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To examine the adsorption isotherm in the process of treatment of wastewater using batch process

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Abstract

In batch-type contact operations, a fixed amount of adsorbent is stirred with a fixed amount of contaminated water or a fixed amount of an adsorbate's solution until the contaminant or adsorbate's concentration in the aqueous phase has either dropped to a specified level or has been fully eliminated. According to the requirements, the amount of adsorbent and the duration of contact are adjusted. Following removal, the adsorbent is either discarded or recycled for later use. The concentration of adsorbate species, system agitation speed, amount of adsorbent, adsorbent particle size, etc. all affect how long it takes to reach equilibrium. In the batch adsorption process, single-stage and multi-stage counter-current operation procedures are typically employed. Small volumes of wastewater can only be treated by single stage operations, which rely on fill and draw processes. Large volumes of wastewater must be treated by multistage operations, which are utilised in series and alternate between fill and treat modes. The adsorbent employed for this function is often powdered, increasing surface area while lowering diffusion resistance inside pores. Several contaminants have been removed using the batch technique in the past.

Keywords: Batch technique, adsorbate, species, contaminated

1. Introduction

The most practical adsorption techniques are physical and chemical. These procedures typically use a solid substrate to filter out undesirable materials from the effluent stream. These processes are now routinely utilised to purify water and wastewater.

The investigation of the adsorption isotherm in the batch process of wastewater treatment is of utmost significance. Standard procedures for figuring out whether a system is feasible and choosing biosorbents are equally important. When the system is at an equilibrium state in a solid-liquid system, the distribution of some adsorbate species is at the solid-solution interface as well as in the bulk at a specific temperature. It is feasible to express the maximum amount of adsorbate species that can accumulate on a solid surface as a function of its concentration at constant temperature.

The Langmuir isotherm has been found to be a good fit for explaining the sorption process in the current inquiry. The monolayer coverage at the surface of the biosorbent is the foundational premise of the Langmuir adsorption isotherm.

1.1 Adsorption isotherms

In a solid-liquid system, the concentration of solutes on the solid surface and their adsorption from solution grew until equilibrium was established. This process keeps going until the surface solute concentration and the solute concentration that is still in the solution are in dynamic equilibrium. The nature of the adsorbent, the temperature, the kind of solute, the pH, the size of the particles, etc., all affect the equilibrium. Generally, it has been discovered that the equilibrium changes with initial solute concentration. For chemical processes, the design of heterogeneous chemical processes, and the construction of heterogeneous chemical reactors for the adsorption-based treatment of wastes, the study of adsorption equilibrium is essential. All adsorption isotherms share the same quality information regarding how much of the surface is covered by the adsorbent.

Chemical engineers need equilibrium and kinetic data in order to construct an adsorption unit. For determining an adsorbent's absolute capacity in dynamic adsorption, equilibrium data are used.

The mathematical relationship to represent the distribution of adsorbate at the dynamic equilibrium between the adsorbent and liquid-solid systems has been provided by a number of researchers. An adsorption isotherm is a relationship that is used when the temperature is constant during adsorption.

1.2 Rate of adsorption

The research of rate and adsorption is crucial because it helps determine whether a procedure is practical and whether an adsorbent can be used in wastewater treatment. The following three processes are typically involved in the adsorption at the solid solution interface:

(I) Adsorbate species diffuse within the pores of the adsorbent particles, (II) Adsorbate species migrate from solution to the exterior surface of the adsorbent particles through the aqueous film that surrounds the adsorbent, and (III) Adsorbate species bind the adsorbent's pores and capillary species by adhering to sites on the interior surface of the adsorbent particles.

The third phase in the adsorption process is extremely quick and not rate limiting. The first and second phases are therefore typically regarded as rate-limiting steps. Due to the high level of agitation in batch mode of operation, pore diffusion⁶⁴⁻⁷⁰ is frequently the rate-limiting phase. While film diffusion in continuous flow systems is the rate-limiting stage because of the low level of agitation.

2. Research methodology

The type of metal ion and the biosorbents used in the process have a significant impact on the removal of contaminants using the biosorption approach. Both the rate and the capacity of the removal are significantly impacted. Depending on the source, the chemical makeup of sorbents varies greatly from sample to sample. Characterizing them is crucial to ensure a better understanding of the mechanism of sorption since the nature of sorption depends on the sorbate species and the elements of the sorbents. The origins, concentrations, and toxicity of adsorbates in the aqueous system are discussed in this chapter, which also incorporates the outcomes of several physico-chemical techniques used to characterize the adsorbents.

2.1 Procedure

To track the advancement of adsorption in the current experiments, the batch mode of operation was chosen. The process involved shaking 1.0 gm of desired grade adsorbent, namely *Mucor hiemalis* and *Spirogyra* sp., with 50 mL of an aqueous solution of the adsorbate, namely cadmium chloride, lead nitrate, and potassium dichromate, at a constant speed of 125 rpm in various glass bottles. Prior to each run of the experiment, the pH of the adsorbate solution was adjusted by adding HCl and NaOH of the appropriate strength. Up until saturation was reached, the adsorption process was tracked at various intervals. The residual adsorbate concentration was determined by analysing the

supernatant liquid using an atomic absorption spectrophotometer (Shimadzu AA- 6300, Japan) and an ion selective titrator plus system (Orion Ion Selective Titrator plus System, model no. 960, made by Thermo Orion, USA), after the completion of predetermined time intervals.

To account for any adsorption on the inside surface of the bottles, blanks were always run without adsorbent under identical concentration, pH, and temperature conditions.

However, sorption isotherms were investigated in several glass bottles containing 50 ml of each of the aqueous solutions of Cd (II), Pb (II), and Cr (VI), which were stirred with 1.0 g of various biosorbents until the adsorbate-biosorbent systems in each case reached equilibrium.

3. Results and Discussion

Langmuir isotherms are used to visually display the equilibrium isotherm data for various systems. The plots of C_e/q_e vs. C_e for all systems demonstrate the linear character. The above isotherm is valid in the specified concentration range, as shown by the linearity of graphs. The values of Q_0 and b for each system at various temperatures were calculated from the slopes and intercepts of the corresponding plots.

The findings show that with increasing temperature, the values of adsorption capacity Q_0 for Cd (II) and Pb (II) utilising both biosorbents decrease. However, with both biosorbents and Cr (VI), the value of adsorption capacity rises as temperature rises. Additionally, it supports the exothermic and endothermic natures of the system's processes. The values of Q_0 in endothermic processes rise as the temperature rises, which is in good agreement with the findings formerly published by other workers. However, due to the exothermic character of the process, the values Q_0 drop as the temperature rises. Other researchers have already reported similar findings as a result of their research. The equilibrium parameter or separation factor R_L of the Langmuir isotherm is described by the relation:

$$R_L = 1/1 + bC_i$$

Table 1: R_L values and type of reaction

R_L Values	Type of Reaction
$R_L > 1$	Unfavorable
$R_L = 1$	Linear
$0 < R_L < 1$	Favorable
$R_L = 0$	Irreversible

Where C_0 (mg L⁻¹) is the initial adsorbate concentration and b (l mg⁻¹) is the Langmuir constant. The values of the equilibrium parameter R_L in the current inquiry are shown in Tables 2-4 and were found to be in the range 0- R_L -1, showing that the adsorption process was favourable and the Langmuir isotherm was applicable.

The enthalpy (H) of adsorption can be calculated thanks to the Langmuir constant, b . However, the Langmuir constant Q_0 , which describes the adsorption capacity, is utilised to determine specific surface area (S_i), which is defined as the portion of the total surface area that is available for adsorption.

Table 2: Langmuir constants and separation factor for cd (ii) of various biosorbents at different temperatures

Biosorbent	Adsorbate	Temp. °C	Langmuir Constants		R _L
			Q ⁰ (m _g g ⁻¹)	b (l _m g ⁻¹)	
		20	80.10	39.01	1.680 X 10 ⁻²
<i>Mucor hiemalis</i>	Cd (II)	30	76.70	27.95	1.926 X 10 ⁻²
		40	74.25	13.75	4.624 X 10 ⁻²
		20	77.15	34.17	1.914 X 10 ⁻²
<i>Spirogyra</i> sp.	Cd (II)	30	74.30	22.43	2.886 X 10 ⁻²
		40	72.05	12.62	5.015 X 10 ⁻²

Table 3: Langmuir constants and separation factor for pb (ii) of various biosorbents at different temperatures

Biosorbent	Adsorbate	Temp. °C	Langmuir Constants		R _L
			Q ⁰ (m _g g ⁻¹)	b (l _m g ⁻¹)	
		20	39.25	3.644	4.374 X 10 ⁻²
<i>Mucor hiemalis</i>	Pb (II)	30	38.55	2.029	7.591 X 10 ⁻²
		40	37.75	1.263	11.646 X 10 ⁻²
		20	38.75	2.871	5.487 X 10 ⁻²
<i>Spirogyra</i> sp.	Pb (II)	30	38.05	1.962	7.829 X 10 ⁻²
		40	37.20	1.200	12.195 X 10 ⁻²

Table 4: Langmuir constants and separation factor for cr (vi) of various biosorbents at different temperatures

Biosorbent	Adsorbate	Temp. °C	Langmuir Constants		R _L
			Q ⁰ (m _g g ⁻¹)	b (l _m g ⁻¹)	
		20	102.20	11.51	4.163 X 10 ⁻²
<i>Mucor hiemalis</i>	Cr (VI)	30	107.70	18.57	2.622 X 10 ⁻²
		40	111.10	30.00	1.639 X 10 ⁻²
		20	100.00	7.143	6.542 X 10 ⁻²
<i>Spirogyra</i> sp.	Cr (VI)	30	105.80	9.450	5.025 X 10 ⁻²
		40	109.20	16.65	2.915 X 10 ⁻²

The assumption that the maximum adsorption corresponds to saturation monolayer coverage of adsorbate species on the surface of the biosorbent is the foundation for the Langmuir adsorption isotherm's application. The Langmuir constant has a relationship with the apparent heat change or net enthalpy (H) of adsorption. By calculating the logarithm of both sides of the equation, the aforementioned equation can be reduced to a linear form.

The equilibrium data may be helpful in designing and fabricating a water treatment plant with a low input and high output policy, and the comparative study of the adsorption capacity of different biosorbents would be helpful to public health engineers in choosing a specific biosorbent in order to get maximum removal. These findings, which are presented in this chapter and come from the aforementioned studies, may prove crucial to environmentalists and technologists.

Table 5: Apparent heat of adsorption for saturation coverage of adsorbate ions calculated from langmuir adsorption isotherm of different temperatures.

Adsorbate	Biosorbent	Apparent heat of adsorption (ΔH) (kcal mol ⁻¹)
Cd (II)	<i>Mucor hiemalis</i>	-9.420
	<i>Spirogyra</i> sp.	-8.987
Pb (II)	<i>Mucor hiemalis</i>	-8.972
	<i>Spirogyra</i> sp.	-8.058
Cr (VI)	<i>Mucor hiemalis</i>	8.661
	<i>Spirogyra</i> sp.	7.668

4. Conclusion

The system of procedures used to restrict the degradation of the water quality for human consumption, the air they breathe, and the land they depend on. It seeks to accomplish

three goals. Protecting individuals against harmful organisms, poisonous substances, and excessive physical energies is priority number one. The second is to prevent adverse circumstances in the air, the water, and the land from causing human aggravation, irritation, and suffering. Protecting ecosystem balances on Earth is the goal in order to preserve natural resources.

In industrialised nations, organised action to reduce environmental pollution began in the 19th century with municipal services like water supply, sewage, street cleaning, and solid waste collection. These were gradually expanded to include sewage treatment and solid waste disposal by land filling, incineration, and ocean dumping as the demand arose. The majority of nations' government agencies now firmly institutionalise environmental protection. Now more than ever, it is supported and strengthened. The sources of pollution are under control. Numerous streams and air sheds are improving. Ocean dumping has significantly decreased. Solid garbage is being handled much better than in the past. On a global scale, the amount of carbon monoxide, hydrocarbons, and particulates in the air has decreased. Most nations have reinforced their state-level environmental protection agencies.

This study examines the isotherm of adsorption. According to research on how temperature affects the sorption of Cd (II), Pb (II), and Cr (VI), a rise in temperature decreases the extent and pace of Cd (II), Pb (II) adsorption, whereas a rise in temperature promotes the removal of Cr (VI) via adsorption. The equilibrium period, however, is unaffected by temperature. The data for several adsorbent-adsorbate systems' adsorption equilibrium are found to follow the Langmuir model reasonably well.

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