REMOVAL OF ORGANIC MATTERS, NUTRIENTS, AND SUSPENDED SOLIDS USING COCKLE SHELL (*Cerastoderma Edule*) FROM CONTAMINATED WATER

WEN-PEI LOW[1,*], LEE DE MIN[1], FUNG-LUNG CHANG[1],
HOONG-PIN LEE[1], YEE YONG LEE[2], NURHARNIZA ABDUL RAHMAN[1],
EUNIZA JUSLI[3,4]

[1]Department of Civil Engineering, Faculty of Engineering and Quantity Surveying, INTI International University, Persiaran Perdana BBN, Putra Nilai, 71800 Nilai, Negeri Sembilan, Malaysia
[2]Department of Civil Engineering, Faculty of Engineering, University Malaysia Sarawak, 94300 Kota Samarahan, Sarawak, Malaysia
[3]Department of Civil Engineering, School of Engineering, Monash University Malaysia, Jalan Lagoon Selatan, 47500 Bandar Sunway, Selangor, Malaysia.
[4]Monash Climate-Resilient Infrastructure Research Hub (M-CRInfra), School of Engineering, Monash University Malaysia, Jalan Lagoon Selatan, 47500 Bandar Sunway, Selangor, Malaysia
*Corresponding Author: wenpei.low@newinti.ed.my

Abstract

High production and consumption of cockle shells (CS) have raised severe environmental concerns due to the improper waste management of shells. In this study, the feasibility of CS in treating chemical oxygen demand (COD), biochemical oxygen demand (BOD), Ammoniacal Nitrogen (AN), and total suspended solids (TSS) from naturally contaminated water were explored by using a fabricated model. The optimum dosage of CS was firstly determined from the jar test. Then, each pollutant's removal efficiency and adsorption capacity were monitored and circulated in the fabricated model using the optimum CS dosage for five consecutive days, respectively. The jar test results displayed that the optimal CS dosage was 3g/L with a maximum of 42.86% removal of COD. The dynamic adsorption test in the fabricated model further identified the adsorption potential of the CS in removing 98.39% of AN, 52.78% of COD, 66.67% of BOD, and 31.25% of TSS. The adsorption isotherm analysis demonstrated that the Langmuir isotherm yielded the best fit for COD, BOD, AN, and TSS. Besides, the AN and BOD fitted well in the pseudo-first-order reaction, while COD fitted well in the pseudo-second-order reaction. In short, it produces encouraging results to be utilized as a low-cost green adsorbent in treating water pollution and as a protection of our ecosystem.

Keywords: Adsorption isotherms, Adsorption kinetics, Cockle shells, Jar test, Fabricated model.

1. Introduction

In Malaysia, ninety-seven percent of the water supply is contributed from rivers and streams [1]. However, according to the Global Food Security Index (GFSI) in 2020, water resources in Malaysia are at risk, and this severe issue will directly affect the food security in the country [2]. One of the reasons behind this is the rapid industrialization and the overgrowth of the world population, municipal waste management, and domestic and agricultural activities that contribute to water contamination and subsequently degrade the water quality, which in turn threatens the environment and public health [3]. To overcome these issues, there are various water treatment techniques have been employed for the removal of contaminants from the water system based on biological, physical, chemical, electrical, and thermal fundamentals. These approaches include sedimentation, adsorption, biodegradation, phytoremediation, chemical oxidation, coagulation, flocculation, distillation, electrolysis, ion exchange, membrane filtration, and reverse osmosis. However, most of the methods above have constraints such as high expense, low removal efficiency, inconvenience of sludge disposal, and production of hazardous by-products.

Among the various approaches, adsorption is the most effective process due to its universal nature, simplicity in design, inexpensiveness, and high efficiency. Consequently, non-conventional, low-cost green adsorbents prepared from natural materials, agricultural waste, and industrial waste become the preferred alternatives for removing organic pollutants due to their abundance in nature and significant reduction of solid waste which promotes waste recycling [4, 5]. Biogenic calcium-carbonate ($CaCO_3$) rich materials have been utilized extensively as cost-effective adsorbents because they demonstrate high affinity to many organic and inorganic pollutants [6]. Shells of marine organisms such as oysters, mollusks, clams, mussels, and cockles constitute a high concentration of calcium carbonate in either calcite, aragonite, or vaterite. It was found that aragonite exists naturally in cockle shells (Anadara granosa) around 98 to 99% [7]. It was investigated that the bivalve shell provides promising results in the elimination of heavy metal ions such as lead, cadmium, and zinc [8].

The global mass production and consumption of cockle represent the significant increase in the amount of waste CS generated. The annual global cockle production hikes up to a total volume of more than 15 million tonnes per year [9]. Statistics by the Department of Fisheries Malaysia in the year 2018, indicated 16642.73 tonnes of aquaculture production for blood cockle in Malaysia [10]. The blood cockle aquaculture flourishes and the mass production of cockle represent the significant increase in the amount of waste CS generated. The remnant CS are often disposed of without proper waste management. The improper management of these wastes has caused severe environmental concerns. The pressing need for the alleviation of environmental issues and re-utilization of waste has fuelled this research. Previous studies of bivalve shells emphasize more on the adsorption of heavy metal ions, with the studies on the utilization of bivalve shells in extracting nutrients and organic matter being less comprehensive and yet to be unravelled. Concerning this, this research had been conducted to focus on (1) the identification of the optimum dosage of cockle shell in COD removal using jar test; (2) the effectiveness of cockle shell in removing AN, COD, BOD, and TSS from contaminated river water using adsorption isotherms and kinetics models.

2. Materials and Experiments Procedures

The methods and materials are prepared in the following sections.

2.3. Adsorbent preparation

The CS was obtained from local markets and restaurants. Firstly, the CS was immersed in clean water for 12 hours followed by thorough rinsing under running tap water to remove surface debris. Next, the CS was naturally sun-dried for 3 days and later oven-dried at 105 °C for 24 hours to remove moisture content. After cooling, the dried CS was ground using a heavy blender followed by sieving to acquire average fine particle sizes of approximately 1 mm [11]. The pulverized CS was then kept in a sealed plastic bag to avoid contact with excess moisture.

2.4. Static adsorption experiment (Jar test)

Figure 1 illustrates the jar test experiment setup. Six water samples collected from Batang Labu River were prepared with a constant volume of 1 liter for each sample in the beakers. A pre-determined amount of crushed CS was added to different beakers of the water sample, making up the adsorbent concentrations of 1g/L, 2g/L, 3g/L, 4g/L, and 5g/L respectively. A sample without CS was prepared to act as a control. All the beakers were placed under the jar test machines and the paddles were lowered to stir the water samples at 150 rpm at room temperature to ensure homogeneous mixing. Before COD testing, the stirrers were turned off to allow the water sample to settle completely. The jar test was conducted spanning across 5 days with the COD content being tested each day to access the effect of adsorbent dosage on COD removal.

Fig. 1. Jar test experiment setup.

2.5. Dynamic adsorption experiment

Figure 2 illustrates the schematic diagram of the dynamic adsorption experiment setup. The model was designed to circulate and pump the water sample through the adsorbent continuously. The concentration of crushed CS implemented was the optimum adsorbent dosage which achieved the maximum COD removal percentage in the former jar test. This experiment was conducted for 5 consecutive days with the concentration of each pollutant remaining in the water sample being measured each day to investigate the feasibility of waste CS in removing AN, COD, BOD, and TSS.
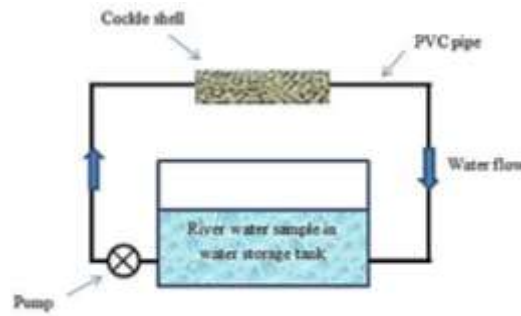
Fig. 2. Schematic diagram of dynamic adsorption experiment setup.

2.6. Analytical methods

The practicability of raw CS as an adsorbent in eliminating the tested parameters was determined through the removal efficiency and adsorption capacity. The total removal efficiency of each pollutant was obtained using Eq. (1).

$$R = \left(\frac{C_o - C_e}{C_o}\right) \times 100 \tag{1}$$

The number of contaminants adsorbed per unit of CS at equilibrium was computed based on Eq. (2).

$$q_e = \left(\frac{C_o - C_e}{m}\right) \times V \tag{2}$$

Adsorption isotherm provides insight into the adsorbent-adsorbate interaction and surface characteristics of adsorbent. The two proposed isotherm models in this study were the Langmuir and Freundlich isotherms. The isotherm which provides a magnitude of the correlation coefficient for the regression (R^2) closest to unity will be assumed to fit the data the best [12].

Langmuir isotherm describes chemical adsorption with monolayer coverage on homogeneous surfaces [13]. The linearized Langmuir isotherm equation is represented in Eq. (3) to produce a linear plot of $\frac{Ce}{q_e}$ versus Ce with a gradient of $\frac{1}{q_{max}}$ and an intercept of $\frac{1}{q_{max}K_L}$ [13].

$$\frac{Ce}{q_e} = \left(\frac{1}{q_{max}}\right)Ce + \frac{1}{q_{max}K_L} \tag{3}$$

Freundlich isotherm is an empirical model that suggests both monolayer and multilayer coverage on heterogeneous surfaces. The linearized Freundlich isotherm equation is represented in Eq. (4) to express a linear plot of log q_e versus log Ce that yields a gradient of $\frac{1}{n}$ and an intercept value of log K_F [13].

$$\log \log q_e = \log \frac{1}{n} \log C_e + \log \log K_F \tag{4}$$

Then, the adsorption kinetics of the pollutants onto CS was calculated by using Pseudo-first-order, Pseudo-second-order, Elovich, and Intra-particle diffusion reactions, as displayed in Eqs. (5) to (8).

Pseudo-first-order model:

$$\log \log (q_e - q_t) = \log \log q_e - \left(\frac{k_1}{2.303}\right) t \tag{5}$$

Pseudo-second-order model:

$$\frac{t}{q_t} = \frac{1}{k_2 q_e^2} + \left(\frac{1}{q_e}\right)(t) \tag{6}$$

Elovich model:

$$q_t = \left(\frac{1}{\beta}\right) \ln \ln \alpha\beta \ + \frac{1}{\beta} \ln \ln t \tag{7}$$

Intra-particle diffusion model:

$$q_t = k_{id} t^{1/2} + C \tag{8}$$

3. Result and Discussion

The result obtained was further discussed in the following section.

3.1. Effect of cockle shell dosage on chemical oxygen demand

The performance of the different amounts of CS utilized in governing the adsorption of COD in naturally contaminated water ranging from 0 g/L to 5 g/L is depicted in Figs. 3 and 4.
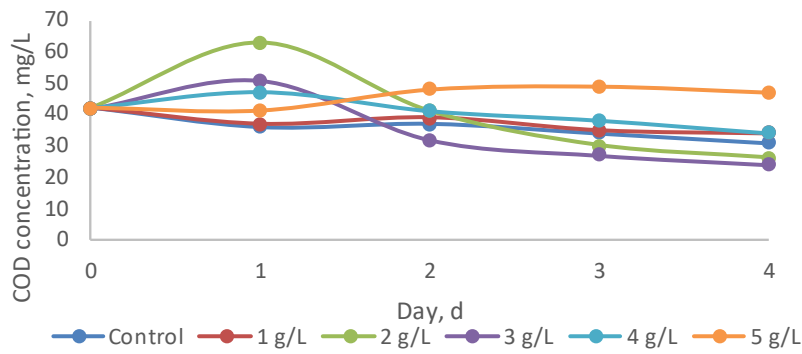

Fig. 3. COD concentration level for various amounts of CS.

The drop found from the graph indicated that 3g is the optimum amount of CS to be used for COD removal.
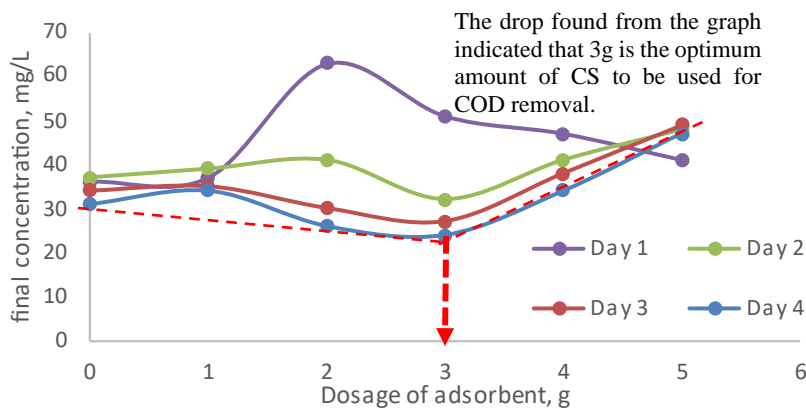
Fig. 4. Effect of adsorbent dosage on COD removal.

From the result, the COD concentration level for different amounts of CS displayed an overall decreasing trend except for 5g/L CS. As shown in Fig. 3, the COD concentration did not decline continuously but fluctuated over the consecutive 5 days of treatment. This unstable trend might be attributed to the accumulated organic content in CS in a fixed volume of naturally contaminated river water, which further contributes to the organic matter concentration after the first day of the experiment. There might be leakage of carbonaceous COD into the water from the CS during the initial stage of the experiment [14]. In addition, the biodegradability of CS possibly causes the microorganisms present in the collected water sample to break down the CS into organic matter which further increases the COD concentration.

In Fig. 4, the optimum dosage of CS was 3g/L where the final concentration of COD in the jar test was 24 mg/L, and the total percentage removal of COD was 42.86 %. From the result, it can be identified that the COD removal percentage increased rapidly with an increase in the adsorbent dosage until it reached an optimum dosage of 3g/L. Beyond the optimum limit, the COD removal percentage fell with further increments in the adsorbent dosage. This behavior can be explained that an increase in adsorbent concentration associated with an increase in the amount of available specific binding sites until the optimum mass was reached. Thereafter, any additional increment in adsorbent concentration led to the aggregation of adsorbents that reduced the chance of COD (adsorbate) contacting with all the available active sites, lowering the COD removal efficiency [15]. However, COD removal for 1g/L CS was noticed to be less than that of the control since an insufficient amount of shell might become the food for the microorganism within the water sample rather than the shell can be performed as an adsorbent. The COD removal in control (0 g/L) could be accredited to the stirring of the water sample within the beaker and the microorganisms in the natural river water. When the water sample was stirred, turbulence took place and there was a gas exchange between air and water. This introduced oxygen into the water and raised the dissolved oxygen level, causing a drop in COD concentration.

3.2. Performance of crushed cockle shell in fabricated model

The optimum dosage of 3g/L CS was employed to treat the polluted water sample in the fabricated model. The efficacy of raw cockle shells in clearing away the tested water quality parameters were evaluated via the removal percentage of contaminants (calculated based on Eq. (1)) and equilibrium adsorption capacity (calculated based on Eq. (2)), as shown in Fig. 5.
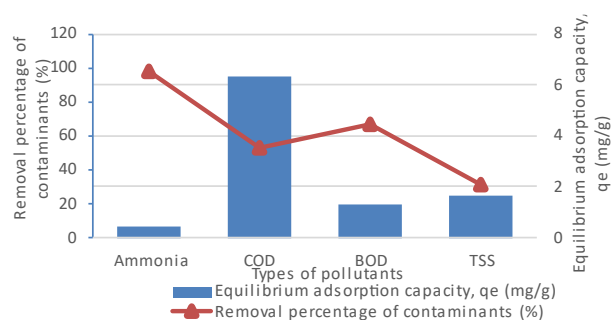
Fig. 5. The removal percentage and equilibrium adsorption capacity of contaminants (AN, COD, BOD, and TSS) by CS.

It was investigated that the raw CS is an excellent candidate to act as an adsorbent in the elimination of AN, COD, BOD, and TSS since all these pollutants had their concentration level reduced while achieving a certain percentage of removal. It was noticed that AN decreased to 98.39%, COD was reduced to 52.78%, BOD was removed up to 66.67%, and TSS was eliminated up to 31.25%. This infers that the CS filter exhibits better removal capability for AN with the highest removal percentage, followed by BOD, COD, and finally, TSS.

The feasibility of raw CS as an adsorbent was also evaluated through the adsorption capacity for each contaminant, computed based on Eq. (2). It was found that the adsorption affinity of contaminants onto CS has arranged accordingly in the selectivity sequence of COD (6.33 mg/g) > TSS (1.67 mg/g) > BOD (1.33mg/g) > AN (0.41 mg/g). In other words, this implies that 1 gram of CS possesses the most significant ability to adsorb 6.33mg/L of COD, followed by 1.67mg/L of TSS, 1.33mg/L of BOD, and ultimately 0.41mg/L of AN.

Nevertheless, the amount of AN and TSS molecules being adsorbed to the surface of CS was of minor significance, causing the result to be less representative. For AN, this could be ascribed to its low initial concentration of only 1.24mg/L. For TSS, this was also attributed to its low initial concentration (16 mg/L) in which the water quality was categorized as the least polluted as issued in Interim National Water Quality Standards (INWQS). On the other hand, the initial concentration of COD and BOD are 36 mg/L and 6mg/L respectively. A driving force created by the initial concentration of adsorbate is considered an essential factor in overcoming all the mass transfer resistance of the adsorbate molecules in the solid-aqueous phase. A higher initial adsorbate concentration provides a larger driving force on the adsorbent surface, enhancing the chance of adsorbates coming into contact with active sites available on the adsorbent [16].

It was demonstrated that the adsorption capacities of organic matter including COD and BOD were both greater than that of AN. Since the collected water sample was being pumped through the prototype continuously, circulation improves the biodegradability of organic matter in the contaminated water sample [14]. On top of that, as a natural adsorbent, the raw CS is perceived to serve as base media for biological growth. The presence of microorganisms naturally in the polluted water sample can develop biofilms on CS and consume all organic pollutants as food sources. The rough surface of CS further encourages biofilm formation. The organic matter in the water sample is not only being adsorbed to the surface of CS but also being decomposed by the microorganism present simultaneously in the water sample and on the CS, hence resulting in greater COD and BOD reduction. Previous research conducted by Qureshi et al. [17] reported a similar result that microorganisms occurring naturally in water would form a microbial film on the adsorbent and lower the COD level concurrently in the water.

3.3. Adsorption isotherm

Adsorption isotherm analysis is essential in modeling the adsorption process. Table 1 summarizes Langmuir and Freundlich isotherms for AN, COD, BOD, and TSS removal using pulverized CS with the optimum dosage of 3g/L.

As displayed in Table 1, it can be noticed that a greater R^2 value was obtained in the Freundlich isotherm for COD, BOD, and TSS elimination were higher than

the Langmuir isotherm with a magnitude of 0.9972, 0.895, and 0.8365 respectively. Therefore, the Freundlich isotherm model is supposed to fit the experimental data best and is more suitable to describe the behavior of the CS surface in adsorbing COD, BOD, and TSS. However, the negative slope of the graphs from the Freundlich isotherm interprets the negative value of $1/n$ obtained, which can be concluded that the adsorption process does not fit well with the Freundlich isotherm. This is due to the range of $1/n$ value should be between 0 to 1 to describe the degree of non-linearity for both the adsorption process and solution concentration [12]. Owing to this, the adsorption result is more favourable to Langmuir isotherm.

Table 1. Parameters for Langmuir and Freundlich isotherm.

	Langmuir				Freundlich			
	K_L (L/mg)	q_{max} (mg/g)	R_L	R^2	K_f (mg/g)(mg/L)	$1/n$	n	R^2
AN	- 22.9676	0.1659	-0.0004	0.9523	0.1690	-0.2286	-4.3745	0.9106
COD	-0.1001	2.6441	-0.1248	0.9968	150.7301	-1.1170	-0.8953	0.9972
BOD	-0.4915	0.2299	-0.0212	0.8626	4.1229	-1.4377	-0.6956	0.8950
TSS	-0.1733	0.4851	-0.0652	0.7830	48.5400	-1.5014	-0.6660	0.8365

The R^2 value in the Langmuir isotherms for COD, BOD, AN, and TSS were 0.9968, 0.8626, 0.9523, and 0.730, respectively. It suggests that the COD, BOD, AN, and TSS adsorption could take place via chemical processes. The adsorbate molecules are also adsorbed on a homogeneous surface. For the q_{max} value, the CS achieved a maximum adsorption capacity of 2.6441 mg/g for COD, 0.2299 mg/g for BOD, 0.1659 mg/g, and 0.4851 mg/g for TSS. This analysis also assumes the attachment of contaminants (COD, BOD, AN, and TSS) to the CS surface is only allowed when the finite specific binding sites are not fully occupied by a single layer [13].

3.4. Adsorption kinetics

Adsorption kinetic analysis is used to describe the adsorption rate of pollutants (AN, COD, and BOD) on the CS by controlling the time taken to achieve equilibrium [18]. Table 2 summarizes The Pseudo-first-order, Pseudo-second-order, Elovich, and Intra-particle diffusion kinetics of AN, COD, and BOD by CS respectively.

Table 2. The result of the Pseudo-first-order model, Pseudo-second-order model, Elovich model, and Intra-particle diffusion kinetic model.

	Pseudo-first-order Model			Pseudo-second-order Model		
	K_1 (1/day)	q_e (mg/g)	R^2	k_2 (1/day)	q_e (mg/g)	R^2
AN	0.0877	2.4395	0.8944	0.3753	2.5049	0.6265
COD	5.2621	18479.9163	0.5676	5.9666	1.8240	0.9650
BOD	0.3000	18.4799	0.8100	1.3333	0.4688	0.2841
	Elovich Model			Intra-particle diffusion Model		
	α	β	R^2	k_{id}	C	R^2
AN	5.7937	0.1560	0.8478	0.1726	-0.0175	0.8478
COD	0.3949	8.0340	0.3803	2.9789	0.8715	0.8095
BOD	1.6987	0.5344	0.7626	0.5887	-0.0570	0.7626

The magnitude of the regression coefficient R^2 value, as shown in Table 2 was used to validate the adsorption kinetics model for the pollutants (AN, COD, and BOD) in the CS. The correlation coefficients of the pseudo-first-order model indicated the best fitting for AN and BOD adsorption by CS because the R^2 value is higher (R^2= 0.8944 and 0.8100 respectively). For the pseudo-first-order reaction, the predicted equilibrium adsorption capacity of AN and BOD was 2.4395 mg/g ad 18.4799 mg/g respectively. The adsorption process is assumed to depend on the initial concentration of the adsorbate (AN and BOD) in the contaminated water and the interfacial diffusion reactions that occurred within the adsorbate and adsorbent [19]. Nevertheless, the adsorption rate is also directly proportional to the uptake rate of the adsorbent and the difference in saturation concentration between the adsorbate and adsorbent [20]. Based on the result obtained, the rate constant of the adsorption process for AN (0.0877 day^{-1}) is shorter as compared to BOD (0.3 day^{-1}) as the initial concentration of AN is smaller than the BOD in the contaminated water, thus affecting the equilibrium adsorption capacity as BOD is greater than AN.

In contrast, the application of the pseudo-second-order model was fitted well for COD adsorption by CS where the R^2 value is 0.9650. The pseudo-second-order reaction represents the chemisorption kinetics that occurs in COD adsorption [20]. The good fit of the pseudo-second-order model demonstrates the high driving force of COD molecules to the CS and causes the fast transfer of pollutants onto the CS. Besides this, the adsorption magnitude may also be influenced by the availability of active surfaces and porosity on the CS [21]. The calculated qe value from the pseudo-second-order reaction of CS on COD pollutants was 1.8240 mg/g. The result obtained showed that the chemical interaction between the COD pollutant and the CS is the main dominant of the adsorption mechanics [22] with other weak binding mechanisms such as physisorption and surface diffusion that might occur simultaneously during the adsorption process [23].

4. Conclusion

Based on the jar test experiment, the optimum CS dosage in eliminating COD was found to be 3g/L with a maximum removal percentage of 42.86%. It is established from this research that waste CS is viable as an adsorbent in water decontamination with a satisfactory removal percentage of 98.39% for AN, followed by 66.67% for BOD, 52.78% for COD, and 31.25% for TSS. Langmuir isotherm best described the adsorption of COD, BOD, AN, and TSS as chemical monolayer adsorption. From the adsorption kinetic models, AN and BOD adsorption on the CS were favourable to pseudo-first-order reaction. While COD adsorption on the CS was favourable to pseudo-second-order reaction. In short, it can be concluded that CS is a suitable alternative adsorbent material used to treat the organic matter and nutrients in contaminated river water.

Nomenclatures	
C	interception constant for the intra-particle diffusion
Ce	Ce is the equilibrium concentration of pollutant (mg/L)
C_O	The initial concentration of pollutant (mg/L)
k_1	the rate constant of Pseudo first order adsorption (min^{-1})
k_2	the rate constant of Pseudo second-order adsorption (g/mg·min)

k_F	Freundlich constant related to adsorption capacity $[(mg/g)(mg/L)^{-1/n}]$
k_{id}	the rate constant for the Intraparticle diffusion (min^{-1})
k_L	Langmuir constant related to the energy of adsorption (L/mg)
m	mass of adsorbent utilized (g)
n	Freundlich exponent related to adsorption intensity or heterogeneity factor of the surface of the adsorbent
q_e	equilibrium capacity of pollutant (mg/g)
q_{max}	the maximum adsorption capacity (mg/g)
q_t	amount of adsorbate adsorbed into adsorbent at the time (mg/g)
R	the total removal efficiency of each pollutant (%)
t	reaction time (min^{-1})
V	water sample volume (L)

Greek Symbols

α	adsorption mechanism
α	adsorption mechanism
β	desorption constant of Elovich reaction (g/mg)

Abbreviations

AN	Ammoniacal Nitrogen
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
CS	Cockle Shells
INWQS	Interim National Water Quality Standards
TSS	Total Suspended Solids

References

1. Anuar, H.M.; Yaacob, N.; Wahab, H.A.; and Khalid, R.M. (2022). Strengthening river basin governance through Green Courts towards ensuring water security (Goal 6). *Good Governance and the Sustainable Development Goals in Southeast Asia*, Routledge. 69-83.

2. Kamal, A. (2021). We forgot water in the food security equation. The Start. Retrieved October 21, 2022, from https://www.thestar.com.my/opinion/letters/2021/04/26/we-forgot-water-in-the-food-security-equation

3. Shahi, S. (2022). Water pollution: Perceptions, source and variety of factors. *Social Science Journal for Advanced Research*, 2(2), 12-17.

4. Karić, N.; Maia, A.S.; Teodorović, A.; Atanasova, N.; Langergraber, G.; Crini, G.; Ribeiro, A.R.; and Đolić, M. (2022). Bio-waste valorisation: Agricultural wastes as biosorbents for removal of (in) organic pollutants in wastewater treatment. *Chemical Engineering Journal Advances*, 9, 100239.

5. Mallikarjuna, C.; and Dash, R.R. (2022). Removal of Lignin from wastewater using an industrial waste as adsorbent: A statistical and kinetic modeling approach. *Journal of Hazardous, Toxic, and Radioactive Waste*, 26(2), 04021054.

6. Hart, A.; and Aliu, E. (2022). *Materials from eggshells and animal bones and their catalytic applications.* In Pham Minh, D. (Ed.). *Design and applications of hydroxyapatite-based catalysts.* Wiley-VCH GmbH, Boschstr, 437-479.

7. Mohamed, M.; Yusup, S.; and Maitra, S. (2012). Decomposition study of calcium carbonate in cockle shell. *Journal of Engineering Science and Technology*, 7(1), 1-10.

8. Yap, C.K.; Pang, B.H.; Cheng, W.H.; Kumar, K.; Avtar, R.; Okamura, H.; Horie, Y.; Sharifinia, M.; Keshavarzifard, M.; Ong, M.C.; and Naji, A. (2023). Heavy metal exposures on freshwater snail Pomacea insularum: Understanding its biomonitoring potentials. *Applied Sciences*, 13(2), 1042.

9. Wijsman, J.W.M.; Troost, K.; Fang, J.; and Roncarati, A. (2019). Global production of marine bivalves. Trends and challenges. In Smaal, A.C.; Ferreira, J.G.; Grant, J.; Petersen, J.K.; and Strand, Ø. *Goods and services of marine bivalves*, Springer International Publishing, 7-26.

10. Department of Fisheries Malaysia. (2018). *Annual fisheries statistics 2018*. Malaysia: Department of Fisheries.

11. Daud, Z.; Abubakar, M.H.; Kadir, A.A.; Latiff, A.A.A.; Awang, H.; Halim, A.A.; and Marto, A. (2017). Adsorption studies of leachate on cockle shells. *International Journal of GEOMATE*, 12(29), 46-52.

12. Crini, G.; Lichtfouse, E.; Wilson, L.D.; and Morin-Crini, N. (2018). Adsorption-oriented processes using conventional and non-conventional adsorbents for wastewater treatment. In: Crini, G.; and Lichtfouse, E. (Eds.). *Green adsorbents for pollutant removal. environmental chemistry for a sustainable world*. Vol 18. Springer, Cham, 23-71.

13. Singh, N.B.; Nagpal, G.; and Agrawal, S. (2018). Water purification by using adsorbents: A review. *Environmental Technology & Innovation*, 11, 187-240.

14. Low, W.P.; Fadhil Md Din, M.; Ponraj, M.; Ali Fulazzaky, M.; Iwao, K.; Rahman Songip, A.; and Chelliapan, S. (2015). Application of low-cost fabricated column model for the adsorption analysis of pollutants from river water using coconut coir. *Desalination and Water Treatment*, 53(5), 1342-1351.

15. Soni, A.; Rai, N.; and Sar, S.K. (2015). Removal of Anionic Surfactants from Industrial And Domestic Waste Water Using a Bio Adsorbent Embelia Ribes in Region Bilaspur Chhattisgarh, India. *Chemical Science Review and Letters*, 4 (13), 203-208.

16. Vilvanathan, S.; and Shanthakumar, S. (2017). Column adsorption studies on nickel and cobalt removal from aqueous solution using native and biochar form of Tectona grandis. *Environmental Progress & Sustainable Energy*, 36(4), 1030-1038.

17. Qureshi, N.; Annous, B.A.; Ezeji, T.C.; Karcher, P.; and Maddox, I.S. (2005). Biofilm reactors for industrial bioconversion processes: employing potential of enhanced reaction rates. *Microbial Cell Factories,* 4(1), 1-21.

18. Neto, V.O.S.; Oliveira, A.G.; Teixeira, R.N.P.; Silva, M. A. A.; Freire, P.T.C.; Keukeleire, D.D.; and Nascimento, R.F. (2011). Use of coconut bagasse as alternative adsorbent for separation of copper(II) ions from aqueous solutions: Isotherms, kinetics, and thermodynamic studies. *BioResources*, 6(3), 3376-3395.

19. Gowda, S.A.; Goveas, L.C.; and Dakshayini, K. (2022). Adsorption of methylene blue by silver nanoparticles synthesized from Urena lobata leaf extract: Kinetics and equilibrium analysis. *Materials Chemistry and Physics*, 288, 126431.

20. Sahoo, T.R.; and Prelot, B. (2020). Adsorption processes for the removal of contaminants from wastewater: the perspective role of nanomaterials and nanotechnology. *Nanomaterials for the detection and removal of wastewater pollutants*, 161-222.

21. Hasani, N.; Selimi, T.; Mele, A.; Thaçi, V.; Halili, J.; Berisha, A.; and Sadiku, M. (2022). Theoretical, equilibrium, kinetics and thermodynamic investigations of methylene blue adsorption onto lignite coal. *Molecules*, 27(6), 1856.

22. Mohadi, R.; Normah, N.; Palapa, N.R.; and Lesbani, A. (2022). M2+ (Ni, Cu, Zn)/Al-LDH composites with hydrochar from rambutan peel and study the adsorption efficiency for organic dyes. *Environment and Natural Resources Journal*, 20(2), 221-233.

23. Nathan, R.J.; Barr, D.; and Rosengren, R.J. (2022). Six fruit and vegetable peel beads for the simultaneous removal of heavy metals by biosorption. *Environmental technology*, 43(13), 1935-1952.