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Batch Adsorber Design for Different Solution Volume/Adsorbate Mass Ratios of Bentazon, Carbofuran and 2,4-D Adsorption on to Date Seeds Activated Carbon

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Abstract

The Adsorption isotherms and equilibrium of bentazon, carbofuran and 2,4-Dichlorophenoxyacetic acid (2,4-D) onto date seeds activated carbon (DSAC) were examined in batch process. Adsorption studies were conducted in the pesticides initial concentrations range of 25–250 mg/L and temperature of 30 °C. The experimental equilibrium data were analyzed by non-linear fitting using Langmuir, Freundlich and Temkin isotherm models. Equilibrium data fitted better with the Langmuir model showing maximum monolayer adsorption capacity of 78.13, 135.14 and 175.4 mg/g, for bentazon, carbofuran and 2,4-D respectively onto DSAC. A single stage batch absorber was designed for different operating line (V/M) ratios. Equilibrium data were obtained from the Langmuir isotherm at different V/M ratios using the mass balance equation for the batch absorber system. A simple linear expression relating the parameters involved in the batch absorber design was proposed for the studied system.

Keywords: Bentazon; Carbofuran; 2,4-D; Adsorption; Isotherm models; Batch absorber design

Introduction

Pesticides are indispensable in modern agriculture, but their use and/or misuse may lead to serious deterioration in water quality which could impair the use of water for purposes of crop protection, animal production or even human consumption [1,2].

Bentazon is a newly emerging herbicide used for selective control of broadleaf weeds and sedges in beans, rice, corn, peanuts, and mint. It is one of the most commonly used herbicides in agriculture and gardening. However, through leaching or run-off from agricultural lands, deposition from aerial applications and indiscriminate discharge of industrial wastewaters, bentazon has become a reckoned source of contaminant to water resources with its attendant threats to the ecosystem and environment in general; the maximum allowable concentration is 0.05 mg/L in tap water [3-7].

Carbofuran is a broad spectrum systemic acaricides, insecticide and nematocide included in the general group of the carbamate derivative pesticides. It is widely used for the control of soil dwelling and foliar feeding insects including wireworms, white grubs, weevils, stem borers, aphids and several other insects. *The maximum acceptable concentration (MAC) for carbofuran in drinking water is 0.09 mg/L* [7-12].

2,4-Dichlorophenoxyacetic acid (2,4-D) is one of the oldest herbicides used in the world, 2,4-D is a selective herbicide that kills dicots (but not grasses) by mimicking the growth hormone auxin, which causes uncontrolled growth and eventually death in susceptible plants. It is considered as moderately toxic and maximum allowable concentration is 0.1 mg/l in drinking water [13-20].

Adsorption techniques have gained popularity recently due to their efficiency in the removal of pollutants; in addition adsorption produces high quality products and is an economically feasible process [21,22]. Adsorption is considered to be superior compared to other techniques due to its low cost, availability, simplicity of design, high efficiency, ease of operation biodegradability and ability to treat pollutants in more concentrated form [12]. Besides, adsorption does not result in the formation of harmful substances [15]. Adsorption onto activated carbon is one of the most promising techniques for pesticide removal

due to flexibility in design and operation [18]. Pits of date palm (seeds) are waste products which were used as precursors for preparation mesoporous activated carbon [20-23].

The effect of volume of solution to the adsorbent mass ratio (V/M) on the equilibrium uptake of pesticide solution at different initial concentrations is an important factor to be considered in adsorber design. However, this requires an extensive experimental work to determine the isotherm parameters for different V/M ratios and also at different initial pesticide concentrations. In this study a single stage batch adsorber was designed for different V/M ratio of bentazon solutions on date seeds activated carbon using the experimental equilibrium data obtained at a single V/M ratio.

In this study a single stage batch absorber was achieved. The design objective is to reduce the pesticide solution of volume V (L) from the initial concentration of Co to C1 (mg/L). The amount of adsorbent is M (g) and the solute loading changes from qo to q1 (mg/g). At the time t = 0, qo = 0 and as time proceeds the mass balance equates the pesticides removed from the liquid to that picked up by the solid [1,23].

Materials and Methods

Pesticides

Bentazon, carbofuran and 2,4-D were obtained from Sigma-Aldrich (M) Sdn. Bhd., Malaysia and were used as adsorbate. It was of analytical grade and was used without further purification. Distilled water was used in the preparation of all solutions. Some properties and chemical structures of the bentazon herbicide are given in Table 1.

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| Pesticide | Formula | Chemical structure | Molecule weight (g/mol) | Solubility in water (g/L) |
|------------|---|--|-------------------------|---------------------------|
| Bentazon | C ₁₀ H ₁₂ N ₂ O ₃ S | | 240.3 | 0.50 |
| Carbofuran | C ₁₂ H ₁₅ NO ₃ | O C NHCH ₃ O C C H ₃ | 221.3 | 0.70 |
| 2,4-D | C ₈ H ₆ Cl ₂ O ₃ | CI CI CI | 221.0 | 0.90 |

| Table 1: Some of | properties of | pesticides use | ed and their | chemical structures. |
|------------------|---------------|----------------|--------------|-----------------------|
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| R_{L} value | Nature of adsorption process |
|--------------------|------------------------------|
| $R_{L}=0$ | Irreversible |
| R, = 1 | Linear |
| R _L >1 | Unfavorable |
| 0 < <i>R</i> , < 1 | Favorable |

Table 2: Separation factors.

Preparation and characterization of activated carbon

Date fruits seeds (DS) used for preparation of activated carbon. The procedure used to prepare the activated carbon was referred to our previous work [4]. The raw material, DS was collected, firstly washed with distilled water to remove all dirt and then oven dried overnight at 105°C. The dried pits were then crushed to desired mesh size (1-4 mm). The process of converting DS to AC comprises of two stages: carbonization and activation. Both carbonization and activation were carried out in a stainless steel vertical tubular reactor placed in a tube furnace. The dried DS were placed on a stainless steel sampling cylinder inside the reactor, then heated at a rate of 10°C /min to 700°C and held at this temperature for 2 h in a N₂ atmosphere. The carbonized material was then soaked in 6M potassium hydroxide (KOH) solution with impregnation ratio (KOH: char) of 3.75 (w/w). The mixture was then dehydrated in an oven overnight at 105°C to remove moisture and then activated under the same conditions as carbonization, but to activation temperature of 850°C. Once the final temperature was reached, the nitrogen gas flow was switched to carbon dioxide (CO₂) and activation was held for 3 h and 37 min. The CO₂ was used as the gasifying agent for the improvement of the porosity of the AC produced. The resulting AC was washed with 0.1 M HCl to dissolve and remove any residual ash followed by washing with hot distilled water to regulate the pH around 7 and finally drying overnight at 70°C.

Batch adsorption equilibrium studies

The adsorption experiments of pesticides onto DSAC were carried out in a set of 250 mL Erlenmeyer flasks 200 mL of the pesticides solutions of various initial concentrations in the range 25–250 mg/L. Equal mass of 0.20 g of the prepared activated carbon with particle size of (200 –300 μ m) was added to each flask and kept in an isothermal

shaker of 120 rpm at 30°C for 30 h to reach equilibrium. The pH of the solutions was original without any pH adjustment.

Aqueous samples were taken from each of the pesticides solutions at preset time intervals using disposable syringes and the concentrations were then analyzed. All samples were filtered prior to analysis in order to minimize interference of the carbon fines with the analysis. The concentrations of pesticides in the supernatant solution before and after adsorption were determined using a double beam UV-visible spectrophotometer (UV-1700 Shimadzu, Japan) at 333, 273 and 283 nm for bentazon, carbofuran and 2,4-D, respectively.

The amount of adsorption at equilibrium, qe (mg/g), was:

$$q_e = \frac{(C_o - C_e)V}{W} \tag{1}$$

where C_o and Ce (mg/L) are the liquid phase concentrations of pesticide at the initial and equilibrium conditions, respectively. V (L) is the volume of the solution and W (g) is the mass of DSAC.

Langmuir isotherm

Langmuir isotherm assumes monolayer adsorption onto a surface containing a finite number of adsorption sites of uniform strategies of adsorption with no transmigration of adsorbate in the plane of surface [24]. The linear form of Langmuir isotherm equation is given as:

$$C_e/q_e = C_e/q_m + 1/K_a q_m \tag{2}$$

where C_e is the equilibrium concentration (mg/L); q_e the amount pesticides adsorbed at equilibrium (mg/g); q_m the adsorption for complete monolayer (mg/g); K_a is the sorption equilibrium constant (L/mg).

The essential characteristic of the Langmuir isotherm is defined by Weber and Chakkravorti as:

$$R_L = \frac{1}{1 + bC_o} \tag{3}$$

wher *b* (L/mg) is the Langmuir constant and C_o (mg/L) is the adsorbate initial concentration. The parameter R_L indicates the nature of the adsorption process as explained in Table 2.



Freundlich isotherm

Freundlich isotherm in the other hand assumes heterogeneous surface energies, in which the energy term in Langmuir equation varies as a function of the surface coverage [24,25]. The well-known logarithmic form of the Freundlich isotherm is given by the following equation:

$$\ln q_{e} = \ln K_{F} + (1/n) \ln C_{e}$$
(4)

where C_e is the equilibrium concentration of the adsorbate (mg/L), q_e is the amount of adsorbate adsorbed per unit mass of adsorbent (mg/g), K_F and n are Freundlich constants with n giving an indication of how favorable the adsorption process. K_F (mg/g (l/mg)1/n) is the adsorption capacity of the adsorbent which can be defined as the adsorption or distribution coefficient and represents the quantity of herbicide adsorbed onto activated carbon for a unit equilibrium concentration. The slope of 1/n ranging between 0 and 1 is a measure of adsorption intensity or surface heterogeneity, becoming more heterogeneous as its value gets closer to zero. A value for 1/n below one indicates a normal Langmuir isotherm while 1/n above one is indicative of cooperative adsorption.

Temkin isotherm

Temkin and Pyzhev [26] considered the effects of indirect adsorbate/ adsorbate interactions on adsorption isotherms. The heat of adsorption of all the molecules in the layer would decrease linearly with coverage due to adsorbate/adsorbate interactions. The Temkin isotherm has been used in the form as follows:

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$$q_e = B \ln A + B \ln C_e \tag{5}$$

where B = RT/b, b is the Temkin constant related to heat of sorption (J/mol); A is the Temkin isotherm constant (L/g), R the gas constant (8.314 J/mol K) and T the absolute temperature (K).

Results and Discussion

Effect of contact time and initial concentration on adsorption equilibrium

The adsorption uptake at equilibrium was found to increase with an increase in the initial pesticides concentration. This was because when the initial concentration increased; the mass transfer driving force would become larger consequently resulting in higher pesticide adsorption.

Figure 1a show that the contact times needed for bentazon solutions with initial concentrations of 25-50 mg/L to reach equilibrium onto DSAC was around 5 h, and for the concentrations of 100-200 mg/L 25-27 h was required, while for bentazon solutions of higher initial concentration 250 mg/L equilibrium time of 34-36 h was required.

For the case of adsorption of carbofuran on to DSAC, the adsorption capacity at various carbofuran initial concentration of 25- 250 mg/L, the amount of carbofuran adsorbed, qt increased in a similar pattern to bentazon pesticide adsorption onto DSAC surface. The adsorption uptake at equilibrium was found to increase with an increase in the initial insecticide concentration as appear in Figure 1- b, which shows that longer contact times were required to reach equilibrium by the carbofuran solutions of higher initial concentrations. The contact time needed for carbofuran solutions with initial concentration of 25-100 mg/L to reach equilibrium on DSAC was around 4-5h, and for higher initial concentrations (150-250 mg/L) an equilibrium time of 14-16 h was required.

For the case of adsorption 2,4-D pesticide onto DSAC, the adsorption uptake at various 2,4-D initial concentration of (25-250 mg/L) at 30°C were as shown in Figure 1-c. It is clear from this Figure that the amount of 2,4-D adsorbed, qt increased with time. The equilibrium adsorption was achieved in 5-7 h for 2,4-D solution with initial concertinos of 50-200 mg/L and 11-14 h for 250-300 mg/L to reach equilibrium.

Adsorption isotherms

Adsorption isotherms are mathematical models that describe the distribution of the pesticides species between the liquid phase and the solid phase when the adsorption process reaches equilibrium state. The experimental data obtained in this study were fitted to the three most commonly used isotherm models: Langmuir, Freundlich and Temkin models. The adsorption isotherm parameters values obtained for adsorption of bentazon, carbofuran and 2,4-D onto DSAC at 30 °C are listed in Table 3.

Based on the correlation coefficient, R^2 listed in Table 3 it can be concluded that the adsorption of bentazon onto DSAC at 30°C was demonstrated well by both of Langmuir and Freundlich isotherm models. The correlation coefficient, R^2 for both models was $0.925 \le R^2$

| Isotherm models | | Para | ameters |
|-----------------|---|-----------------|----------------|
| | Bentazon onto DSA | AC | |
| Langmuir | <i>q_m</i> (mg/g) | <i>b</i> (L/mg) | R ² |
| | 78.13 | 0.061 | 0.925 |
| Freundlich | K _F (mg/g(L/mg) ^{1/n}) | 1/n | R^2 |
| | 12.48 | 0.405 | 0.960 |
| Temkin | A (L/g) | В | R^2 |
| | 1.18 | 13.75 | 0.890 |
| | Carbofuran onto DS | AC | |
| Langmuir | <i>q_m</i> (mg/g) | <i>b</i> (L/mg) | R^2 |
| | 135.14 | 0.041 | 0.960 |
| Freundlich | K _F (mg/g(L/mg) ^{1/n}) | 1/n | R^2 |
| | 10.47 | 0.546 | 0.934 |
| Temkin | A (L/g) | В | R^2 |
| | 1.65 | 26.24 | 0.870 |
| | 2,4-D onto DSAC | ; | |
| Langmuir | <i>q_m</i> (mg/g) | <i>b</i> (L/mg) | R^2 |
| | 175.4 | 0.036 | 0.898 |
| Freundlich | K _F (mg/g(L/mg) ^{1/n}) | 1/n | R ² |
| | 19.32 | 0.433 | 0.952 |
| Temkin | A (L/g) | В | R ² |
| | 5.05 | 29.28 | 0.975 |

Table 3: Isotherm model parameters and correlation coefficients for adsorption of bentazon, carbofuran and 2,4-D onto DSAC at 30 °C.



 \leq 0.960. The adsorption process was favorable as Langmuir separation factor, R_L was 0 < R_L < 1 and supported by 1/n values of Freundlich which were less than 1. A value for 1/n below one indicates a Langmuir-type isotherm because it becomes more and more difficult to adsorb additional adsorbate molecules at higher and higher adsorbate concentrations. In the case of adsorption of carbofuran and 2,4-D on DSAC, the experimental adsorption isotherm data fits to both of Langmuir and Freundlich isotherm equations.

Batch adsorber

A schematic diagram of a single stage batch adsorber is shown in Figure 2. The design objective is to reduce the herbicide solution of volume V (L) from the initial concentration of C_a to C_1 (mg/L). The

amount of adsorbent is M (g) and the solute loading changes from q_o to q_1 (mg/g). At the time t = 0, $q_o = 0$ and as time proceeds the mass balance equates the pesticides removed from the liquid to that picked up by the solid [23].

The mass balance equation for the sorption system in Figure 2 can be written as:

$$V(C_{q} - C_{l}) = M(q_{q} - q_{l}) = Mq_{l}$$
(6)

At equilibrium conditions; $C1 \rightarrow Ce \text{ and } q1 \rightarrow qe$ (7)

Since the sorption isotherm studies confirm that the equilibrium data for pesticides onto DSAC fitted well in Langmuir isotherm, Langmuir isotherm equation can be used for q_1 in equation batch absorber design.

Equation (6) can be rearranged as:

$$\frac{M}{V} = \frac{(C_o - C_e)}{q_1} = \frac{(C_o - C_e)}{q_e} = \frac{(C_o - C_e)}{(q_m K_L C_e / 1 + K_L C_e)}$$
(8)

Figure 3 show the plot between the predicted amounts of activated carbon prepared as adsorbent for bentazon removal at initial concentration of 50 mg/L for different percentage removal and solution volume at 30° C

From this Figure the amount of the adsorbent (DSAC) used with pesticides in this study can detect with the range of pesticides removal (60-90%) and solution volume range of 2–16 L.

Also this Fig. can be extended to include other values of pesticides removals till 100%, and can be modification to include any other conditions from initial concentration and solution temperature.





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Conclusion

The present study shows that the DSAC proved to be an effective adsorbent for removing bentazon, carbofuran and 2,4-D from aqueous solutions. The equilibrium data were best described by the Langmuir and Freundlich isotherm model. A single stage batch adsorber was designed for different V/M ratios of pesticides and activated carbon selected using the experimental equilibrium data obtained at a single V/M ratio.

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