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A Sustainable Approach for Removing Organic Pollutants from Food Processing Effluents Using Unmodified Cocopeat as an Adsorbent

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Abstract: Food production (chips) uses raw materials such as tapioca, cassava, banana, and many more, which contribute to excessive pollutants in the water. Thus, there is a need to treat effluent sufficiently to prevent undesired pollutants from being released into the receiving water bodies, such as rivers and agricultural drainage systems. This study aims to investigate the effectiveness of cocopeat in removing targeted parameters such as suspended solids (SS), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), and total phosphorus (TP) from the chips processing effluent. Batch experiments were conducted to determine optimum operating parameters, including the adsorbent dosage, contact time, and shaking speed. This was done to identify the best removal rates of SS, COD, NH_3-N and TP from effluent food processing samples taken from two different discharge points based on their usages. The experimental results show that at the optimum conditions of pH 7, cocopeat dosages of 800 mg/L, contact time of 30 minutes, and shaking speeds of 200 rpm, the unmodified cocopeat achieved 17.3% and 19.8% of SS removal, 35.5% and 28.9% of COD removal, 40.7% and 30.5% of NH_3-N removal, and 53.5% and 59.2% of TP removal, from Point A and Point B effluent, respectively. Besides, the maximum adsorption capacity achieved by unmodified cocopeat towards SS (1.5-14.0 mg/g), COD (16.88-17.75 mg/g), NH_3-N (0.31-0.32 mg/g) and TP (1.46-1.50 mg/g) are comparable to the adsorption capacities reported by previous researchers. This finding suggests that cocopeat could potentially replace the commercially developed adsorbents for the treatment. Furthermore, this study gave insights into the feasibility of sustainable treatment using cocopeat as an adsorbent for medium-strength effluent. However, it is suggested that further alteration of the cocopeat characteristics, either by chemical or physical modifications, and its sludge disposal method could be explored further to enhance the treatment performance.

Keywords: Agricultural waste-based adsorbent, suspended solids, chemical oxygen demand, ammoniacal nitrogen, total phosphorus, food processing wastewater

1. Introduction

The rapid growth of food processing industries in Malaysia has contributed to the undesired release of untreated effluent, which causes the intrusion of harmful amounts of pollutants into the nearby receiving water bodies, such as

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rivers and water drainage systems. Thus, there is a need to treat effluent sufficiently to prevent undesired contaminants from being released into the receiving water bodies, such as rivers and agricultural drainage systems. In addition, the high concentrations of organic substances, such as carbohydrates, starches, proteins, vitamins, pectin, and sugars, which are responsible for high chemical oxygen demand and suspended solids, are commonly found in significant amounts in effluents from the processing of food (Radeef & Ismail, 2021).

Numerous treatments for removing pollutants from industrial effluents include precipitation, chemical oxidation, electrochemical, membrane filtration, phytoremediation, ion exchange, and adsorption (Cid et al., 2018; Hashem et al., 2020; Parnian & Furze, 2021; Sahu, 2019; Wang et al., 2021; Wu et al., 2021; Zhang & Duan, 2020). Alternatives for simple and low-cost treatment agents are required to ensure the treated effluent quality can be safely disposed of at the receiving water bodies. The installation of conventional effluent treatment units for every food manufacturing factory is less feasible due to process complexity and less viability of installing conventional effluent treatment units in every food manufacturing factory due to economic reasons. Nevertheless, it also requires extra efforts and financial budgets to provide facilities which enable the transportation of this effluent from the factory to the nearby municipal effluent treatment plant to get treated. Unfortunately, few actions have been taken to prevent this situation until it gets worse and can hardly be cured. This unresolved problem has led to significant visible impacts on the environment, including eutrophication, odour problems, disturbing aquatic ecosystem and waterborne health issues faced by the local communities. Therefore, a simple and practical treatment technology that uses non-conventional adsorbents is expected to be installed on-site to help the food processing factory to reduce water quality contaminants, particularly organic pollutants, to the levels which comply with Malaysia's Environmental Quality (Industrial Effluent) Regulations 2009. The classification of conventional and non-conventional adsorbents is depicted in Figure 1.

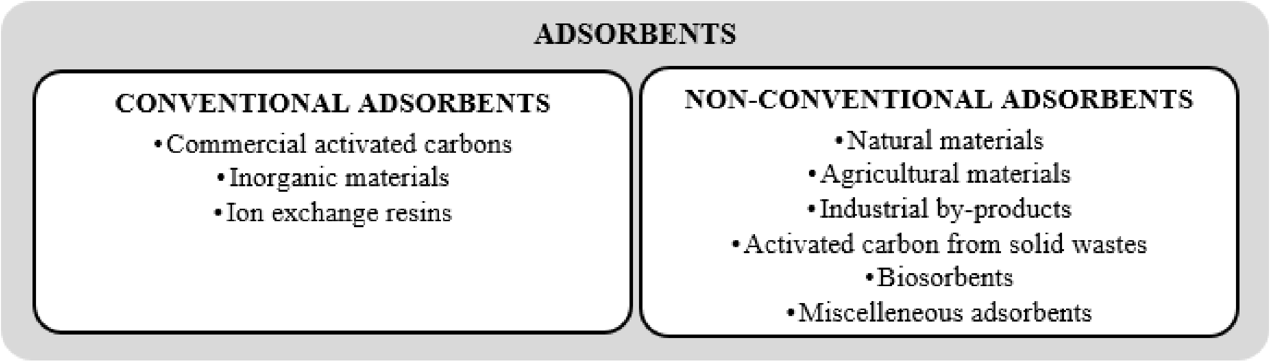


Fig. 1 - Conventional and non-conventional adsorbent materials for industrial effluents treatment (Crini et al., 2019)

Researchers worldwide have investigated several processes to remove organic pollutants and excessive nutrients from industrial effluents. The use of various adsorbents to remove multiple contaminants from effluent has shown great potential. Although expensive because of high processing expenses, activated carbon is a valuable material. Many natural adsorbents have been tested to reduce organic pollutants and nutrients from various effluents (Awad et al., 2019; Karić et al., 2022). Alternatively, due to their low cost among the natural materials used as adsorbents, agricultural waste-based wastes are emerging resources for adsorbents (Danley-Thomson et al., 2016). They have proved to be very efficient for organic pollutant and nutrient removal from effluent due to high lignocellulose material, which is part of their constituents (Pamidipati & Ahmed, 2019). These wastes are less expensive, more readily accessible, and renewable than other substances employed as adsorbents. They are superior to other adsorbents because agricultural wastes are typically employed with little to no processing. They lower production costs by utilising inexpensive raw materials and removing the energy expenses involved with heat treatment (Yee et al., 2021).

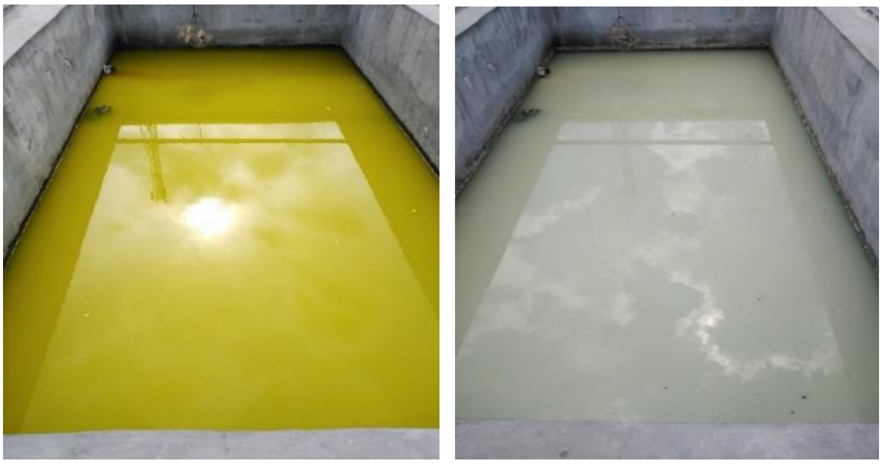
In Malaysia, 5280 kg of coconut trash per hectare, primarily coconut husk, is produced, but the majority has not yet been appropriately processed and used. With sufficient water capacity storage, good water retention, and environmental friendliness, coco peat is extremely probable (Haziatul et al., 2021). Coconut peat, also known as cocopeat, is an agricultural waste that can support the adsorption treatment process. According to a morphological study by Lee et al. (2018), the surface structure of the cocopeat surface revealed that the number of large pores reduced with increasing contact time and increased the fraction of smaller pores, indicating the attachment of substances within the cocopeat macropores (Verasoundarapandian et al., 2021). Furthermore, the efficiency of cocopeat as an adsorbent material has been demonstrated in treating various contaminants from various types of water, including multiple types of heavy metals (Atikah et al., 2017; Samaniego & Tanchuling, 2019; Shakeri et al., 2012).

Therefore, the present study aimed to investigate the effectiveness of cocopeat-derived adsorbents against targeted organic pollutants such as suspended solids, chemical oxygen demand, ammoniacal nitrogen and total phosphorus. Furthermore, the feasibility of the proposed low-cost treatment for medium-strength effluent that focuses on effluent from food processing industries for safe disposal was investigated in this study. In addition, an experimental adsorption strategy was developed to evaluate and analyse the efficiency of cocopeat as an adsorbent in treating various contaminants. The batch adsorption experiments were employed with the different values of adsorbent dosage, contact time, and shaking speed to obtain the optimum simultaneous removal of suspended solids, chemical oxygen demand, ammoniacal nitrogen and total phosphorus from the food processing effluent.

2. Materials and Methods

2.1 Sampling of Food (Chips) Processing Effluent

The effluent samples were taken at the food (variety chips) processing factory in Batu Pahat, Johor. On-site, the manufacturing has two different discharge points; effluent of raw product cleaning (Point A effluent) and effluent of the cooking process (Point B effluent), as shown in Figures 2(a) and 2(b). The factory is involved in the production of chips, cakes, dried foods, pickles and confectionaries. Big objects such as leaves and small tree branches were screened prior to transferring into glass bottles, transported to the laboratory and stored at 4ºC. pH, temperature and dissolved oxygen (DO) were analysed in situ. In addition, other parameters such as suspended solids (SS), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), and total phosphorus (TP) were analysed within two days of sample collection according to standard methods for the examination of water & wastewater (APHA & AWWA, 2005). All the chemicals used for the analytical determinations were of analytical grades. In addition, main targeted parameters such as SS (HACH Method 8006), COD (HACH Method 8000), NH_3-N (Nessler, Method 8038) and TP (HACH Method 10127) were analysed using the DR6000 instrument.



(a) (b)

Fig. 2 - (a) effluent of raw product cleaning (point a effluent); (b) effluent of the cooking process (point b effluent)

The initial characteristics of the effluent are recorded in Table 1. The pH of the effluent is acidic for point A and B effluents (pH 4.3±0.2 and pH 5.1±0.61, respectively), whereby according to Malaysia Environmental Quality (Industrial Effluent) Regulations 2009, the recommended pH for the effluent discharge must be within 5.5 to 9.0 (Standard B). Besides, the temperatures were recorded between 22.9±0.61°C (point A effluent) and 23.3±1.30°C (point B effluent). In situ analyses were also done for DO which the concentrations were 0.9±0.15 mg/L (point A effluent) and 3.5±0.83 (point B effluent), SS concentrations were 192.7±73.96 mg/L (point A effluent) and 547.7±341.86 mg/L (point B effluent), COD concentrations were 560.0±214.8 (point A effluent) and 340.3±208.79 mg/L (point B effluent), NH_3-N concentrations were 11.7±4.51 (point A effluent) and 6.1±1.92 mg/L (point B effluent), and TP concentrations were 23.8±1.88 (point A effluent) and 23.1±2.35 mg/L (point B effluent).

Table 1 - Initial characteristics of food processing effluent and Malaysia Environmental Quality (Industrial Effluent) Regulations

Parameter	Mean value±SD (Present study)		Malaysia Environmental Quality Regulations (Industrial Effluent)
	Point A effluent	**Point B effluent**	**Limit value**
pH	4.3±0.20	5.1±0.61	5.5-9.0
Temperature (°C)	22.9± 0.61	23.3±1.30	40
DO (mg/L)	0.9±0.15	3.5±0.83	*
SS (mg/L)	192.7±73.96	547.7±341.86	100

COD (mg/L)	560±214.8	340.3±208.79	200
NH_3-N (mg/L)	11.7±4.51	6.1±1.92	20
TP (mg/L)	23.8±1.88	23.1±2.35	*

* – Not stated in the referred standard;
SD – Standard deviation

2.2 Preparation of Adsorbent (Cocopeat)

Cocopeat used in this study was purchased from the local commercial market (Figure 3). Cocopeat fibre was repeatedly rinsed with tap water until the remaining-coloured extract turned to clean water after being soaked in distilled water for three days. Then, it was oven dried at 60°C for 24 hours and sieved using a 50–100 µm sieve to get particles in this size range (Etim et al., 2016). The cocopeat was stored in an air-tight plastic container prior to use for batch experiments.

Fig. 3 - Cocopeat fibre

2.3 Batch Experiments Setup

Batch experiments were carried out at pH 7 in 250 mL flasks, and the total volume of the samples from the food processing plants was maintained at 100 mL in the individual flask. The initial solution pH was adjusted to pH 7 using 0.1M H_2SO_4 or 0.1M NaOH. The pH was adjusted to the natural pH due to the reason that the adsorption capacity had only a slight difference when the pH was within the range of 4 to 10 (Etim et al., 2016). Their research reveals that in addition to the electrostatic mechanism, the chemical interactions between the adsorbent and the desired contaminants also impacted the adsorption process.

In the first stage of the optimisation study, the effects of adsorbent dosage on the removals of SS, COD, NH_3-N and TP were studied with adsorbent dosages ranging between 20 to 100 mg in a 100 mL food processing effluent sample and the flasks were shaken at 200 rpm for 30 minutes on an orbital shaker. Next, the effect of contact time on the removal of targeted parameters was investigated over the contact time ranging between 15 to 120 minutes using the optimum adsorbent as previously determined. Finally, the effect of shaking speed on the removal of targeted parameters was also studied, with the shaking speed varying between 50 to 250 rpm. The following is the equation (1) used to determine the removal efficiencies of SS, COD, NH_3-N and TP. The optimum conditions were selected based on the highest removal efficiencies for removing targeted parameters.

$$\%\ Removal = \frac{C_0 - C_e}{C_0} \times 100 \qquad (1)$$

where C_0 is the initial concentration of the targeted pollutant; C_e is the residual concentration of the targeted pollutant. All experiments were duplicated to ensure the reliability of the presented data.

2.4 Adsorption Capacity

The amount of targeted pollutant adsorbed per unit mass of cocopeat at equilibrium time t, q (expressed in mg targeted pollutant/g cocopeat) is calculated using the following equation (2).

$$q = \left(\frac{C_0 - C_t}{m}\right)V \qquad (2)$$

where C_0 is the initial metal concentration in mg/L; C_t is the measured targeted parameter concentration at time t expressed in mg/L; V is the volume of effluent sample used in L; m is the mass of adsorbent in grams.

3. Results and Discussion

3.1 Effect of Adsorbent Dosage

The removals of suspended solids (SS), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N) and total phosphorus (TP) during the optimisation of adsorbent (cocopeat) dosage were observed during the batch experiments. The removal rates for all targeted pollutants increased with the adsorbent dosage from 200 to 800 mg/L. The highest removal percentages for SS (6.5% and 14.1%), COD (19.5% and 28.9%), NH_3-N (39.0% and 29.3%), and TP (52.6% and 58.5%) were recorded when applying 800 mg/L of adsorbent, for effluent samples taken from point A and point B, respectively as shown in Figure 4. At this stage, the experimental condition was maintained at pH 7, shaking speed of 200 rpm, contact time of 30 minutes and settling time of 30 minutes.

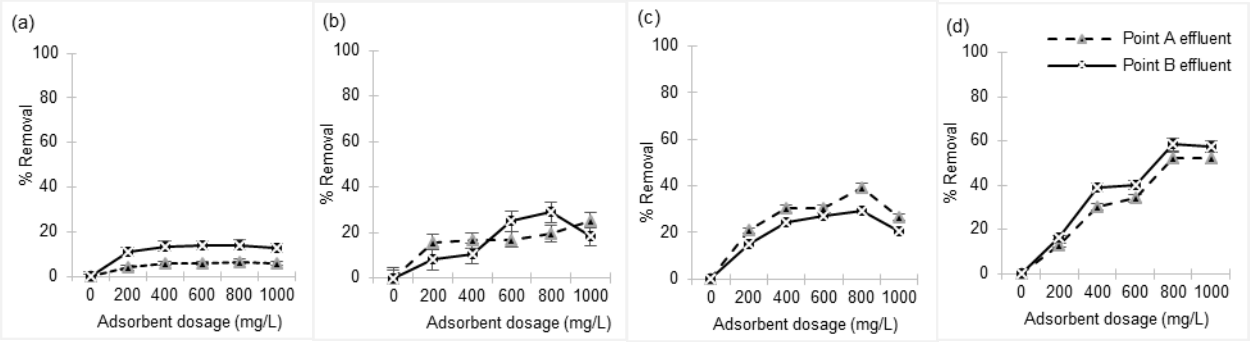


Fig. 4 - Effect of adsorbent dosage for (a) SS; (b) COD; (c) NH_3-N; (d) TP removals at fixed conditions of pH 7, shaking speed of 200 rpm and contact time of 30 minutes

Figure 4 also depicts the removal rates for all targeted parameters, showing decreasing trends when 800 mg/L of adsorbent dosage was applied to the treatment. On the other hand, it is worth to be noted that, even though the characteristics of point A effluent were slightly different to that of point B effluent, as recorded in Table 1, the performance of cocopeat demonstrated the same trend of removal for all targeted pollutants. This indicates that the cocopeat would consistently perform insignificant differences in removal efficiency for reducing SS, COD, NH_3-N and TP. Theoretically, it is well understood that the adsorption process increases the adsorption activity with the adsorbent dosage since the adsorption surface expands and more adsorption sites are available (SenthilKumar et al., 2010). According to the morphology study of Raju et al. (2014) on cocopeat, it was found that the surface of cocopeat is rich with fine pores confirming that it can provide adsorption sites for the attachment of pollutants. Although the availability of more adsorption sites and an increase in the adsorption surface contribute to the improvement in adsorption with dosage, the removal effectiveness declines when the adsorbent dosage is applied over the optimum point. The reason could be due to the saturation of adsorption sites available for the attachment of the targeted pollutants may compete with the other elements that may present in the effluent. Based on the finding, 800 mg/L of adsorbent dosage will be applied as the optimum dosage for the subsequent optimisation studies of contact time and shaking speed.

3.2 Effect of Contact Time

At this stage, the batch experiments were done using the previously determined optimum adsorbent dosage of 800 mg/L, at a natural pH of 7, and at a shaking speed of 200 rpm to study the effect of contact time. The optimum contact time for the adsorption of SS, COD, NH_3-N and TP was found at 30 minutes. Figure 5 also shows that, after the initial 30 minutes, there is a rapid increase, which is followed by a stable removal rate beyond 60 minutes. It also can be seen that the highest removal rates were recorded as follow; 7.7% and 14.8% (for SS), 19.7% and 28.9% (for COD), 22.5% and 24.0% (for NH_3-N), and 52.6% and 58.5% (for TP), for Point A and Point B effluent, respectively. This indicates that the cocopeat is capable of reaching a considerable adsorption rate for all targeted parameters within a short time. It is expected that a short period of contact time would indicate a good deciding factor for the industries to help them decide on which treatment technique they would adopt for their industries. In addition, this would reduce the cost of operation when involving the power and energy required to operate the treatment process. This finding is similar to Jalu Waskita et al. (2012), which carried out an adsorption study using cocopeat to remove lead and zinc cations. Even though the targeted parameters for the present study are different, this shows that cocopeat favoured a short period of 30 minutes as its optimum contact time regardless of the type of targeted water pollutants. Therefore, 30 minutes will be applied to study the effect of shaking speed in the subsequent stage of batch experiments.

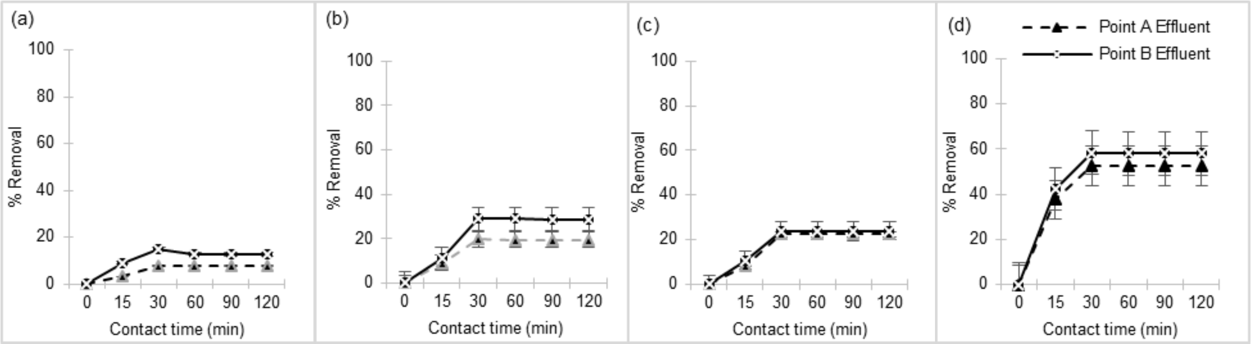


Fig. 5 - Effect of contact time for (a) SS; (b) COD; (c) NH_3-N; (d) TP removals at fixed conditions of pH 7, adsorbent dosage of 800 mg/L, and shaking speed of 200 rpm

3.3 Effect of Shaking Speed

Figure 6 shows that SS, COD, NH_3-N and TP were all optimised at a shaking speed of 200 rpm. The observation indicates that the higher the shaking speed applied, the higher the removal rate of targeted parameters can be achieved until it reaches the optimum point. In all cases, the removal rates show a reduction trend and reached an equilibrium state when the shaking speed increased beyond 200 rpm. This indicates that, at a higher shaking speed than 200 rpm, pollutants trapped within the pores in the cocopeat surface may be resuspended and detached from the adsorbent surface, thus, making the condition unfavourable for the binding process.

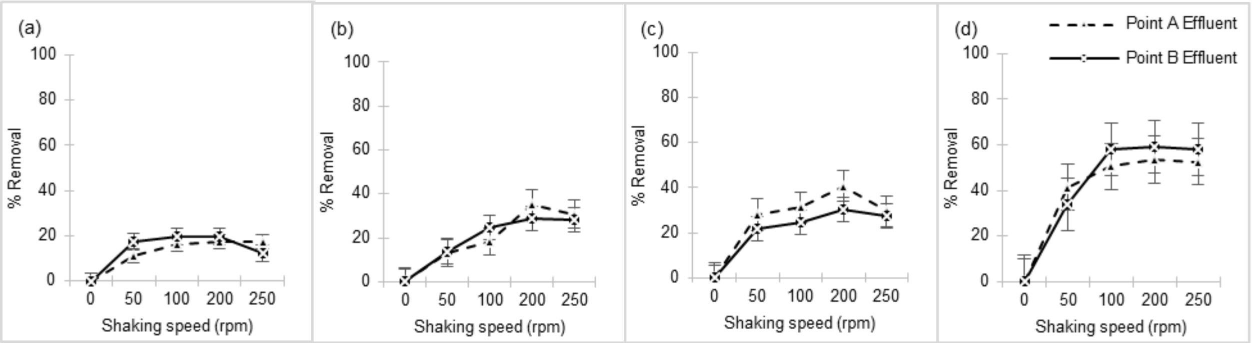


Fig. 6 - Effect of shaking speed for (a) SS; (b) COD; (c) NH_3-N; (d) TP removals at fixed conditions of pH 7, adsorbent dosage of 800 mg/L, and contact time of 30 minutes

For comparison, Shakeri et al. (2012) found that the shaking speed was optimised at a lower shaking speed of 100 rpm when removing lead from an aqueous solution using the same materials (cocopeat) as applied in the present study. This suggests that the shaking speed may be influenced by the type of water quality pollutant that will be removed.

3.4 Adsorption Capacity

The adsorption capacities of different targeted pollutants are affected by the contact time between the pollutants and the adsorbent. Hence, the adsorption capacities of targeted pollutants onto cocopeat were studied over contact time from 15 minutes to 120 minutes and at the optimum adsorbent dosage of 800 mg/L, contact time of 30 minutes and shaking speed of 200 rpm. It can be seen from Figure 7 that the adsorptions of SS, COD, NH_3-N and TP for both discharge points of effluents (Point A and Point B) show increasing trends with increasing contact time. There is a significant increase for the first 30 minutes, and the value remains steady after 60 minutes. The adsorption of SS, COD, NH_3-N and TP, as shown in Figure 7, followed the common trend of increasing adsorption capacity with increasing contact time, similar to that reported by Jalu Waskita et al. (2012). Experimental results have shown that the adsorption capacities of cocopeat were calculated in the ranges of 1.5 to 14.0 mg/g (SS), 16.88 to 17.75 mg/g (COD), 0.31 to 0.32 mg/g (NH_3-N), and 1.46 to 1.50 (TP) as tabulated in Table 2.

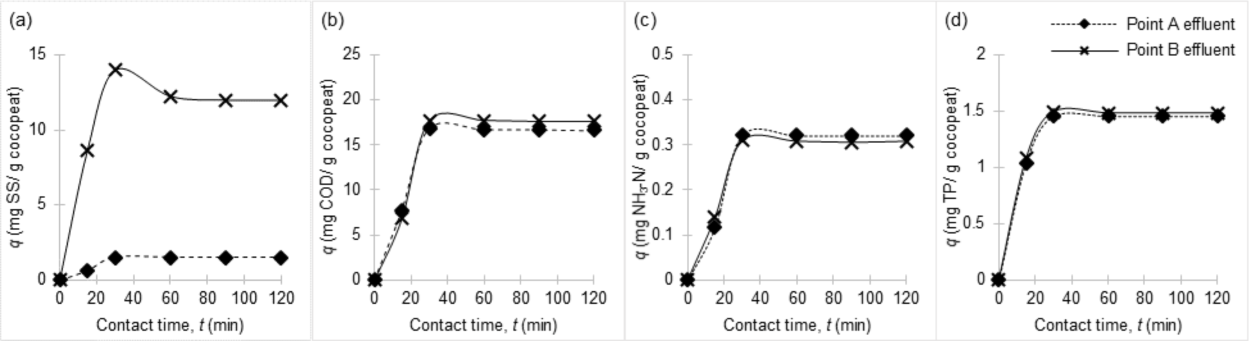


Fig. 7 - Adsorption behaviour of (a) SS; (b) COD; (c) NH_3-N; (d) TP over time at different target pollutant concentrations of effluents (Point A effluent and Point B effluent) under the conditions (adsorbent dosage = 800 mg/L; shaking speed = 200 rpm; pH 7)

The data tabulated in Table 2 show that the cocopeat adsorption capacity towards COD is higher than the other studied parameters (SS, NH_3-N and TP) in the present study. The reason could be that the initial concentration of COD in the effluent (present study) is far higher than concentrations of SS, NH_3-N and TP. However, the data on the adsorption of organic pollutants onto cocopeat is hardly found. Still, the data were compared to previous studies of the adsorption of metal ions onto cocopeat (Jalu Waskita et al., 2012; Shakeri et al., 2012).

Table 2 - Maximum adsorption capacity of unmodified cocopeat towards different water quality pollutants

Water quality parameter	Adsorption capacity (mg/g)	Reference
SS	1.5-14.0	Present study
COD	16.88-17.75	Present study
NH_3-N	0.31-0.32	Present study
TP	1.46-1.50	Present study
Zinc	7.29	(Jalu Waskita et al., 2012)
Lead	2.201-2.74	(Shakeri et al., 2012)

4. Conclusion

By The unmodified cocopeat exhibits considerable promise as an adsorbent given its ability to fairly remove suspended solids (SS), chemical oxygen demand (COD), ammoniacal nitrogen (NH_3-N), and moderately remove total phosphorus (TP) from food (chips) processing effluent. The optimum conditions for the adsorption of unmodified cocopeat were found when 800 mg/L of cocopeat dosages were applied over 30 minutes of contact time and shaking speeds of 200 rpm. On the other hand, however, the maximum adsorption capabilities for SS (1.5-14.0 mg/g), COD (16.88-17.75 mg/g), NH_3-N (0.31-0.32 mg/g), and TP (1.46-1.50 mg/g) achieved by unmodified cocopeat are comparable to those reported by prior researchers. This finding implies that cocopeat may be capable of replacing commercially developed adsorbents for medium-strength effluent treatment. Nonetheless, this study provided insight into cocopeat, which may be desirable for decentralized, on-site effluent treatment because it is easily accessible and reasonably priced. The efficacy and adoption of cocopeat as a sustainable adsorbent in the packing medium in the effluent treatment unit would necessitate extensive upcoming research.

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