

CONCLUSION

This study showed the higher percentage of removal of Phosphorus at lower concentration synthetic wastewater which is 10mg/L is 99.54% which is RCA size 5 mm to 10 mm and it was proved that RCA is one of the absorbent that is good efficiency for removal of phosphorus.

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