Treatment of laundry wastewater using chemically treated sugarcane bagasse

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Abstract. Laundry wastewater constitutes of detergent compounds, bleaching agent, textile color pigments and dirt. These compounds are hazardous once discharged into the water source without proper treatment due to the adverse effects on the aquatic life in the freshwater bodies. This fixed-bed column adsorption study using the natural biomass from chemically treated sugarcane bagasse is proven to be effective for the removal of constituents present in the laundry wastewater. The synthetic laundry wastewater was prepared in the laboratory from a powder type of detergent with a concentration of 50mg/L and 250mg/L to be further used in the adsorption process. The characteristics of the synthetic laundry wastewater were analyzed by the turbidity, pH, dissolved oxygen (DO) and chemical oxygen demand (COD). The fixed-bed column experiment with the treated sugarcane bagasse was conducted under different parameters such as the effect of pH, initial concentration and bed height. The best removal efficiency was observed at a bed height of 10 cm with a concentration of 50 mg/L is 65%, followed by 33% and 20% for bed heights of 4 and 2 cm respectively. As for the concentration of 250 mg/L, the best removal efficiency was at a bed height of 10 cm which was found to be 58% followed by 26% and 17% removal for a bed height of 4 cm and 2 cm respectively. The kinetics of the adsorption was investigated using the kinetic models of Thomas and Yoon-Nelson. The experimental results fitted well on the Thomas model and Yoon-Nelson which showed a high linear regression value greater than 0.9. These results prove that chemically treated sugarcane bagasse is an effective low-cost adsorbent for reducing turbidity, pH, COD and increasing the DO concentration.

Keywords: biomass waste; breakthrough; fixed-bed; detergent; COD

1. Introduction

Life as known today would not have existed without water, as it is the essence and important to not only humans but also natural biological systems. Any threat to water bodies and resources is considered a direct attack on the life of the many types of life forms. These threats are often seen coming from domestic wastewater, urban and industrial activities. These threats can be tackled by raising awareness and implementing strict governmental rules. However, with the damage that has already been done, matters can only get worse and worse. Environmentalists have expressed their concern for the unbalanced cycle of supply and demand of water around the world, during which the next world crisis would be a water crisis. Besides GEO-2000, other environmental organizations also include World Health Organization expressed concern on freshwater depletion where freshwater is scarce in many parts
of the globe. The pollutants that constitute the laundry wastewater are mainly detergent compounds coming from laundry activities. The effects of discharged wastewater can be both physical and chemical [1]. Physically, it affects aquatic life by increasing total suspended solids and turbidity. On the other hand, chemically, the complex toxic compounds presence can alter the composition of the laundry wastewater by increasing levels of chemical oxygen demand and also, pH levels, subsequently, changing the characteristics of natural water [2]. A study has been done by Imhof and Muhleman, (2005) on the percentage of greywater and blackwater by its sources based on household level in developing countries. The study shows that greywater is comprised of 69% source of wastewater from bath/laundry. Therefore, these parameters are targets to reduction by treating them before the discharge of the laundry wastewater using a natural biomass filter which in this study is treated sugarcane bagasse. There are limited studies focusing on treating laundry wastewater using biomass waste in adsorption method. Most of the studies focusing on enhancing conventional method which is the flocculation and coagulation method by using biobased agent. The aim of this study to reduce the contaminants that are present in the laundry wastewater such as COD, DO, pH and turbidity using chemically modified sugarcane bagasse.

2. Materials and methodology

The main equipments used in this study were the COD reactor (HACH DRB-200), pH meter (HI8424), colorimeter (HACH DR-900), Nicolet iS5 FT-IR Spectrometer, Oakton T-100 Handheld Turbidity Meter, DO meter (MILWAUKEE DO600) and Glass Column. Meanwhile, the materials involved were powder detergent, COD vials and treated sugarcane bagasse.

2.1. Preparation of synthetic laundry wastewater solution

Stock solution of 5 g/L was prepared by adding 5 g of laundry detergent powder into 1 L of distilled water. Two samples of solution were prepared by diluting the stock solution into a concentration of 50 mg/L and 250 mg/L.

2.2. Preparation of adsorbent

The adsorbent, sugarcane bagasse, was collected from Pasar Pagi Jalan Jujur Bandar Tun Razak, Cheras, Kuala Lumpur, Malaysia. The sugarcane bagasse was washed to remove the impurities and dried in the oven to remove moisture. After drying process, the sugarcane bagasse was ground into powder form then impregnated in 0.1 M HCl solution for 18 hours to improve the pore size. Treated sugarcane bagasse was then packed in a sealed container to be used for the column adsorption process.

2.3. Effect of pH

The pH effect was studied in a batch adsorption process by adjusting the sample solution into different pH values of 2, 4, 7, 9 and 11 using 0.1 M NaOH solution and 0.1 M HCl solution. All samples were run on magnetic hotplates at room temperature at 150 rpm for 1 hour.

2.4. Effect of bed height

The column bed heights studied on adsorption process were 2 cm, 4 cm and 10 cm. The flow rate was set at 4 ml/min and the initial concentration was kept constant for each bed height.

2.5. Effect of initial concentration

The initial concentration studies were carried out using 50 mg/L and 250 mg/l by keeping the bed height constant for each concentration. The fixed-bed column was filled with the desired amount of sugarcane and flow rate was set to 4 ml/min.

2.6. Column Adsorption set up

A glass column with a diameter of 2 cm and a height of 25 cm was used for the continuous adsorption process. The treated sugarcane bagasse was packed into the column to the desired bed height. Fig 1. shows the set up of the column used in the studies.
2.7. Column adsorption model

The breakthrough curve was analyzed with the mathematical models of Yoon-Nelson and Thomas.

2.7.1. Thomas Model. Thomas model assumes the second order reversible reaction kinetics, constant flow rate, no axial dispersion and isotherm of Langmuir. Langmuir isotherm fits on adsorption processes whereby external and internal limitations of diffusion was absent [4]. The expression is given by:

$$\frac{C_t}{C_0} = \frac{1}{1+\exp\left[\frac{K_{th}q_mx}{Q}-K_{th}C_0t\right]}$$  \hspace{1cm} (1)



$K_{th}$ is the Thomas rate constant (L/mg.min), $x$ is the amount of adsorbent (g) in the column, $q_m$ is maximum capacity of adsorption (mg/g), $Q$ is volumetric flow rate (L/min), $C_t$ (mg/L) is the effluent’s outlet concentration at a given time, $C_0$ (mg/L) is inlet concentration. $Q_m$ and $K_{th}$ are derived through a linear equation ($y = mx + c$) by the graph of $\ln\left[(C_o/C_t)−1\right]$ vs time $[5]$:  

$$m = K_{th}C_0$$  \hspace{1cm} (2)

$$c = \frac{K_{th}q_mx}{Q}$$  \hspace{1cm} (3)

2.7.2. Yoon-Nelson Model. The Yoon-Nelson model assumes the rate of decrease in probability of adsorption for each absorbate molecule is directly proportional to the probability of absorbate adsorption and absorbate breakthrough on the adsorbent. This model is calculated by:

$$\frac{C_t}{C_0} = \frac{\exp\left[K_{yn}(\tau - t)\right]}{1 + \exp\left[K_{yn}(\tau - t)\right]}$$  \hspace{1cm} (4)

$K_{yn}$ is the Yoon-Nelson rate constant (min$^{-1}$), $C_o$ is inlet concentration of solute (mg/L), $C_t$ is the solute concentration in effluent (mg/L) at time $t$, $t$ is sampling time (min) and $\tau$ (min) is the time when $C_t/C_0 = 0.5$. A plot of $\ln[C_t/C_o-C_t]$ vs time gives straight line curve in which the $K_{yn}$ can be determined by taking the graph’s slope and $\tau$ from the intercept of $-\tau.K_{yn}$ [6]. Once the rate constant and $\tau$ were obtained, the adsorption capacity can be calculated using:
In which, $q_o$ referring to adsorption capacity, $Q$ is the flowrate and $X$ is weight of adsorbent.

3. Results and Discussions

3.1 Effect of pH

The pH value for the raw sample was 11.68 while the turbidity was 1.45 NTU. Fig 2 shows the pH effect on removal of turbidity, the removal trend is decreasing as the pH value increased. According to WHO drinking water standard, the turbidity should be below 1 NTU, therefore, from the results obtained, pH 5-6 is the suitable condition to obtained the desired water quality.

![Figure 2. Effect of pH on turbidity removal](image)

3.2 Effect of initial concentration and bed height on turbidity removal

For the effect of initial concentrations, 50 mg/L and 250 mg/L were used at a fixed bed height of 2 cm. Meanwhile, the effect of bed height was studied at 2 cm, 4 cm and 10 cm. Bed height and adsorbent dosage are two important factors to be considered in the column adsorption studies as they highly affect the adsorption efficiency. Table 1 shows the results of the breakthrough and exhaustion time of the adsorbent for a concentration of 50 mg/L and 250 mg/L at different bed height.

At 250 mg/l, the curve was steeper compared to 50 mg/L for all bed heights. This phenomenon explains that there is a high amount of pollutants in the sample with a concentration of 250 mg/L. At bed height of 2 cm, the breakthrough time for 250 mg/l happened after 11 min and exhaustion was reached at a time of 50 min. On the other hand, when the concentration was 50 mg/L, the sugarcane was able to adsorb the pollutants for a longer time then exhausted at 60 min. Meanwhile, at bed height of 4 cm, the breakthrough time increased to 20 min for 250 mg/l and 40 min for 50 mg/l. At higher bed height such as 10 cm, breakthrough time increased to 53 min for 250 mg/l and 86 min for 50 mg/l. This result concludes that breakthrough time and exhaustion time increased with increasing bed height but decreased with increasing initial concentration.

The more the adsorbent dosage, the more active sites present to adsorb the solute. Additionally, increment in the adsorbent dosage also allows the adsorbate to be contacted longer than the lower dosage and the mass transfer zone to have longer distance before the adsorbate reaches the outlet. Thus, the binding sites will be more for the adsorption which will result in less concentration of solute in the effluent. When the binding sites are completely occupied by contaminants which is known as the exhaustion point, the equilibrium is reached. The trend is in agreement with most of the fixed bed column study such as studies done by Abu Bakar et al., (2019), Ataei-Germi et al., (2016) and Tsai et al., (2016).

| Initial concentration (mg/L) | Breakthrough time (min) | Exhaustion time (min) |
|-----------------------------|-------------------------|-----------------------|
|                             | 2 cm | 4 cm | 10 cm | 2 cm | 4 cm | 10 cm |
| 50                          | 23   | 40   | 86    | 60   | 100  | 93    |
| 250                         | 11   | 20   | 53    | 50   | 89   | 126.45 |
Table 2 below summarized the result of the adsorption process of synthetic laundry wastewater before and after treated with modified sugarcane bagasse. It can be seen that the trend of the treated wastewater improved by adsorption treatment.

| Parameter | Before treatment | After treatment |
|-----------|-----------------|-----------------|
| COD       | 298             | 238             |
| pH        | 9               | 7.25            |
| DO        | 3.5             | 5.2             |
| Turbidity | 1.29            | 1.01            |

3.3 Column Adsorption Model
3.3.1. Thomas Model. Figure of ln(Co/Ct)-1 versus the time was plotted and the results were presented in Table 3. Table 3 shows that the Thomas constant was decreasing as the initial concentration increasing, but the opposite happened for the Qo which the maximum solid-phase concentration. The reason behind this phenomenon is that the concentration difference is the driving force between the wastewater sample solution and the wastewater on the adsorbent. Thus, high driving force due to higher concentration in the wastewater contributes to better [10,11]

As for the Thomas studies on the effect of bed height, it shows that as the bed height increases, the, Kth decreases, however the Qo increases. Therefore, it can be said that as the concentration of the solution and bed height increases, the adsorption process is favoured on the treated sugarcane bagasse.

Table 3: Thomas model results at different concentrations and bed heights

| Thomas Parameters | Initial concentration (mg/l) at 10 cm | Bed height (cm) at 250 mg/l |
|-------------------|---------------------------------------|-----------------------------|
| Kth (ml/mg.min)   | 0.0463                                | 0.047                       |
| Qo (mg/g)         | 3.8527                                | 2.558                       |
| R²                | 0.9411                                | 0.8959                      |

3.3.2. Yoon-Nelson Model. The Yoon-Nelson kinetic models were plotted based on the effect of initial concentration and different bed heights and the results were tabulated in Table 4. It is noticed that the trend is the same for both constants at increasing initial concentration and bed height which KYN increases and τ (min) decrease. This phenomenon explains that there is a competition between the molecules of adsorbate in the adsorption sites, which then affect the uptake rate to be increased for the increment of initial concentration [12,13] Furthermore, from the results obtained, it is said that Yoon-Nelson model agreed with the values due to the high rise in the linear regression coefficient R²[7].

Table 4: Yoon Nelson model constants

| Yoon-Nelson parameters | Initial concentration (mg/l) at 10 cm | Bed height (cm) at 250 mg/l |
|------------------------|---------------------------------------|-----------------------------|
| KYN (L min⁻¹)          | 0.0871                                | 0.0886                      |
| τ (min)                | 69.448                                | 48.407                      |
| R²                     | 0.8713                                | 0.9333                      |
4. Conclusion
The adsorption process has shown that the modified sugarcane bagasse is an efficient adsorbent to be used for removal of synthetic laundry wastewater in terms of turbidity, pH, DO and COD. The obtained results showed that the best removal happened at a bed height of 10 cm and 50 mg/L due to the low concentration and also the amount of treated sugarcane bagasse which was 5 g. As for Thomas kinetic model, it showed that when bed height increases, the $K_{Th}$ decreases, however the $Q_o$ increases. Therefore, it can be said that when the concentration of the solution and bed height increase, the adsorption process is favoured on the treated sugarcane bagasse. Moreover, Yoon-Nelson studies showed that when bed height increases, the $K_{YN}$ increases while $\tau$ (min) decreases. Therefore, the high value of linear regression coefficient has also proved this kinetic model can be utilised in this experiment.

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