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# Recovery of Phosphorus through Different Masses Calcined Chicken Eggshells Adsorbent in Water: Prediction, Kinetic and Isotherm Model

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**ABSTRACT**

Phosphorus (P) is a vital chemical element for the growth of living beings. However, the excess of phosphorus in wastewater due to discharge by the public causes' nutrient pollution, leading to eutrophication through algae bloom. Eutrophication causes the death of aquatic life due to the absence of oxygen in the aquatic ecosystem and spreads diseases across the community through bioaccumulation when consumed. Recent studies have shown that eco-friendly adsorbents can remove excess phosphorus from wastewater. In recent research, a study was conducted to investigate the removal of phosphorus from water onto calcined waste chicken eggshells with different masses of adsorbents. Phosphorus was removed from the synthetic solution and domestic wastewater using waste chicken eggshell calcined at 900 °C with different adsorbent masses (2, 4, 6, 8 and 10 g). The result of the batch experiment was analysed using kinetic and isotherm models to reveal the adsorption mechanics. It was shown that the optimum contact time was 60 min and the optimum particle mass was 10 g of the adsorbent with 99.4% removal efficiency and 0.0328 mg/g for adsorption capacity. Between the two kinetic models, the Pseudo-First-Order model and the Pseudo-Second-Order model, Pseudo-Second-Order was more fitted for kinetic isotherm with a correlation coefficient, $R^2$, of 0.9992, which implies that the adsorption happens on low concentration solution and the adsorption rate is linearly proportional to the active sites on the adsorbent. The adsorption isotherm fits the Freundlich isotherm model with the correlation coefficient, $R^2$, of 0.6681, indicating that the adsorption process occurred in heterogenous sites and multilayer states. The study has shown that the calcined chicken eggshells were an excellent adsorbent to remove phosphorus from wastewater and suitable as an eco-friendly adsorbent to implement in the tertiary wastewater treatment for future environmental improvement.

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## 1. Introduction

Nutrient pollution is the cause of anthropogenic impacts on the quality of water resources [1]. Most nutrients come from wastewater from urban and agricultural activities and stimulate excessive algae growth, called eutrophication. Eutrophication is the major cause of the dearth of fish biodiversity and the destruction of aquatic ecosystems. Due to excessive fertilizer inputs, eutrophication has polluted more than 50% of lakes globally, including 60% in Malaysia [2].

These nutrients come from home, industrial and agricultural wastes and contain phosphorus and nitrogen. Phosphorus is a crucial chemical element for the growth of living beings and daily life uses. Global use of common fertilizers in agricultural activities, which contains a high percentage of inorganic nitrogen and phosphorus, is the major lead of eutrophication [3]. Malaysian standard A established a 5 mg/L phosphorus effluent discharge restriction into any inland water within the watershed, while standard B established a 10 mg/L limit for any other inland water or Malaysian waters. The Water Environmental Partnership in Asia (WEPA) has set a standard for phosphorus limitations. In general, Industrial Wastewater Discharge Standards, the phosphorus limit set is 1 mg/L at maximum concentration [4]. All these regulations were created to protect the environment from excessive phosphorus discharge.

Various methods have been developed to reduce nutrient pollution, such as biological treatment, physical treatment, membrane separation technology and chemical precipitation. One of the most effective and economical methods is adsorption, using eco-friendly adsorbent to remove adsorbate from solutions [5,6]. Calcined waste chicken eggshells have a high percentage of $CaCO_3$ which is 99.56% [7]. Having heterogeneous, varying pores and cavities on the irregular surface structure of the chicken eggshells provides enormous exposed surface area for the adsorption process [8]. According to previous studies, the adsorbent reached phosphorus removal efficiency higher than 97% [9].

However, with such reputable achievement, not much research has been done to correlate the connection between the mass of adsorbent and the removal efficiency at different initial concentrations. Hypothetically, the removal efficiency of waste chicken eggshells correlates to the mass or dose of the adsorbent used; the higher the mass, the higher the removal efficiency [10]. In this recent study, calcined waste chicken eggshells were used:

i. to investigate the ability to remove phosphorus from different initial concentrations of solution through different masses of adsorbents
ii. to analyse the batch experimental data with the application of different masses of adsorbents in removing phosphorus in municipal wastewater with kinetic and isotherm models
iii. to create the contour prediction for phosphorus removal efficiency and required mass of adsorbent with different initial concentrations.

## 2. Materials and Methods

### *2.1 Adsorbents*

The adsorbent was prepared using 1 kg of waste chicken eggshells. The eggshells were washed thoroughly using tap water to remove any impurities, followed by distilled water rinsing. Then, the eggshells were dried for 2 days at 30°C in an oven. After this, the eggshells were crushed and sieved to obtain particles ranging from 1.18 to 2.36 mm. The adsorbent was finally calcined in a furnace for 2 hours at 900°C.

### *2.2 Synthetic Solution*

A 1L of 100mg/L $PO_4^{3-}$ solution was produced by adding 0.1433g of potassium dihydrogen phosphate, $KH_2PO_4$, into a 1L volumetric flask and deionised water was topped up to 1L. This stock solution was then diluted to different concentrations of 5, 10, 15, 20 and 25mg/L $PO_4^{3-}$.

### *2.3 Analytical Methods*

HACH DR 6000 UV-VIS Spectrophotometer was used to examine the initial and final concentration of phosphorus in the aqueous solutions through the phosphorus procedure using the amino acid method 8178 programme. COXEM EM – 30 AX PLUS SEM was used by the researchers to determine the surface morphology of the membrane on the calcine waste chicken eggshells through the EDXRF test and SEM test. Perkin Elmer Spectrum Two FTIR Spectrometer was used to describe the functional groups of the shell and display the infrared spectrum of adsorption before and after the adsorption process. Second-generation BRUKER D2 Phaser Benchtop XRD was used by the researchers to characterise the crystallisation composition of the eggshells in XRD analysis.

### *2.4 Batch Experiments*

Two batch experiments were conducted using an aqueous solution and domestic wastewater to study the adsorption. In the first batch experiment, the effect of initial concentration and the effect of the mass of the adsorbent was conducted by adding 2, 4, 6, 8 and 10 g of adsorbent into a 100 mL conical flask. Each conical flask contains synthetic wastewater of 5, 10, 15, 20 and 25 mg/L $PO_4^{3-}$ concentrations. The effect of absorbent mass and time is investigated in the second batch of experiments. In the experiment of the second group, the effect of the adsorbent mass is carried out with 2, 4, 6, 8 and 10 g of the absorbent into a 100 mL conical flask with different contact times of 5, 15, 30, 60 and 90 min. Each mass of adsorbent has five 100 mL of municipal wastewater in five conical flasks. The municipal wastewater was collected at a sampling location in front of IIUM residential college, Pagoh. For the first batch, each sample was shaken at 170 rpm for a given contact period of 90 minutes and for the second batch, according to contact times. Phosphate concentration was determined after filtering each sample using a filtration pump to remove the suspended particles from the solution. Models for isotherms and kinetics were used to fit the data.

### *2.5 Analytical Methods*
#### *2.5.1 Pseudo-first-order kinetic model*

The fundamental premise underlying the pseudo-first-order (PFO) kinetic model is the overall rate of vacant sites equalling occupied sorption sites. Many models for the adsorption of different solutes have been created, but assessing the suitability of both their linear and nonlinear forms is still necessary. In a linear PFO model, the graph of $\ln(q_e - q_t)$ vs $t_i$ was plotted [11]. The equation of the linear pseudo-first-order model is as Eq. (1).

$$\ln(q_e - q_t) = \ln(q_e) - k_1 t \quad (1)$$

where, $q_t$ (mg/g) and $q_e$ (mg/g) represent the molarities of solute adsorbed and adsorbent at any given time and equilibrium, respectively and $k_1$ is the rate constant of the pseudo-first-order model [12].

### *2.5.2 Pseudo-second-order kinetic model*

The pseudo-second-order kinetic model assumes that the number of accessible sites on the adsorbent equals the total amount of solute adsorbed. Furthermore, the kinetics is the same as the number of active sites and the rate at which reaction occurs is linearly proportional to the adsorbate concentration on the surface of the adsorbent. The equation of this model is as Eq. (2).

$$\frac{t_i}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t_i \tag{2}$$

where $q_t$ (mg/g) indicates the phosphorus molarity adsorbed at any time *t*, whereas $q_e$ (mg/g) is the phosphorus amount adsorbed during equilibrium and k2 denotes the pseudo-second-order constant which can be identified when plotting $\frac{t}{q}$ against $t_i$ [12].

### *2.6 Adsorption Isotherm Models*

The adsorption isotherm is essential in determining the adsorption interaction reaction on the adsorbent's surface. The information from this reaction will be sufficient to show that an effective adsorbent can be adsorbed. The stability of the adsorbent-adsorbate contacts and the adsorption affinities of the molecules are expressed by the shape of the isotherm [13].

### *2.6.1 Langmuir isotherm*

The adsorption data were linearised and adjusted based on the Langmuir and Freundlich models to determine the better-fitting model representing the adsorption isotherm. Langmuir's linear model is as Eq. (3).

$$\frac{c_e}{q_e} = \frac{1}{q_m K_L} + \frac{c_e}{q_m} t_i \tag{3}$$

where $c_e$ is the molarity of adsorbate at equilibrium, $q_e$ (mg/L) is the adsorbate amount at equilibrium, $q_m$ (mg/L) is the maximum adsorption capacity and $K_L$ is Langmuir isotherm constant. The slope and interception of the plot of $\frac{c_e}{q_e}$ against $c_e$ are used to calculate the values of the constants $K_L$ and $q_m$, which are related to the energy of adsorption and maximum adsorption capacity, respectively [14].

### *2.6.2 Freundlich isotherm*

The linear Freundlich isotherm model is expressed as Eq. (4).

$$\ln q_e = \ln K_f - \frac{1}{n} \ln c_e \tag{4}$$

The Freundlich constants $K_f$ and $n$, which are adsorption capacity and intensity, respectively, were used here. Plotting $\ln q_e$ vs $\ln c_e$ allowed researchers to calculate the Freundlich equilibrium constants. When $n=1$, the adsorption is linear; when $n<1$, it is a chemical process and the value of n represents the non-linearity constant correlation between solution concentration and absorbance. A value of $n$ between 1 and 10 represents good adsorption. With $n>1$, a physical adsorption process is the most common case and could result from the distribution of surface sites or any other factor that reduces the relative adsorption [14].

## 3. Result and Discussion

### *3.1 Physical Chemical Characteristics of Adsorbent*

FTIR analysis was conducted to study the change in the frequency spectrum of the adsorption and to indicate specific functional groups present in the adsorbent. The FTIR reveals the frequency spectra range from 872.427 to 3694.116cm$^{-1}$, according to Figure 1. Each spectrum was compared and matched to identify the surface functional groups present in the adsorbent.

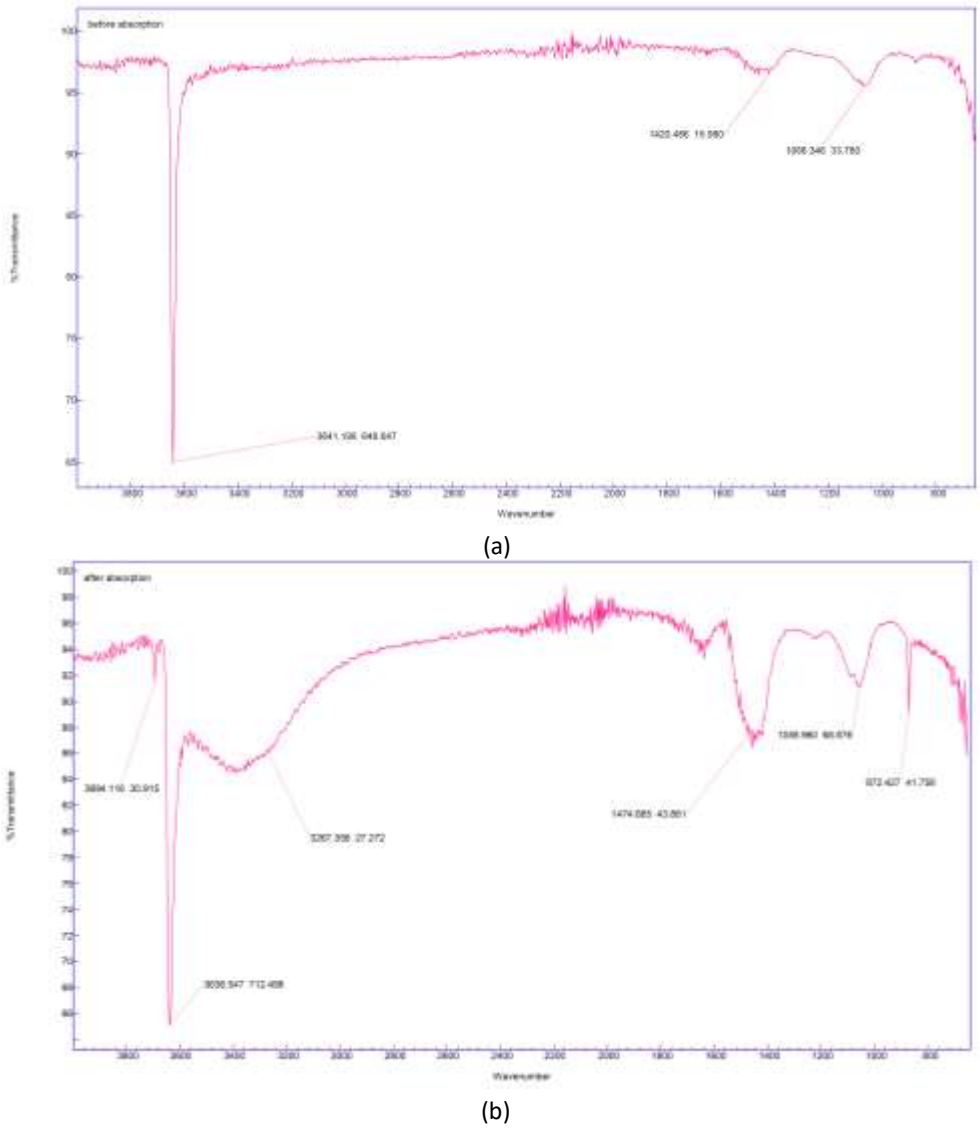


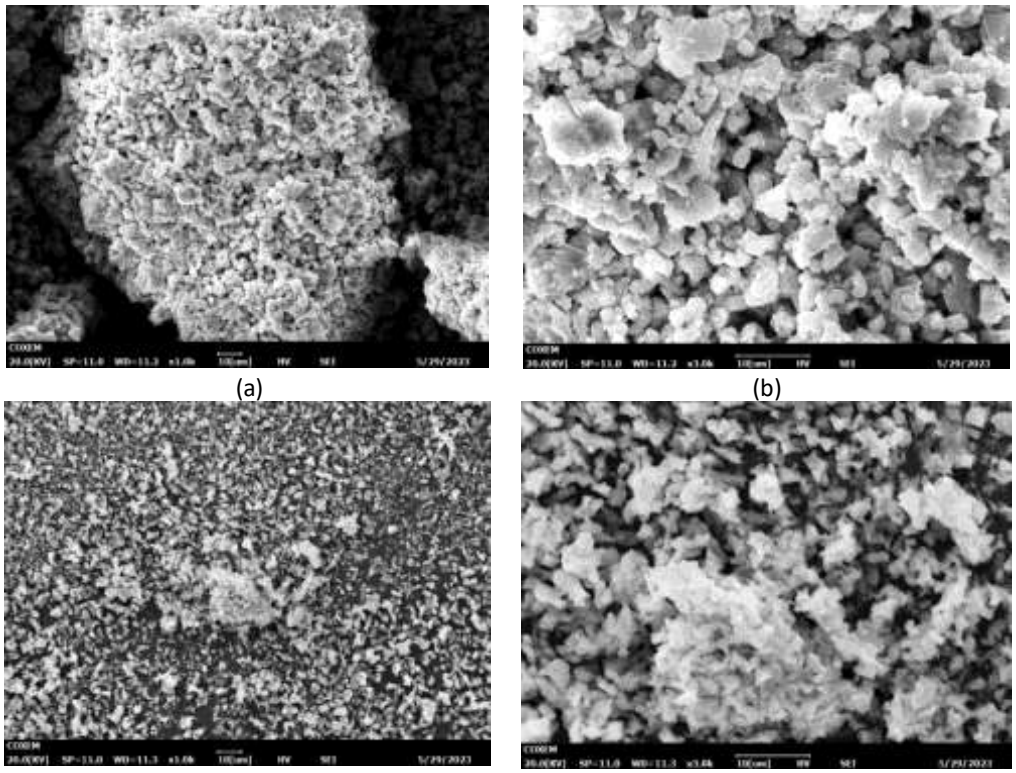

**Fig. 1.** FTIR spectra of adsorbent (a) before adsorption and (b) after adsorption of phosphorus ($PO_4^{3-}$)

Table 1 shows the FTIR spectra before and after the adsorption of phosphate ions. The evident analysis shows that carbonate ions, $CO_4^{3-}$, were released after adsorption, causing the spectrum to increase by 54.199 $cm^{-1}$ (1474.685–1420.486). The phosphate ions were present in the adsorbent, as evident in the spectrum decreased by 7.386 $cm^{-1}$ (1068.960–1066.346) and the OH stretch group was also present due to the decrease of spectrum by 4.651 $cm^{-1}$ (3636.547–3641.198).

**Table 1**
FTIR spectra analysis before and after adsorption of $PO_4^{3-}$ ions

| Frequency spectrum ($cm^{-1}$) | | | Functional group indication | References |
|---|---|---|---|---|
| Before adsorption | After adsorption | Difference | | |
| - | 872.427 | - | Carbonate ions, $CO_4^{3-}$ | [15,16] |
| 1066.346 | 1058.960 | −7.386 | Phosphate ions, $PO_4^{3-}$ | [15] |
| 1420.486 | 1474.685 | 54.199 | Carbonate ions, $CO_4^{3-}$ | [15,16] |
| - | 3267.358 | - | H-bonded OH stretch | [11,15,17] |
| 3641.198 | 3636.547 | −4.651 | Primary OH stretch | [11,15,17] |
| - | 3694.116 | - | OH stretch | [11,15,17] |

Evident data by SEM analysis disclosed the surface structure of the adsorbent (Figure 2), before and after adsorption. Due to extreme temperature calcination, the abundance of pores on the irregular crystal-like surface of the adsorbent provided the strong connection between eggshells and phosphate ions through intermolecular forces of attraction during adsorption, allowing the removal efficiency to increase [16]. The eggshells particles had dispersed after adsorption, likely due to the particles fused together with phosphate ions.



(a) (b) (c) (d)

**Fig. 2.** Surface morphology of the adsorbent before: (a) at 1000× magnification (b) at 3000× magnification, after: (c) at 1000× magnification (d) at 3000× magnification

The chemical composition of the adsorbent before and after the adsorption process was revealed in the EDXRF test, as presented in Table 2. The detection of elements in the test reveals that Ca, P, K, Mg, Fe, O, Al, C, Si and Cu are present in the eggshells with their atomic weight per eggshell molecule. The highest percentage belongs to the Ca and O in the composition. The adsorption process was said to have occurred when the leading element, Ca, displayed a decline in atomic weight (49.69% to 39.66%) and O (48.27% to 47.61%) after adsorption, as shown in Table 2. However, C shows increasing atomic weight (0.48% to 9.72%) after adsorption. The increase is likely due to the formation of carbonate ions, $CO_4^{3-}$, that remains intact on the adsorbent surface [16].

The SEM and EDXRF show similar circumstances to the previous study provided by Abdullah *et al.,* [11], with Ca and O being the highest in the percentage of the chemical composition, although overall elements displayed a lower rate than the previous study. The SEM shown by Abdullah *et al.,* [11], is almost similar; however, the recent research shows the surface structure resembles crystal, likely due to the higher combustion temperature.

**Table 2**
Chemical composition of adsorbent from EDXRF analysis

| Element | Weight (%) | |
|---|---|---|
| | Before | After |
| Ca | 49.69 | 39.66 |
| P | 0.15 | 0.00 |
| K | 0.25 | 0.00 |
| Mg | 0.40 | 1.34 |
| Fe | 0.28 | 0.45 |
| O | 48.27 | 47.61 |
| Al | 0.00 | 0.15 |
| C | 0.48 | 9.72 |
| Si | 0.09 | 0.00 |
| Cu | 0.39 | 1.08 |
| Total | 100.00 | 100.00 |

Second-generation BRUKER D2 Phaser Benchtop XRD was used to determine the XRD pattern to calcine the chicken eggshell. The XRD pattern shows that the major components of the calcined chicken eggshell are calcite and aragonite. Calcite and aragonite have a similar chemical composition which is $CaCO_3$. Aragonite and calcite are effective for removing phosphate and have good phosphate adsorption properties [18]. The XRD analysis reveals the percentage of aragonite (76%) and calcite (24%) as the components of the adsorbent remain the same before and after the adsorption, as shown in Figure 3(a) and 3(b), respectively. The results uncover that the elements Ca, C and O remain the same amount, although phosphorus has fused with these elements [19]. The XRD spectra emitted by the calcite component of the adsorbent conversely decrease after phosphorus adsorption due to the fusion of the elements stated, as shown in Figure 3(a) and 3(b).

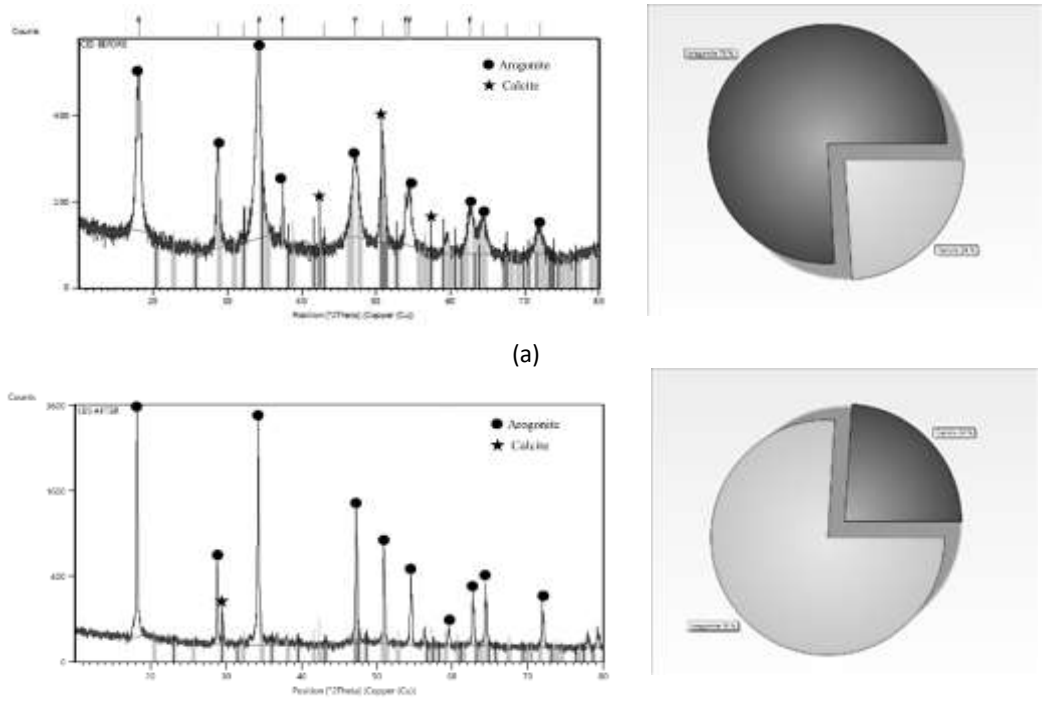



**Fig. 3.** XRD spectra of aragonite and calcite components of the adsorbent (a) before adsorption and (b) after adsorption

### *3.2 Adsorption Capacity and Performance of Phosphorus Removal*

To estimate the equilibrium-corresponding contact duration, the rate at which phosphorus is removed using calcined chicken eggshells was monitored over time [20]. Using adsorption kinetics, the amount of adsorbate diffused at contact pores can be calculated by monitoring the adsorption uptake over time at the given pressure or concentration [21]. Due to the active surface sites at the beginning of the adsorption and those still present after a specific amount of time, the first few minutes can be described as the speed of adsorption kinetic present in a significant quantity as the adsorption is the transition from liquid to solid phase [22].

The amount of adsorbate being absorbed per unit mass is known as adsorption capacity performance [10]. The overall value of the calcined waste chicken eggshells employed in this study to eradicate phosphorus from the wastewater, or the adsorption capacity of each particle mass, is referred to as adsorption ability. The adsorption capacity was calculated using Eq. (5).

$$q = \frac{c_i - c_f}{m} \times V \tag{5}$$

where $C_i$ and $C_f$ are the initial and final concentrations of the solution, respectively, $m$ is the mass of the adsorbent used and $V$ is the volume of the solution. The adsorption capacity from the start of the experiment until equilibrium was plotted using the formula for every particle mass, as shown in Figure 4.

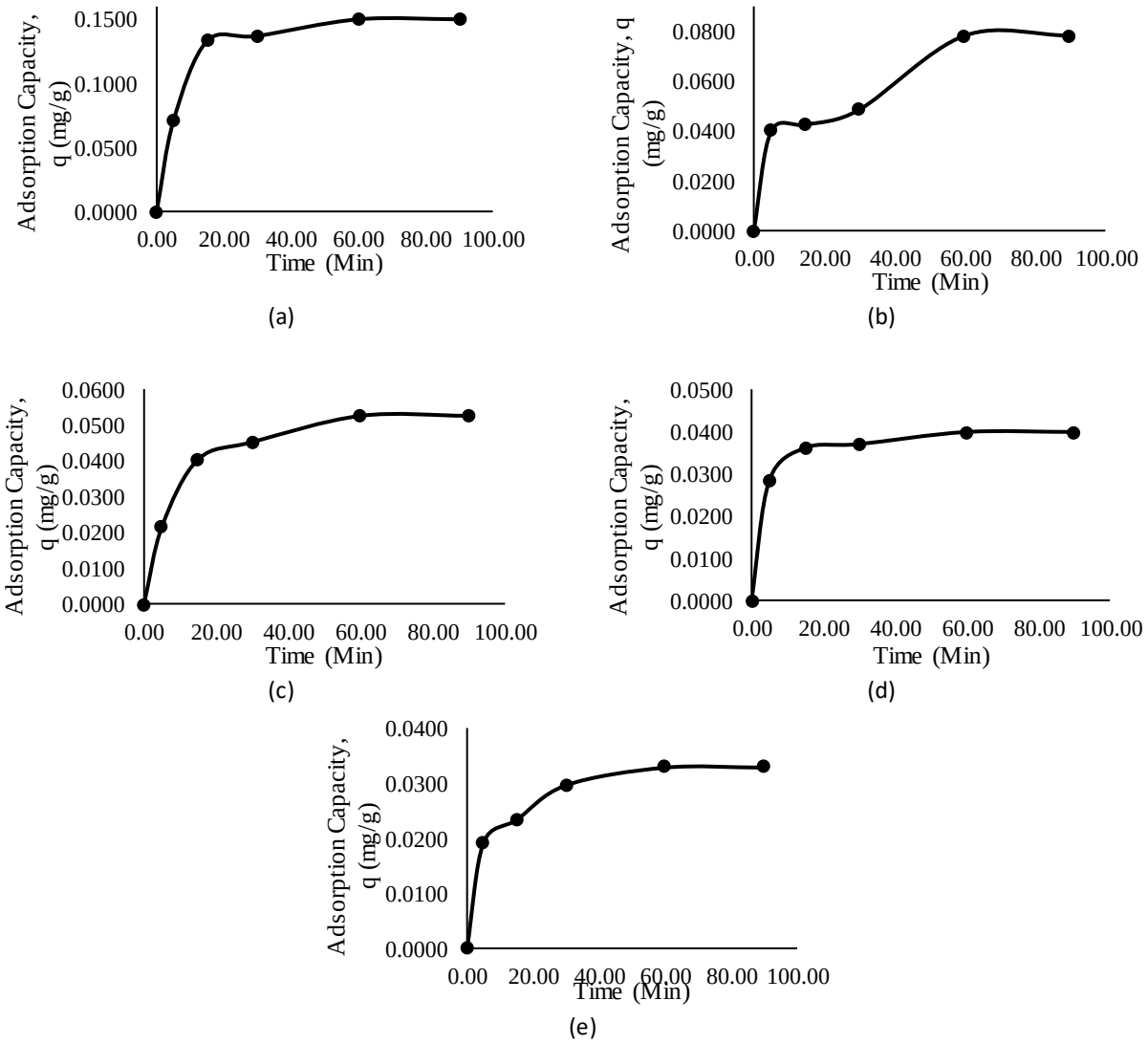



**Fig. 4.** Effect of adsorption capacity on phosphorus removal for (a) 2 g (b) 4 g (c) 6 g (d) 8 g and (e) 10 g

The removal efficiency of the adsorbent was also calculated to determine how effective the calcined waste chicken eggshells were on removing phosphorus from domestic wastewater [23]. The equation below was used to determine the removal efficiency, E (%), as shown in Eq. (6).

$$E = \frac{c_i - c_f}{v} \times 100\% \tag{6}$$

Figure 5 shows the performance of adsorption capacity for five different particle masses of calcined waste chicken eggshells. The adsorption capacity reached equilibrium at 60 min for every particle mass as the adsorption capacity remained constant for the next 30 min. The adsorption capacity, $q_e$, for each particle mass was 0.1500 mg/g (2 g), 0.0783 mg/g (4 g), 0.0525 mg/g (6 g), 0.0399 mg/g (8 g) and 0.0328 mg/g (10 g).

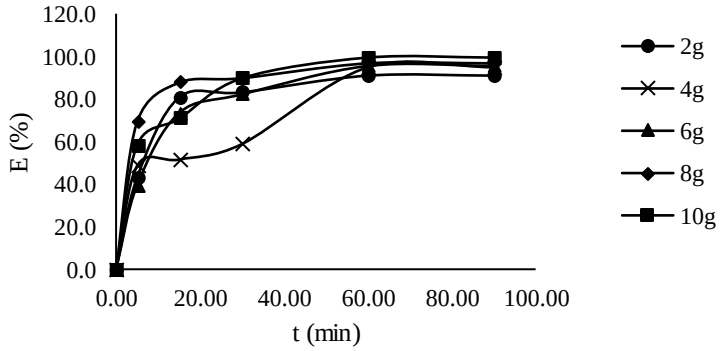



**Fig. 5.** The performance of removal efficiency, *E* (%), against time, *t* (min), for every particle mass

The performance of removal efficiency against contact time was plotted as shown in Figure 5. The removal efficiency increases rapidly as the contact time increases, showing the rapid process of adsorbate occupying the vacant sites on the porous surface of the adsorbent until it reaches an equilibrium where all the vacant sites have been completely occupied. The maximum removal efficiency, which is at equilibrium for every particle mass, was 90.9% (2 g), 94.8% (4 g), 95.5% (6 g), 96.7% (8 g) and 99.4% (10 g). The relationship between maximum removal efficiency and $q_e$ was plotted against particle mass. The trend shows that as the removal efficiency increases with the decrease in adsorption capacity, the adsorption process occurring at active sites rapidly increases, as shown in Figure 6.

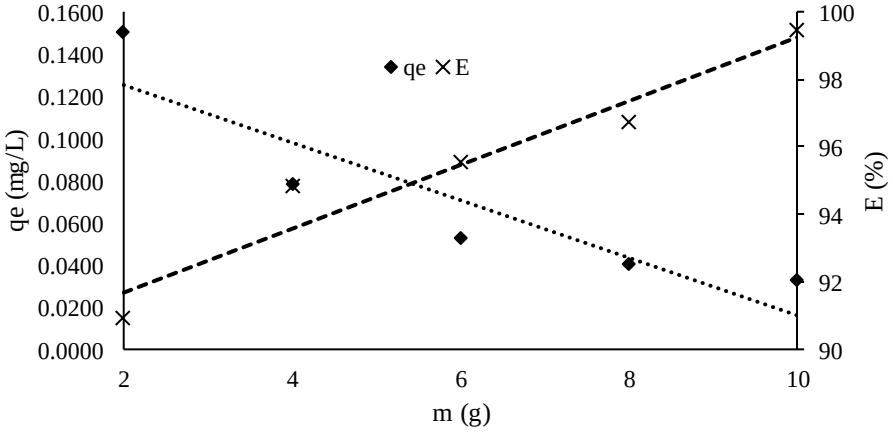



**Fig. 6.** Effect of the different masses of the adsorbent on the adsorption capacity, $q_e$ *and* removal efficiency, *E* (%)

### *3.3 Adsorption Kinetic Models*

The pseudo-first-order and pseudo-second-order kinetic models were studied to describe the adsorption process. The $F_e$ value for both models was calculated. The $R^2$ value for both models was obtained and compared to determine which model is more suitable to represent the adsorption kinetic with the highest $R^2$ and the lowest $F_e$ [24]. $F_e$ can be calculated using the formula as Eq. (7).

$$F_E = \sqrt{\left(\frac{1}{n-p}\right)\sum_i^n \left(q_{t(\exp)} - q_{t(theo)}\right)} \tag{7}$$

where *n* is the measurement number, *p* is the kinetic parameters amount, $q_{t(\exp)}$ and $q_{t(theo)}$ are the experimental and theoretical adsorption capacities. The figure was plotted as the data was fitted into the PFO model, as shown in Figure 7.

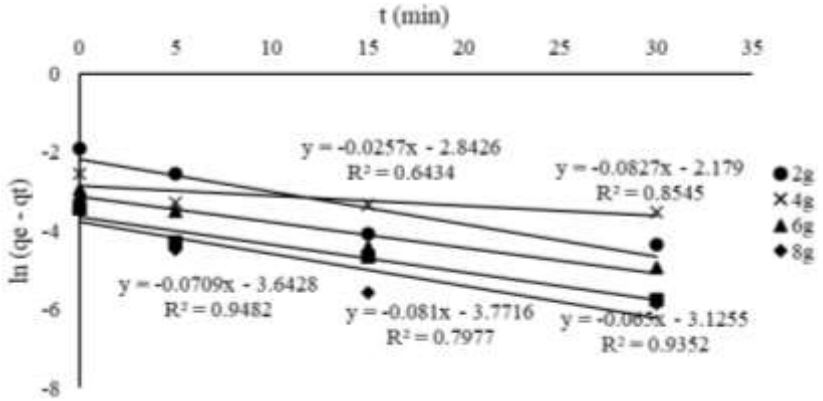



**Fig. 7.** Pseudo-first-order analysis (Plot of linear regression model of pseudo-first-order for the adsorption of $PO_4^{3-}$ onto adsorbent from domestic wastewater)

Table 3 shows that 10 g has a great adsorption capacity and removal efficiency performance with the highest $R^2$ (0.9482) and lowest $F_e$ (0.0654). On the contrary, the particle mass 4 g has a low adsorption capacity and removal efficiency performance with the lowest $R^2$ (0.6434) and $F_e$ (0.2290).

**Table 3**
Kinetic Parameter of Pseudo-First-Order Model

| m (g) | $q_{e\ (theo)}$ (mg/g) | $k_1$ ($min^{-1}$) | $R^2$ | $F_e$ | $q_{e\ (exp)}$ |
|---|---|---|---|---|---|
| 2 | 0.1132 | 0.0827 | 0.8545 | 0.3345 | 0.1500 |
| 4 | 0.0583 | 0.0257 | 0.6434 | 0.2290 | 0.0783 |
| 6 | 0.0439 | 0.0650 | 0.9352 | 0.0834 | 0.0525 |
| 8 | 0.0230 | 0.0810 | 0.7977 | 0.1571 | 0.0399 |
| 10 | 0.0262 | 0.0709 | 0.9482 | 0.0654 | 0.0328 |

The pseudo-second-order kinetic model predicts the behaviour over the whole adsorption range based on the presumption that chemical adsorption is a rate-limiting phase. Adsorption capacity, not adsorbate concentration, will define the adsorption rate in this situation [25]. Figure 8 shows the graph plotted when the data obtained were fitted into the kinetic model.

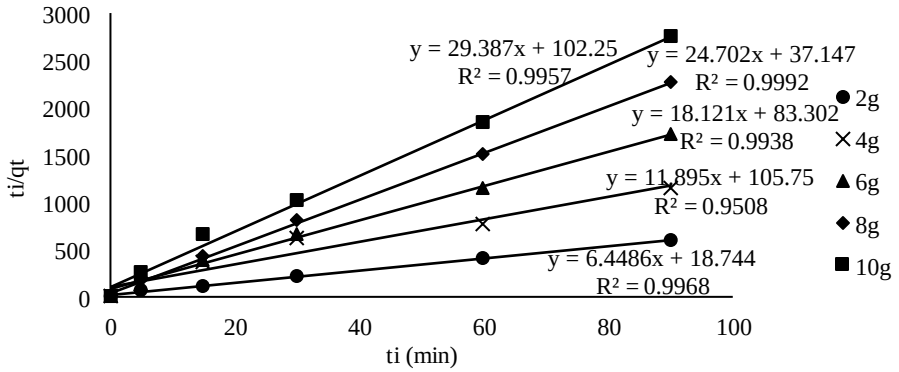



**Fig. 8.** Pseudo-second-order analysis graph (Plot of linear regression model of pseudo-second-order for the adsorption of $PO_4^{3-}$ onto adsorbent from domestic wastewater)

Table 4 shows that all particle masses have a good coefficient correlation approaching 1. However, the particle mass 8 g shows the highest $R^2$ value (0.9992) of all other particle masses, showing that it has the highest adsorption rate than others.

**Table 4**
Kinetic parameter of pseudo-second-order model

| m (g) | $q_{e\ (theo)}$ (mg/g) | $k_2$ (g $mg^{-1}min^{-1}$) | $R^2$ | $F_e$ | $q_{e\ (exp)}$ (mg/g) |
|---|---|---|---|---|---|
| 2 | 0.1551 | 2.2185 | 0.9968 | 0.0638 | 0.1500 |
| 4 | 0.0841 | 1.3380 | 0.9508 | 0.0747 | 0.0783 |
| 6 | 0.0552 | 3.9419 | 0.9938 | 0.0224 | 0.0525 |
| 8 | 0.0405 | 16.4263 | 0.9992 | 0.0091 | 0.0399 |
| 10 | 0.0340 | 8.4459 | 0.9957 | 0.0117 | 0.0328 |

It has been deduced that the pseudo-second-order model is the more suitable kinetic model to represent the adsorption kinetics since the highest $R^2$ of the pseudo-second-order model (0.9992) is higher than that of the pseudo-first-order model (0.9482). In addition, the lowest $F_e$ of the pseudo-second-order model (0.0091) is lower than that of the pseudo-first-order model (0.0654). Similar to previous studies [11,26]. This shows that the data fits better in the pseudo-second-order model than the pseudo-first-order model [11,26]. As the pseudo-second-order model is better, the process was shown to be chemosorption [27].

### *3.4 Adsorption Isotherm Model*

The experimental results were fitted into adsorption isotherm models, the Langmuir and Freundlich models. The fundamental tenet of the Langmuir isotherm model is that adsorption takes place on a particular homogenous site and forms a homogeneous monolayer of adsorbate on the adsorbent [28]. Figure 9 shows the graph plotted as the data was fitted into the Langmuir linear model.

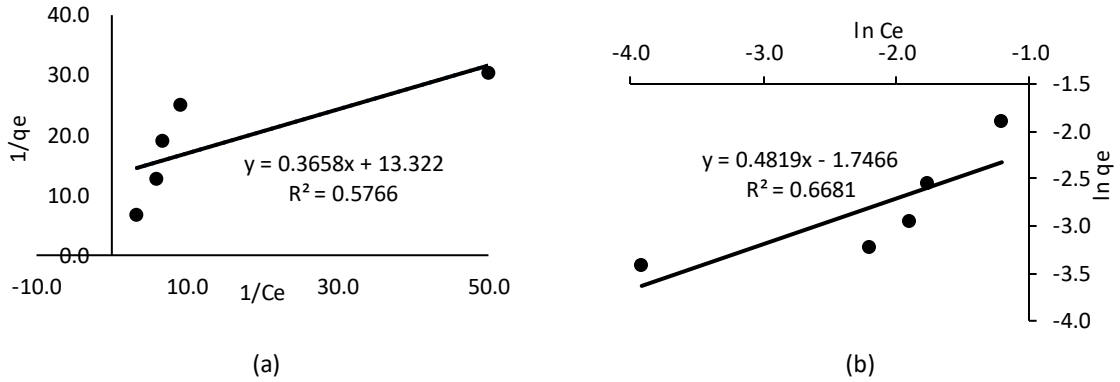



**Fig. 9.** Linear plot of (a) Langmuir model of $1/q_e$ against $1/C_e$ for the adsorption of $PO_4^{3-}$ onto adsorbent from domestic wastewater (b) Freundlich model of ln ($C_e$) against ln($q_e$) for the adsorption of $PO_4^{3-}$ onto adsorbent from domestic wastewater

The value $R^2$ obtained from the plot of $1/q_e$ against $1/C_e$ was 0.5766 and the value was compared with the Freundlich model to determine the more suitable model to represent the isotherm model. The basic assumption of the Freundlich isotherm model is the simultaneous adsorption of cation and anion on the same adsorbent surface. Regarding multilayer adsorption, the Freundlich isotherm model characterises adsorption processes on heterogeneous surfaces and active sites [29]. The linear

plot of the Freundlich model was obtained when the data were fitted into the model. The $R^2$ value obtained was 0.6681, as shown in Figure 7(b), which is higher than that of the Langmuir model; thus, it is the more suitable adsorption isotherm model for this study. The result agrees with the previous studies, according to Abdullah *et al.,* [11], since Freundlich is a better-fitting model than Langmuir. The result shows that the n >1 reveals that the adsorption process is physical according to the Freundlich isotherm. Given n >1, the adsorption shows a good and strong connection between the adsorbent and the adsorbate [14].

### *3.5 Prediction of Removal Efficiency or Required Mass of Adsorbent*

The contour prediction was plotted as the data obtained from the batch experiment using synthetic wastewater. Figure 10 shows the contour prediction of removal efficiency with the required mass of adsorbent at initial concentrations [30].

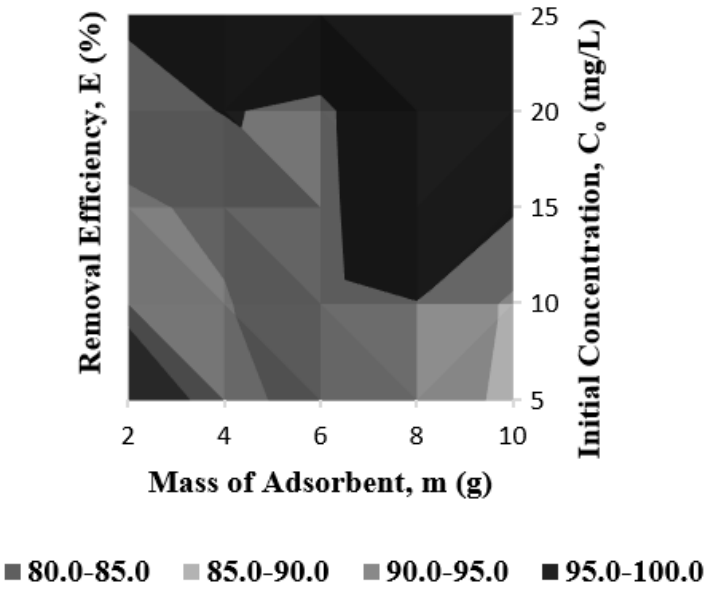



**Fig. 10.** Contour prediction of removal efficiency with the required mass of adsorbent at initial concentrations

The contour plot divided the removal efficiency into 5 ranges, 80–85%, 85–90%, 90–95% and 95–100%. The particle masses of adsorbent were 5 as 2, 4, 6, 8 and 10 g with initial concentrations of 5, 10, 15, 20 and 25 mg/L $PO_4^{3-}$. The plot was set that such adsorbent mass can be predicted by extrapolating the selected initial concentration into the region of preferred removal efficiency. For example, the mass of adsorbent to adsorb phosphorus at the initial concentration of 20 mg/L $PO_4^{3-}$ with a removal efficiency of more than 95% is predicted to be using 8 g of adsorbent.

## 4. Conclusion

Calcined waste chicken eggshells were utilised as adsorbing materials in this research to eradicate phosphorus from domestic wastewater collected at the sampling location. The results obtained from this research showed that the calcined waste chicken eggshells have great potential to be applied in water management industries to counter and reduce the effects of nutrient pollution, eutrophication. With a high percentage of calcium carbonate (99.56%) as the major compound in adsorption, the calcined waste chicken eggshells have proven to be an effective eco-friendly

adsorbent when its removal efficiency of adsorbing phosphorus was 99.4% at peak. The water management industries can easily obtain the adsorbent as they are abundant in Malaysia. The results also agree with the previous research that the adsorption data fitted well in the pseudo-second-order model with R2 of 0.9992, which was shown to be chemosorption. The adsorption data was verified to fit in the Freundlich isotherm model with $R^2$ of 0.6681, revealing a strong connection between the adsorbent and the adsorbate during adsorption. Calcine waste chicken eggshells also have an irregular porous surface, providing multilayer adsorption properties with perfect adsorption capabilities. The contour prediction also provides the reference to choose the required mass of adsorbent with preferred removal efficiency at certain initial concentrations. As well as eradicating phosphorus from solution, waste material can be utilised in actual wastewater treatment systems. This study helps to contribute to society and industries by providing eco-friendly, renewable resources and low-cost materials to counter nutrient pollution.

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