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Using Adsorption as Means to Treat Water Pollution

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Abstract

Background: Water is the source of life form and this crucial source is continuously being polluted through variety of human activities and from natural sources. Many methods have been used to treat water from these pollutants with different degrees of success; one of the most promising techniques is adsorption. Adsorption have been used extensively with variety of adsorbents range from the expensive activated carbon to cheap plant waste.

Aim of study: This review provides a scope on the adsorption process and the factors affect the adsorption, types of adoption, isotherm studies and models as well as some examples on the past studies conducted to eliminate various types of contaminants such as chemical dyes, heavy metals and crude oil and other aromatic compounds.

Keywords: Adsorption, isotherm models, physical adsorption, chemical adsorption, factors, review.

Introduction

Water is essential for all life forms as it consist a substantial part of all human-beings and other living organisms and for that reason and more this valuable resource must be protected from any pollution as well as treated whenever it necessary to sustain its integrity. Generally, water bodies are being continuously and greatly polluted by variable anthropogenic activities (1). With the advance in different aspects of life there is an increase in organic pollutants, hazardous heavy metals, and pharmaceutical waste along with other harmful chemicals waste which impact the water quality significantly (2).

There are many methods that can be used for treating water ranging from oxidation, ozone oxidation, coagulation-filtration, ion exchange to the precipitation, as well as adsorption with different degree of success. each one of these methods has its ups and downs subject to the impurity type required Q to be removed, its composition, physical properties and some other factors such as cost, space and time required for application (3).

Adsorption has recently become a major interest as it shows the highest ability to remove the organic pollutants, inorganic pollutants and industrial pollutants, since it has a low cost and require less space for application (4). In adsorption process the molecules of the pollutants are either physical or chemically attached to the adsorbent active site located on the surface of the adsorbent. In this process the pollutants dynamic is decrease as a result for this attachment and there by reduced from the solution (5).

Adsorption as promising technique to treat water has been studied extensively in all around the world. Ademiluyi, *et al.* (6) used the Nigerian bamboo after converted to activated carbon to remove organic pollutants with good efficiency. Ahmed, *et al.* (7) found that thermally treated Saudian clay has a good potential to remove lead from waste water. Salman, *et al.* (8) found that activated water melon seed shell has ability to remove methylene blue dye with removal efficiency up 82% of the dye. Macias-Garcia, *et al.* (9) found that activated carbon has a respected ability to get rid of paracetamol in hospital waste.

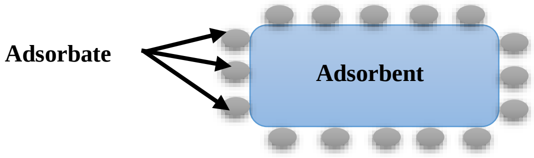

Figure 1: The adsorption process

Types of adsorption

Generally, there are two types of adsorption, these are as follows:

1-Physical Adsorption

Any material (gas or liquid) that become in direct contact with solid surface can be adsorbed. Physical adsorption can be applied by simply placing the adsorbent in a solution that contain the adsorbate (the material that are need to be removed) and the adsorbate will be adsorbed on the surface due to the week Van Der Waals forces or electrostatic force (10,11). Physical adsorption can also happen when an ionic adsorbate is being adsorbed on an ionic or polar surface but without a chemical bond (12).

In physical adsorption the adsorption energy is ranged between 10 to 40 Kj/mole. No chemical change is observed in the matter that are being adsorbed. Physical adsorption does not require heat and has a low specificity to the adsorbate (13), it can occur in multiple layers and because that the physical adsorption is a week connection it can be reversed (desorption may occur) (14), and since it is a reversible process, it can be applied in many techniques and process such as catalyst preparation as well as hydrogen collection and storage (15).

On the other hand, physical adsorption can offer a huge amount of information on the adsorbent surface area, heterogeneity characterization, also the matter distribution on the surface in regard to the adsorption bond energy (16).

2- Chemical Adsorption

Chemical adsorption is a surface attachment where the electrons are shared between the surfaces of both adsorbent and adsorbate, furthermore, adsorption heat is up to 800 Kj mole^{-1}. it is a single layer phenomenon which means it can occur only when there is a direct contact between the adsorbate and the adsorbent surface. However, it must be mentioned that both chemical and physical adsorption can happen in the same time depending on the temperature applied (14). The chemical adsorption includes the attachment of both molecules and atoms to the solid surface of adsorbent. Therefore, there is an increasing interest in understanding the crystallography of the adsorb-ate that involved in this process (17).

Chemical adsorption depends on the chemical bond and so that there is a high specificity between adsorbent and its adsorb-ate. Since it requires a high energy, the process is irreversible and the adsorbed materials are chemically different from the original material (13).in the term of energy involve in the process there are two type of chemical adsorption: activated adsorption that require high temperature and energy and non-activated adsorption which require less energy (8.4-83.7) Kj mole^{-1}(18).

Isotherm Studies

The adsorption isotherm is used to determine the adsorbent capability. They used an mathematical equation to represent the equilibrium of the adsorbate bulk presented on the active sites of the adsorbent to the adsorbate bulk still in solution(13).they are called isotherm to note the importance of temperature in this process. According to the shape of the slope presented it can be devided to four types: C shape it also called distribution coeffecient, it represent the simplest type, this type represent an equilibrium between the amount of the adsorbate in solution and adsorbate on adsobent surface at any concentration, it show a straight line. The 2nd is L shape in this type the amount of the adsobated adsorped by adsobent active sites decrease by the elevation in concentration. The 3rd type is H shape which is a special case of the L shape where there is a high effeinty between adsorbate and the adsorbent. The 4th shape is the S shape it took place when the material being adsorbed is non-polar so that the first layer is slow to form and then the following layers are fromed, it took the shape of S litter (19). The four types are detailed in Figure 2.

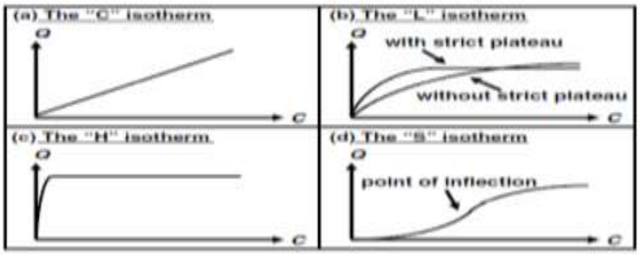

Figure 2: The four types of isotherms (19)

Isotherm models

On the other hand, there are six isotherms' models. The first one is the **Langmuir isotherm** equation even sites of adsorption and there are no lateral interactions. It must be noted that just solutions with low concentration can be explained by this model. The Langmuir equation can be stated as follow:

$$C_e/q_e = 1/b\ Xm + Ce/Xm$$

C_e is the equilibrium concentration, q_e is the amount of adsorbate adsorbed, Xm is the adsorption capacity and b is a constant (20).

The second model is the **Freundlich isotherm** defines heterogeneous adsorption of the surface. In this model the distribution energy of the adsorptive site is an exponential type which is similar to the real situation. The Freundlich equation is:

$$x = Kc^{\beta}$$

Where X is the adsorption isotherm equation, K is an empirical parameter, C is the concentration of equilibrium solution, $\beta = 1$(21)

The third model is **Temkin isotherm**. It can be expressed as follow:

$$q_e = \frac{RT}{b} \ln (ACe)$$

R is the adsorbate constant, T is the temperature, A and b are the Temkin constant, C_e unabsorbed adsorbate concentration, q_e adsorbed adsorbate concentration (22).

The fourth model is the **Brunauer, Emmett, and Teller (BET) isotherm** model; it is a generalization of Langmuir isotherm. It was attempting to present a integrated theory for physical adsorption, descripting both monolayer and multilayer adsorption. It is generally used to measure surface area of porous solid material (23).

The fifth model is **Gibbs isotherm** which can be used for measuring the reduction in the free surface energy which indicates the occurrences of adsorption the Gibbs isotherm equation can be stated as follow:

$$r = -2 \frac{a}{RT} \left(\frac{\partial \Upsilon}{\partial a}\right)_T$$

Where r is the surface excess measured in moles cm^2 , Υ is the surface tension measured in dynes cm^{-1} , a is the solute activity, T temperature, R is constant (24).

The sixth **Giles model isotherm**, the Giles isotherm form a special curve in which adsorbate will be adsorbed rapidly resulting in the shape of hill at the first part of the curve and flat out (25).

Factors affecting the adsorption process

A- Contact time

In general, the adsorption will increase as the retention time of adsorbent and the adsorbate together increase till it reaches equilibrium between the adsorption and desorption processes. After reaching a saturation of the active sites there will be no benefit gained of increasing the contact time any more (26). The best adsorption of pollutants can be achieved by determine the best contact time (27). The contact time is a crucial element that can affect both economic and efficiency of the removal process (28).

B- Adsorbent dose

The adsorbent capacity will be affected by the amount of active site available for adsorption (27), which means that the rise in the adsorbent amount will increase the adsorbent capacity, since that the increase in the adsorbent amount will cause an increase in the adsorbent active site, which can boost removal efficiency (26). In general, it was mention that the overall adsorption will decrease as adsorbent amount increase because of the interposition and aggregation of adsorbent active site (28, 29).

C- PH value

This value is a critical factor that can change adsorption outcome completely, as it affects adsorbent surface charge. Acidic condition (low pH) will favor the adsorption of anionic pollutants, while the alkaline media (high pH) will favor the adsorption of cationic pollutants (26). As the pH value rise it will cause an increase in hydrogen groups in the solution and subsequently increment the amount of negatively charged active sites that enticement positively charged adsorbate (30). Since that the condition and ionizing state of functional groups presented on the surface of the adsorbent can be changed by the change in pH of the solution, it must be set at the beginning of the process (27).

D- Initial concentration of the adsorbate

In general, each adsorbent had a limited number of active sites on their surface that can adsorb the adsorbate and exceeding this limit will decrease adsorbent ability to adsorb it which lowers the adsorption capacity of the adsorbate (26). increasing the initial concentration can increase the driving force for adsorbate mass will be expanding, while in low initial dye concentration the adsorption site available for adsorption is higher than the amount of adsorbate molecules presented in the solution (30).

E- Temperature

It is a vital parameter that affects the adsorption process. The theory of adsorption state that as the temperature elevate the adsorption will decrease and adsorbate molecules can be desorbed back to solution (31). The temperature of the solution can affect the adsorption process through many ways, it was found that rising the temperature can increments the adsorption process through establishment of transferrable sites, pore amplification as well as the sorption increase through the energy barrier (28)

F- Agitation Speed

In aqueous systems, the rise in the speed of agitation rate will boost the efficiency of the adsorption through changing film thickness around particles of the adsorbent (30). In other words, it improves the contact of adsorbate to the active sites of the adsorbent (29). Or it can increment the turbulence which causes a reduction in the layer frontier thickness around the molecules or particles of the adsorbent (25).

Previous Studies

There are a lot of studies conducted using adsorption to remove a variety of pollutants from aqueous solutions, such as removal of different dyes as illustrated in Table 1, removal of heavy metals as shown in Table 2 and removal of crude oil and other aromatic compounds as presented in Table 3.

Table1: Previous researches and studies on adsorption of chemical dyes from aqueous solutions

No.	Name of the dye	adsorbent	Reference	Year of publication
1	**Methylene Blue**	**Cashew nut shell**	**Kumar, *et al.* (32)**	**2011**
2	**Methylene Blue**	**Different commercial activated carbon**	**Xaviera, *et al.* (33)**	**2012**
3	**Methylene Blue**	**Pine cone powder**	**Yagub, *et al.* (34)**	**2013**
4	**Methylene Blue**	**Eggshells**	**Hassan and Hassan (35)**	**2013**
5	**Congo Red**	**Roots of *Eichhornia crassipes***	**Wanyonyi, *et al.* (36)**	**2014**
6	**Congo Red**	**Groundnut shells and coconut shells**	**Chine, *et al.* (37)**	**2015**
7	**Congo Red**	**Montmorillonite**	**Khaniabadi, *et al.* (38)**	**2017**
8	**Malachite Green**	**Wood apple / shell**	**Sartape (39)**	**2013**
9	**Malachite Green**	**Spent coffee grounds**	**Mat, *et al.* (40)**	**2018**
10	**Malachite Green**	**Pine cone**	**Kavci (41)**	**2020**
11	**Methyl Orange**	**Pumpkin seed**	**Subbaiah and Kim (42)**	**2016**
12	**Methyl Orange**	**Chitosan/diatomite composite**	**Zhao, *et al.* (43)**	**2017**
13	**Methyl Orange**	**Activated carbon**	**Jasni, *et al.* (44)**	**2019**
14	**Safranin-O**	**Kaolinite Clay**	**Adebowale, *et al.* (45)**	**2014**
15	**Safranin-O**	**Soybean hull**	**Chandane and Singh (46)**	**2016**
16	**Safranin-O**	**Lignin nanoparticle-g-polyacrylic acid**	**Azimvand, *et al.* (47)**	**2018**
17	**Remazol Brilliant Blue**	**Rambutan peel**	**Alrozi, *et al.* (48)**	**2012**
18	**Remazol Brilliant Blue**	**Pineapple leaf powder and Lime peel powder**	**Rahmat, *et al.* (49)**	**2016**
19	**Amido Black 10B**	**Stem carbon of *Ricinus communis***	**Kaur and Kaur (50)**	**2019**
20	**Evans Blue**	**Magnetic spinel $ZnFe_2O_4$ nanomaterial**	**Vergis, *et al.* (51)**	**2019**

Table 2: Some of the previous studies conducted to remove heavy metals from aqueous solutions by adsorption.

No.	Heavy Metals type	Adsorbent	Reference	Year of publication
1	Lead	Siderite	Erdem, and Özverdi (52)	2005
2	Lead	Leaves of phoenix tree	Liang, *et al.* (53)	2016
3	Lead	Sugarcane bagasse activated carbon	Salihi, *et al.* (54)	2017
4	Lead	Polypyrrole-Based Activated Carbon	Alghamdi, *et al.* (55)	2019
5	Nickel	13 types of Indian soils	Ramachandran and D'Souza (56)	2013
6	Nickel	Doum seed coat	El-Sadaawy and Abdelwahab (57)	2014
7	Nickel	Pomegranate peel	Khawaja, *et al.* (58)	2015
8	Nickel	Nano-bentonite	Taha, *et al.* (59)	2016
9	Cadmium	Spent Coffee Grounds	Patterer, *et al.* (60)	2017
10	Cadmium	Biogenic aragonite shells	Van, *et al.* (61)	2018
11	Cadmium	Pine sawdust	Liu, *et al.* (62)	2019
12	Coper	Grape bagasse activated carbon	Demiral, *et al.* (63)	2016
13	Coper	Groundnut, sesame seed and coconut wastes	Kumar, *et al.* (64)	2019
14	Chromium	Bamboo waste activated carbon	Dula, *et al.* (65)	2014
15	Chromium	Lignocellulose waste activated carbon	Labied, *et al.* (66)	2018
16	Chromium	silica nanoparticles	Jang, *et al.* (67)	2020
17	Mercury	Activated Carbons	Hadi,*et al.* (68)	2015
18	Mercury	Cassava and Lemon waste	Tovar ,*et al.* (69)	2015
19	Mercury	Dried sewage sludge	Park and Lee (70)	2018
20	Mercury	date pits	Al-Ghouti, *et al.* (71)	2019

Table 3: Some studies that dealt with the removal of crude oil and other aromatic compounds from aqueous solutions by adsorption:

No.	Pollutant	Adsorbent	Reference	Year of publication
1	Benzene and Toluene	Activated carbon	Wibowo, *et al.* (72)	2007
2	Benzene and Toluene	Diatomite	Sheshdeh, *et al.* (73)	2014
3	Benzene and Toluene	Cupric Oxide Nanoparticles	Mohammadi, *et al.* (74)	2017
4	Phenol	Rice husk	Daffalla , *et al.* (75)	2020
5	Crude oil	Raw rice husk	Razavi, *et al.* (76)	2014
6	Crude oil	Hydrophilic open-cell polymer foams	Cherukupally, *et al.* (77)	2017
7	Crude oil	Hafnium oxide ceramics	Hussain, *et al.* (78)	2020
8	Polycyclic aromatic hydrocarbons	Periodic mesoporous organo-silica	Vidal, *et al.* (79)	2011
9	Polycyclic aromatic hydrocarbons	Silica-based organic–inorganic nanohybrid material	Balati, *et al.* (80)	2015
10	Polycyclic aromatic hydrocarbons	Organic montmorillonite sodium alginate nano-composites	Dai, *et al.* (81)	2020

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إستخدام الامتزاز كوسيلة لمعالجة تلوث المياه

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الخلاصة

خلفية عن الموضوع: ان المياه هي المصدر الرئيسي لكل اشكال الحياة المختلفة وان هذا المصدر المهم يتعرض بشكل مستمر للتلوث نتيجة للظواهر الطبيعية او بسبب تدخل الانسان بشكل مباشر او غير مباشر. لقد تم تطوير العديد من الأساليب والتقنيات لمعالجة المياه من الملوثات المختلفة التي قد تؤثر سلبا على نوعية هذه المياه وان من أكثر التقنيات التي تبدو واعدة في هذا المجال هي تقنية الامتزاز.
الهدف من الدراسة: تم استخدام تقنية الامتزاز في معالجة المياه بصورة مكثفة وباستخدام مواد مازة مختلفة بدأ من استخدام الكاربون المنشط الغالي الثمن نوعا ما الى استخدام المخلفات النباتية المتوفرة والرخيصة وبدرجات مختلفة من النجاح. ان هذه الدراسة تتناول تقنية الامتزاز، أنواع الامتزاز، استخدام الموديلات الرياضية بالإضافة الى استعراض مجموعة من الدراسات السابقة التي تتناول إزالة مجموعة مختلفة من الملوثات كالأصباغ والمعادن الثقيلة ومشتقات النفط.

الكلمات المفتاحية: امتزاز، الموديلات الرياضية، الامتزاز الفيزيائي، الامتزاز الكيميائي، العوامل المؤثرة.
