COD Treatment of Printing Ink Wastewater by Column Adsorption using Activated Carbon

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Abstract

Direct discharge of untreated industrial effluents containing high COD is hazardous to the environment. This study explore the efficiency of commercial activated carbon to uptake of the organic components responsible for the chemical oxygen demand of ink wastewater by column adsorption. The main objective of this research is to reduce the COD of ink wastewater to below its predetermined standard adopted from WHO and Environmental Quality Regulation 2009. For this purpose, the wastewater was investigated by analyzing its characteristic including pH, TSS, TDS, BOD, colour, turbidity and COD. Meanwhile, activated carbon used is PKSAC (Palm Kernel Shell Activated Carbon). COD adsorption studies with this activated carbon were carried out under different conditions and influence by different parameters such as pH and bed height in column adsorption. The performance study showed the condition in which pH does not show significant effect on the COD removal and the highest percentage of COD removal were found at bed height 3 cm with the percentage removal of 55%. This indicate, % of COD removal increase with increasing in bed height. Furthermore, the minimum bed height required to treat the water sample was recorded to be 0.8 cm analyzed by BDST model. The present study prove that the activated carbon was one of the effective way in removal of COD.

1. Introduction

The UN environmental report GEO 2000 proclaims that “the world water cycle seems unlikely to be able to coop with the demands that will be made of it in coming decades”, which will lead to global water crisis in the future[1]. One of the main reason is due to the discharge of untreated wastewater into water bodies that change the physical and chemical characteristic. In Malaysia, municipal and industrial sectors contribute to 2.97 billion cubic meters of wastewater per year [2] and 22% of the total volume of industrial wastewater in Malaysia is originated from textile industry [3]. Textile effluents mostly identified by its severe variation of COD, BOD, pH, colour, salinity and temperature due to its organic, inorganic compound and biological content originated from the dyes, resin, solvent and pigment used during the manufacturing process [4]. When this type of contaminant reaches the receiving water bodies, the impact will result in fluctuation of pH, temperature, colour changes, reduction of dissolved oxygen, formation of toxic substances and increment in nutrient loads [5]. As a result, survival of fish is threatened as the low dissolved oxygen level reduce their resistance to diseases, retardation in growth, swimming ability disorder, alternation in migration and dead. Same goes to agriculture, polluted groundwater contaminate crops, reduce the soil fertility and transmit diseases to the consumer [5]. Therefore, it is necessary to remove contaminants from liquid wastes to below its allowable standard set by WHO and Environmental Quality Act 1974 before the wastes are discharged to the environment. Adsorption technique using activated carbon is found to be the best technique in dyes treatment because it can remove complete molecules including COD, high efficiency, flexible and easy to operate [1] and no harmful substances produced during and after the treatment [6].

In this work, the PKSAC (Palm Kernel Shell Activated Carbon) has been tested for reduction of COD by column adsorption. pH and bed height influence in this adsorption study were identified by the application of Thomas model, Yoon-Nelson model and Bed Depth Service Time (BDST) model.
2. Methodology and material

The main equipment used in this study were the COD reactor (HACH DRB-200), pH meter (EUTECH PH-700), colorimeter (HACH DR-900), Scanning Electron Microscopy with Electron Dispersive X-ray Analysis SEM/EDX, UV/VIS spectrophotometer (HITACHI U-2900), Nicolet iS5 FT-IR Spectrometer, Oakton T-100 Handheld Turbidity Meter and Glass Column. Where the main material involved were ink wastewater, methyl red, methyl orange, COD vial and PKSAC.

2.1. Wastewater and Activated Carbon Characteristic Analysis

Wastewater sample was taken from a company which provide the printing effluent of a cardboard printing and coating located in Johor. The wastewater sample was collected at the sampling point after clarifier process. The commercial granular PKSAC with ranging from 1 mm to 2 mm were washed by distilled water for few times to remove the ash content and dirt and dried for 24 hours in the oven at 90°C before usage [7], [8]. The pore characteristic of PKSAC were analyzed under SEM (Scanning Electron Microscope), while the surface chemistry was determined by FTIR (Fourier Transform Infrared Spectroscopy). The initial ink wastewater and the treated wastewater were measured based on its water characteristic such as COD, BOD, DO, TSS, TDS, pH, concentration, turbidity and colour. The purpose is to identify the adsorption efficiency and compare the quality of the wastewater before and after adsorption. Since the wastewater obtained from GSUS was unknown concentration, calibration curve was used in this study to estimate the dyes concentration presented in the wastewater sample. In order to plot the calibration curve, 100 mg/L of methyl red and methyl orange dye were prepared to be the known concentration dyes due to their colour similarities were almost identical to the water sample when it was diluted. Then, the analysis begins by varying the concentration of standard solution to 2, 4, 6, 8, 10 mg/L and the absorbance was determine under UV-Visible spectrophotometry (HITACHI U-2900) with the wavelength 410nm for Methyl Red and 460 nm for Methyl Orange [9], [10]. With the data obtained, the concentration versus absorbance curve was plotted and the initial concentration was determined.

2.2. Effect of pH

Before begin the treatment process, the optimum pH was determined by batch adsorption. 0.1 gram of PKSAC were fed into each beaker containing 50 mL of ink wastewater solution at various pH 2,3,4,5,6,7,8,9,10,11, stirred for 2 hours at 150 rpm. The final concentration of each samples were measured and recorded based on the COD. The pH versus % removal efficiency graph was plotted to determine the optimum pH that contribute to the highest adsorption capacity. The optimum pH will be used for the whole experiment.

2.3. Column adsorption set up

In this research study, the adsorption was performed in the down flow column. The schematic diagram below which is the improvised design from Abu Bakar, et al., (2019) illustrates the process flow for the column adsorption.
Fig. 1. Down flow column adsorption set up

Certain amount of cotton was inserted into the column and pushed down until it reaches the end of the cone area to anticipate the clogging of granular activated carbon on the outlet of flow controller adapter that will block the flow of the treated wastewater. Then, the desired bed height was marked on the column’s outer surface measured from the top of the cotton. A known weight of commercial granular PKSAC were carefully filled into the column until it reaches the desired bed height. Next, the glass column was placed on the retort stand equipped with two clamps and a set of filter funnel connected with a central pipe was placed on top of the column. The tip of central pipe was adjusted 8 cm away from the activated carbon. The flow controller adapter was manually adjusted to a constant flow rate (10 mL/min). The adjustment was done by measuring the volume of the distilled water out from the column per minute until it gives the desired flowrate.

2.4. Column adsorption model

The shape of breakthrough curve from the plot of Ct/Co versus time illustrate the performance of column adsorption, where Ct and Co are the effluent and influent concentration in mg/L, respectively. The breakthrough curve itself was constructed with different mathematical models.

2.4.1. Thomas Model. Thomas models is the most commonly used model to predict the breakthrough curve. The expression is given by:

\[
\frac{C_t}{C_o} = \frac{1}{1 + \exp \left( \frac{K_{th}Qm.x}{Q} - \frac{K_{th}Co.t}{Q} \right)}
\]

\(K_{th}\) is the Thomas rate constant (L/mg.min), \(x\) is the amount of adsorbent (g) in the column, \(Qm\) is the maximum adsorption capacity (mg/g), \(Q\) is the volumetric flow rate (L/min), \(C_t\) (mg/L) is the outlet dye concentration at time \(t\) given, \(C_o\) (mg/L) is the inlet dye concentration. \(Qm\) and \(K_{th}\) are derived through a linear equation \((y=mx+c)\) from the plot of \(\ln \left( \frac{C_o}{C_t} \right)\) vs time [12]:

\[m = K_{th}C_o\]  
\[c = \frac{K_{th}Qm.x}{Q}\]  

2.4.2. Yoon-Nelson Model. This model is less complicated compared to the other models where certain information like adsorbate’s property, adsorbent type and adsorption bed’s physical property are not taking under consideration. This model is calculated by:

\[
\frac{C_t}{C_o} = \frac{\exp \left( K_{yn}(t-t') \right)}{1 + \exp \left( K_{yn}(t-t') \right)}
\]

\(K_{yn}\) 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 \(t'\) (min) is the time when \(C_t/C_o = 0.5\). A plot \(\ln \left( C_t/C_o - C_t \right)\) vs time gives straight line curve in which the \(K_{yn}\) can be determined by taking the graph’s slope and \(t'\) from the intercept of \(-t'.K_{yn}\) [13]. Once the rate constant and \(t'\) found, the adsorption capacity can be calculated using:

\[Qo = \frac{C_o.Q.t}{x}\]
In which, $Q_o$ referring to adsorption capacity, $Q$ is the flowrate and $X$ is weight of adsorbent [13].

### 2.4.3. BDST Model

The BDST is suggested by Bohart-Adam used to predict the retention time of adsorbent material works to remove the pollutant from solution before replacement is required [14]. Based on BDST theory, surface reaction between adsorbate and the unused capacity of adsorbent control the rate of adsorption [15]. BDST is represented by the linear plot of $Z$ (Bed height) versus $T_b$ (Breakthrough time). The slope and intercept obtained from the linear plot were used to evaluate the adsorption capacity and rate constant.

\[
m = \frac{N_o}{C_o F}
\]  

\[
c = \frac{1}{K_{ab} C_o} \ln \left( \frac{C_o}{C_b} - 1 \right)
\]  

The minimum column height required to achieve an effluent concentration ($C_b$) was calculated using the adsorption capacity and rate constant value, utilizing equation:

\[
X_o = \frac{F}{K_{ab} N_o} \ln \left( \frac{C_t}{C_b} - 1 \right)
\]  

Where, $N_o$ is the adsorption capacity (mg/l), $K_{ab}$ as the rate constant of adsorption (L/mg min), $F$ (cm/min) is the linear velocity determined by dividing the flow rate (mL/min) by the column sectional area (cm$^2$) and $C_b$ represent the breakthrough concentration (mg/L) [16].

### 3. Result and Discussion

#### 3.1. Wastewater characteristic

The wastewater profile (pH, COD, dye content, turbidity, colour concentration, total suspended solid and total dissolved solid) are tabulated in Table I and compared to the standard discharge of industrial wastewater set by WHO and Environmental Quality Act Regulation 2009.

| Components       | Standard of discharge | Original Sample | After adsorption (5cm) | 1st sample |
|------------------|-----------------------|-----------------|------------------------|------------|
| pH               | 5.5 - 9.0             | 6.64            | 7.57                   |
| TSS (mg/L)       | 100                   | 441             | 0.3                    |
| TDS (mg/L)       | 2000                  | 2200            | 0.16                   |
| Turbidity (NTU)  | 5                     | 33.1            | 4.84                   |
| COD (mg/L)       | 250                   | 579             | 202                    |
| DO (mg/L)        | 4.5-8                 | 2.1             | 5.7                    |
| Concentration (mg/L) | 5                     | 3.3962          | 1.54                   |
| PKSAC weight (gram) | Before                | 5.3             |                         |
|                  | After                 |                 | 5.7                    |

The result above shows that the total suspended solid of the ink wastewater collected was above the standard level. The total number of suspended solids contained in the wastewater mostly comes from the black particles seen in the water sample. Similarly to total suspended solid, the total dissolved solid obtained also found to be above the standard level. It defines that the ink wastewater sample consist
a lot of organic and inorganic compound that originated from the dyes, pigment, solvent or resin used during the ink manufacturing process. Hence, the COD reading was also found much higher than the standard discharge, thus, this water sample can be used for further treatment analysis focusing on the COD reduction. The TSS and TDS contained in the wastewater has directly proportional relationship with the turbidity level. In other words, high TSS and TDS leads to high turbidity, 33.1 NTU in this case. The concentration of the water sample was 3.3962 mg/L, utilizing methyl red as the standard solution for the calibration curve.

In addition, the ink wastewater was consisting of methyl red. This statement is supported by the comparison of functional group content between methyl red, methyl orange and water sample by utilizing Nicolet iS5 FT-IR Spectrometer. It shows that the functional group of methyl red, water sample and methyl orange generated from the KnowItAll Academic Edition software. The suggested peak of the original ink wastewater was 3323.7 cm⁻¹ which is closer to methyl red with peak equals to 3351.19 cm⁻¹ rather than the peak of methyl orange 1598.70 cm⁻¹. The functional group of methyl red and original wastewater sample are almost the same. Furthermore, based on the appearance, the ink wastewater sample’s colour showed higher similarities to methyl red solution than methyl orange solution.

3.2. Adsorbent characteristic
In this case study, SEM/EDX (Scanning Electron Microscopy with Energy Dispersive X-Ray Spectroscopy) of model X was utilized to analyze the surface morphology of PKSAC and its composition. Fig. 2. and Fig. 3. show the PKSAC sample has cavity and orderly oval pores distribution on its surface. As the result of evaporation and breakdown of non-carbon compound in the feedstock, the pores structure of the adsorbent were formed [17]. The SEM images also shows that the PKSAC has a rough surface and irregular pores shape. Rough and porous surface offer better adsorption process [1].

Table 2: Result of PKSAC content and pore characteristic

| Quantitative analysis of PKSAC |          |
|-------------------------------|----------|
| Carbon, C                     | 96.24%   |
| Oxygen, O                     | 2.00 %   |
| Silicon, Si                   | 1.76 %   |

| Pore Characteristic of PKSAC   |          |
|--------------------------------|----------|
| BET Surface area               | 16.4027 m²/g |
| Average Pore Diameter          | 36.9 nm   |
| Porosity                       | 0.1513 cm³/g |

Based on the PKSAC’s composition generated from SEM/EDX, the PKSAC consist of carbon as the major component with small admixture of residual oxygen and silicon. The PKSAC used in this research study is produced under stream activation. This is due to the reason that if PKSAC is chemically activated, it should contain small amount of phosphoric acid, zinc or chlorine residue on the surface. However, from reading obtained, no phosphate, zinc or chlorine was found. In addition, from the analysis of the content of PKSAC showed in Table II, it was observed that the BET surface area are considered low comparing to PKSAC’s BET surface area produced in commercial scale which is 1000-
1600 m²/g [18]. In this study, the result obtained indicates that the pore diameter increases as the BET surface area decrease, supported by the research done by [19]. The pore characteristic of the PKSAC has an average diameter of 36.9 nm which is categorized under the group of mesopores [20]. This might be caused by the high steam activation temperature (>1000°C) that gives excessive supply of heat energy toward the carbon leading to the knocking and breaking of some porous wall and reducing the number of porous formations. As a result, this activation condition would yield to decreasing in BET surface area, micropore surface area, micropore volume, total pore volume but increasing in average pore size distribution [19].

3.3. Effect of pH
The effect of pH based on COD reading was plotted with the removal efficiency against pH value s, Fig. 5. Generally, pH affects the degree of ionization of the wastewater and surface properties of the PKSAC, thus affecting the adsorption capacity. However, surprisingly, the data obtained from this research study shows that the changes in pH has insignificant effect on COD removal. It was explained by the fluctuation over the pH range for both acidic and base condition. A reasonable explanation of this case may be due to the presence of both negative and positive functional groups in the ink wastewater sample that cause both repulsion and attraction between H+ and OH- at the same time between the PKSAC active side with the ions in ink wastewater sample [21].

![Fig. 5. Effect of pH in COD removal](image)

3.4. Effect of bed height
The effect of bed height in this study was performed by varying the bed height of the activated carbon in the column to become 1 cm, 2 cm and 3cm with constant concentration and flowrate. As expected, high uptake of contaminants was adsorbed at higher bed depth. The breakthrough curve shown in Fig.6 represent the behavior of the adsorption in the column adsorption. The graph indicates the breakthrough time was obtained quicker under low bed height condition. The time required to reach saturation also decreased significantly with a decrease in bed height. The result obtained was explained by the concept of the active side’s availability and contact time. More active sites were available to bind with the solute as a result of an increment in adsorbent dosage. Higher adsorbent dosage will also allow the solute in contact with the adsorbent quicker than the bed with less adsorbent, create longer distance for the mass transfer zone and give larger service area [22]. An equilibrium or constant will be reached after a certain period when the available sites are fully occupied by the pollutants which is known as exhaustion point.
The highest removal efficiency from the water sample was observed at bed height equals to 3 cm which was around 65 % removal, followed by 48 % and 35 % for 2 cm and 1 cm bed height respectively. The highest percentage of removal and the breakthrough curve pattern obtained were not the most desired result. This might be due to the present of solid particle in the ink wastewater. The solid particle competes with the dye molecules to bind with the active site of the activated carbon surface, thus reducing the amount of active side bind with the dye molecules. Moreover, this phenomenon might also be due to the formation of channeling during the adsorption process. During the first trial, height of the activated carbon in the bed after the adsorption was higher than before the adsorption. It indicates that there were a lot of empty spaces formed in between the activated carbon. This was due to the dispersion of activated carbon over the column when the wastewater entering the column from the top end. During the fall of water sample into the column, the gravitational potential energy is transformed into kinetic energy, hit the activated carbon and cause the activated carbon to disperse. When the activated carbon settled down, more empty spaces were formed in between the adsorbent. In accordance with the nature of water which will always look for a way out, wastewater will flow faster through the gap formed in between the PKSAC and spend less time in contact with the PKSAC inside the column, thus, resulting in low adsorption efficiency. Moreover, if the water sample is filled slowly into column, due to adhesion properties of water, the water will only flow through the glass wall in which most of the water will flow through the activated carbon located near the glass wall. As a result, activated carbon near the glass wall will exhausted quicker than those in the middle. Therefore, the concept of central is applied to provide better adsorption from before, which only reached 37.75% removal. The central pipe will reduce the flow velocity of the water sample into the column due to the friction with the pipe surface and few numbers of holes on the bottom of the pipe will ensure equal distribution of wastewater throughout the adsorption process. Theoretically, with only one holes on the tip, wastewater will only be concentrated in one area which is only on the center, resulting non homogenous adsorption. With perforated pipe, wastewater was able to be distributed equally proven by the lower and more stable COD reading obtained.

After the adsorption with different bed height was conducted, the treated wastewater’s characteristic was determined to analyze the improvement of water profile after adsorption. As shown in Table 1, all the water characteristic parameter was dropped from the original value and fulfill the standard of discharge, meaning that the adsorption technic with PKSAC was worked to treat the ink wastewater. The weight of activated carbon after adsorption was found to be higher than before.
adsorption which indicates that most of the solid particles, dirt and other dissolved particles were trapped in the column and PKSAC’s pores. Hence, the TSS and TDS value of the treated water sample reduced dramatically. When TDS and TDS reduced, turbidity also automatically reduced as high turbidity caused by the presence of chemical precipitates, silt, sand, mud, bacteria, algae and dissolved substance. Nevertheless the rapid reduction, the turbidity of treated water sample from 1cm and 2 cm bed height were found to be above the discharge standard. Therefore, it can be concluded that in this research study, minimum of 3 cm bed depth should be applied to treat the water sample.

3.5. Column adsorption model

3.5.1. Thomas Model. Breakthrough behavior was investigated by using the experimental data with Thomas model. Fig.8 and Table IV presented the parameter used to predict the column adsorption’s behavior at various bed height.

| Z (cm) | Kth (ml/mg.min) | Qo (mg/g) | R² |
|--------|-----------------|-----------|----|
| 1      | 0.0352          | 0.04072   | 0.7472 |
| 2      | 0.0312          | 0.06872   | 0.7256 |
| 3      | 0.0305          | 0.0734    | 0.7669 |

Thomas rate constant decreased from 0.0352 to 0.0312 ml/min.mg and the adsorption capacity increased from 0.04072 to 0.0734 mg/g. In other words, adsorption capacity (Qm) increases as the dosage of activated carbon rise, followed by the reduction in rate constant (Kth) supported by the result from [23], [24]. As the bed height rise, the number of active sites available also increases, resulting in wide mass transfer zone which leads to increment in adsorption capacity. The neglection of axial and radial dispersion in Thomas’s assumption contribute to high adsorption capacity. Whereby, the reduction of adsorption constant with increment of bed depth was indicate the weak affinity or interaction between
adsorbate and adsorbent at higher bed height which can be explained by neglecting of axial dispersion and diffusion from Thomas assumption [25]. The $R^2$ value generated has up to 38% of error which can conclude that this model does not fit to this research study. The possible explanation is because Thomas model predict the breakthrough curve by assuming the second order reversible reaction kinetics, constant flow rate, no axial dispersion and Langmuir isotherm[26]. However, based on adsorption phenomena, the movement of molecules in both axial and radial direction are present during liquid mass transfer [12],[27]. Moreover, Langmuir isotherm assumes no interaction between molecules, monolayer and all sites of the adsorbent are equal in size, shape and affinity. These statements were not reliable because even the same molecules types experience weak force interaction. Other than that, multilayer formation might be present and real solid surfaces are heterogeneous not homogenous [28].

3.5.2. Yoon-Nelson Model. Table V provides the value of $Kyn$ (rate constant), and adsorption capacity obtained in this research study.

It was observed that the rate constant $Kyn$ decreased, where the time required for 50 % breakthrough and adsorption capacity increased with increasing bed height. The value of $\tau$ rises from 3 to 11 min with increment in bed depth supported by the research done by [29], [30]. This phenomenon can be explained by the availability of surface contact area [31] which attributed to long contact period between adsorbate and adsorbent.

![Breakthrough curve at different bed height with Yoon-Nelson Model](image)

Fig.9. Breakthrough curve at different bed height with Yoon-Nelson Model

| $Z$ (cm) | $Kyn$ (1/min) | $\tau$ (min) | $R^2$ | $Qo$ (mg/g) |
|---------|--------------|--------------|-------|-------------|
| 1       | 0.1196       | 3.003        | 0.7468| 0.1020      |
| 2       | 0.1061       | 7.689        | 0.7251| 0.1306      |
| 3       | 0.1037       | 11.023       | 0.7695| 0.1248      |

Similarly to Thomas model, the $R^2$ obtained in this study also shows low accuracy. Yoon-Nelson model does not take the physical properties of adsorption bed and adsorbate’s characteristic into consideration. Also, rate of decrease in the probability of adsorption for each adsorbate molecule is proportional to the probability of adsorbate adsorption and the adsorbate breakthrough on the adsorbent [21]. Yet, the adsorbate’s pH determines the degree of ionization of the adsorbate in the solution which will affect the affinity between the adsorbent and adsorbate [32]. Furthermore, the initial concentration, solubility and size of the adsorbate also plays an important role. The water-soluble adsorbate is more difficult to be removed from the water bodies and only fixed amount in term of concentration and certain size of molecule species can be adsorbed by a given amount of adsorbent. Small size molecule are more easily adsorb or attach on the adsorbent’s pores [33].
3.5.3. **BDST Model.** Bed Depth Service Time Model is a modified form of Adam Bohart Model which show the relationship between the service time of the column and the bed height. Fig.10. shows the plot of service time against bed depth at flow rate of 10 ml/min and influent concentration 3.3962 mg/L. The rate constant, K_ads and the adsorption capacity were predicted to be 255.7258 L/mg.h and 0.076 mg/L respectively. The minimum bed depth required to treat the wastewater was 0.8 cm compared with the experimental result which is minimum 3 cm. The model is not complex enough to represent the adsorption behavior as the model is based on certain assumption [12]. The service time increased with increasing bed depth, indicating that greater bed height would have longer lifespan, thus requiring longer interval for activated carbon replacement.

Table 6: Parameters of BDST model at different bed height

| Kab (L/mg.h) | No (mg/L) | R² |
|-------------|-----------|----|
| 255.7258    | 0.076     | 0.9199 |

4. **Conclusion**

The experimental investigation of COD reduction by column adsorption were carried out on the ink wastewater sample. The ink wastewater was pinkish and visually contains a lot of black particle. The wastewater characteristic such as total suspended solid, total dissolved solid, turbidity, concentration and the COD were found above the discharge standard set by WHO and Environmental Quality (Industrial Effluent) Regulation 2009. Therefore, the column adsorption with PKSAC (Palm Kernel Shell Activated Carbon) was implemented in this research study to treat the wastewater. The water pH was not undergone adjustment as it was found that the COD removal was not affected by pH. The effect of bed height in this study shows that highest removal was achieved at higher bed height due the availability of active site on the PKSAC. The breakthrough time and exhaustion time increase with increasing in bed depth. The wastewater characteristic was also drastically dropped to below the discharge standard at 3 cm bed height after treatment. It was proved that the Column adsorption with PKSAC can be effectively employed for the COD reduction. In Thomas model, in line with the increment in bed height, the adsorption capacity will also increase, followed by a decrease in rate constant. For Yoon-nelson model, the time required for 50% exhaustion of column and adsorption capacity increase with increasing in bed height, where rate constant reduce. BDST model emphasize on the minimum bed height required to treat water sample which is found to be 0.8 cm in this case study. Each model derived from different assumptions where it is only suitable for certain condition but fail to describe others.

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