Removal of Succinic and Phthalic Acid from Aqueous Solutions Using Activated Charcoal Prepared from the Desert Plant

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Abstract:

Because of its effects on ecosystems and human health, environmental pollution including dangerous organic compounds is one of the most pressing problems in the world. Carboxylic acids are among the chemical substances that naturally dissolve in water the quickest and can be extremely harmful to human health. Through this work, the Salsola Incanescens plant a type of desert plant, was used to prepare activated carbon using hydrogen peroxide as activation agent and use it as an adsorbent surface to remove succinic and phthalic. It was diagnosed by different techniques such as FT-IR, XRD, FESEM, TEM and EDX. It was revealed from FT-IR that it contains OH, CH, C-C, C=O. As functional groups. The results of XRD, FESEM, TEM, and EDX showed the crystalline level of the prepared charcoal and the shape of (pores) on the surface of the activated charcoal and the percentage of elements present with the charcoal. The outer and inner surface area was determined using methylene blue and iodine index. The effect of initial concentration, temperature, adsorbent dose, and contact time of adsorbents on the adsorption rate was studied. The obtained results showed that adsorbed amount (Qe) increases with increasing initial concentration. However, the removal rate decreases with increasing initial concentration. The adsorption isotherms (Langmuir and Freundlich) were applied and it was found that the adsorption process is fully consistent with the (Langmuir and Freundlich) equations. Thermodynamic functions (ΔH, ΔS and ΔG) were calculated and it turned out that the adsorption process is exothermic, as the adsorption increases with increasing temperature. The adsorption process is spontaneous and is accompanied by an increase in randomness, meaning that it is less homogeneous on the surface of the adsorbent than it is in the solution.

Key words: Activated carbon, Adsorption, Hydrogen peroxide, Removal, Salsola Incanescens.

إزالة حمض السكسينيك والفثاليك من المحاليل المائية باستخدام الفحم المنشط المحضر من النبات الصحراوي

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المستخلص

بسبب تأثيراتها في النظم البيئية وصحة الإنسان، فإن التلوث البيئي بما في ذلك المركبات العضوية الخطيرة هو أحد أكثر المشاكل إلحاحًا في العالم. تعد الأحماض الكربوكسيلية من بين المواد الكيميائية التي تذوب بشكل طبيعي في الماء بشكل أسرع ويمكن أن تكون ضارة للغاية بصحة الإنسان. من خلال هذا العمل، تم استخدام نبات السالسولا وهو نوع من النباتات الصحراوية، لإعداد الكربون المنشط باستخدام بيروكسيد الهيدروجين كعامل تنشيط واستخدامه كسطح ماص لإزالة السكسينيك والفثاليك. تم تشخيصه بتقنيات مختلفة مثل FT-IR وXRD وFESEM وTEM وEDX. تم الكشف عن أنه يحتوي على OH وCH وC-C وC = O. كمجموعات وظيفية. أظهرت نتائج XRD وFESEM وTEM وEDX المستوى البلوري للفحم المحضر وشكل (المسام) على سطح الفحم المنشط ونسبة العناصر الموجودة بالفحم. تم تحديد مساحة السطح الخارجي والداخلي باستخدام الميثيلين الأزرق ومؤشر اليود. تمت دراسة تأثير التركيز الأولي ودرجة الحرارة وجرعة المادة الماصة وزمن تلامس المواد الماصة على معدل الامتصاص. أظهرت النتائج المتحصل عليها أن الكمية الممتصة (Qe) تزداد بزيادة التركيز الأولي. ومع ذلك، فإن معدل الإزالة ينخفض بزيادة التركيز الأولي. تم تطبيق متساوي الحرارة للامتصاص (Langmuir وFreundlich) ووجد أن عملية الامتزاز متوافقة تمامًا مع معادلات (Langmuir وFreundlich). تم حساب الدوال الديناميكية الحرارية (ΔH وΔS وΔG) واتضح أن عملية الامتزاز طاردة للحرارة، حيث يزداد الامتصاص بزيادة درجة الحرارة. إن عملية الامتزاز تتم بشكل تلقائي ويصاحبها زيادة في العشوائية أي أنها أقل تجانساً على سطح المادة الماصة مما هي عليه في المحلول.

الكلمات المفتاحية: الكربون المنشط، الامتصاص، بيروكسيد الهيدروجين، الإزالة، الساليولا إنكانيسينس.

Introduction

Environmental pollution with hazardous organic substances is one of the most problematic issues worldwide due to its impact on human health and ecosystems (Murray et al.,2010). The presence of organic

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pollutants in the environment is of particular worry since they mess with human hormone balance as well as that of terrestrial species. Chemicals that cause cancer are present in all aspects of the environment, including soil, air, groundwater, and surface water. Because they are constantly released into the environment, even in low amounts, they are regarded as persistent (García-Córcoles et al.,2019). Organic pollutants often undergo an oxidation reaction that results in the final products of carboxylic acids, including dicarboxylic acids (Foya et al., 2014). One of the organic materials that dissolves in water the fastest in nature is carboxylic acids, which can seriously harm human health (Blower et al.,2013).

There are many chemical and physical techniques to deal with the pollution problem, including chemical and electrochemical precipitation, extraction, ion exchange, reverse osmosis, filtration, evaporation, and adsorption. Despite the importance of these techniques, their use is limited due to their high cost (Ren et al., 2015). Adsorption technology is one of the main means of dealing with the pollution problem, due to its relatively low cost. Adsorption is an interaction between the three components the solvent, the adsorbent, and the adsorbate that occurs at the surface. The adsorbate's affinity for the adsorbent and its solubility in the solvent operate as an interaction force that regulates it (Berhe et al.,2015). Natural sources such as clay, carbon, zeolite, organic aggregates and agricultural waste can be used as adsorption surfaces, in addition to the use of waste and nano-oxides (Walter and Worch 2021).

Activated carbon (AC) is a well-known adsorbent because of its porous structure, which has a high surface area, a large pore volume, and activity. Because of these unique properties, activated carbon can be employed as a catalyst, adsorbent, and catalyst support to remove a variety of chemicals (Ahumada et al., 2002) in addition, activated can be regeneration for more than four times (Nazal et al.,2019). With the addition of particular functional groups to the adsorbent surface, activated carbon (AC) can be used to better remove target molecules by adsorption, which can be used to remove a variety of organic and inorganic contaminants from water (Sellaoui et al.,2023).

Adsorption on activated carbon, one of the earliest water treatments, is actually recognized by the USA Environmental Protection Agency as one of the most effective ways to eliminate organic and inorganic pollutants from water meant for human consumption (Méndez-Díaz et al., 2012). *Salsola incanescens* is useful species in dry and semi-arid rangelands. *Salsola incanescens* is a plant that can be utilized to improve and regenerate dry and semi-arid settings. It has significant therapeutic benefits and economic worth for rangeland owners (Neghabi, 2021).

Berhe et al., (2015) Acetic acid's adsorption behavior on activated carbon was investigated in relation to the adsorbent's type, dosage, and adsorbate concentration. Analysis of the data reveals that when the starting concentration of acetic acid grew, so did the acetic acid adsorption process on activated carbon. By applying the Langmuir and Freundlich isotherms, adsorption data was modeled. In the range of the concentrations investigated, these findings fit the Langmuir isotherm models for all samples quite well.

This study aims to explore new applications of activated carbon derived from the Salsola in water purification due to limited existing information on this topic.

Materials and Methods:

Instruments and chemicals

The tools and chemicals used are succinic acid (99%), phthalic acid (99%), ethanol, sodium hydroxide (Qualikems), phenolphthalein indicator, Adsorbents (activated carbon prepared from the Salsola plant by burning it and then activating it with hydrogen peroxide). Distilled water was used throughout the work. H_2O_2, HCl, KOH, H_2SO_4, rotary shaker (JEIO TECH-Korea), electronic balance (Mettler-Switzerland), Burette, Magnetic stirrer, electric grinder (GERMANY), burning oven (LDO-060E-KOREA), drying oven (SANYO-Japan), sieve capacity 53µm (China), FTIR (Bruker-Germany), FESEM (FEI Nova-Japan), XRD (Inspect S50-Japan), TEM (Hitachi-S 4160).

Preparation of the adsorbents

The *Salsola plant* was dried in the sun for two weeks, then it was ground in an electric grinder, then 1 kg of the ground plant was placed in a crucible and placed in a muffule at a temperature of 250°C for two hours, then it was washed with distilled water to get rid of the ash. It was noted that the pH = 9.5, so it was done. It was neutralized with HCl to make pH=7. After that, it was washed with distilled water to get rid of the acid, then dried in a drying oven at a temperature of 100°C. After that, it was sieved in a 53µm sieve it is symbolized by ACT. Then 100g of charcoal burned at a temperature of 250°C was mixed with 200mL of hydrogen peroxide and stirred for 6 hours, then it was filtered, washed three times with distilled water, dried in a drying oven at a temperature of 80°C, and then sieved in a 53µm sieve it is symbolized by ACP as in the (Figure. 1). Then three other adsorbent surfaces were prepared, where 40g of ground and dried *Salsola* were mixed with 80 mL of concentrated sulfuric acid and left for 24 hours until it charred, then washed with distilled water 3 times and neutralized with 0.1 M of NaOH so that the pH = 7 and then washed. With distilled water and dried, it is symbolized by ACS. Also, the *Salsula* was mixed with KOH in a ratio of [1:2], adding 100 mL of distilled water, mixing it, and placing it in the muffule at a temperature of 100°C. Then, after an hour, the temperature was increased to 450°C for an hour, then

it was washed several times with distilled water until it became pH = 7, then dried and symbolized as ACH. Also, prepare another adsorbent surface by mixing 2g of activated charcoal with hydrogen peroxide with (8 mL, 2 M) of aqueous iron nitrate, then adding 0.1 mL of 2 M NaOH solution to maintain the pH. This mixture was heated to a temperature of 100°C for 12 hours and then cooled. Wash and filter it until the filtrate become transparent, then dry the precipitate and denote it as ACF. Samples were taken to measure FTIR, XRD, FESEM, TEM, and EDS, and it was found that the charcoal activated with hydrogen peroxide is nano charcoal. So, it was chosen next experiment as illustrated below.

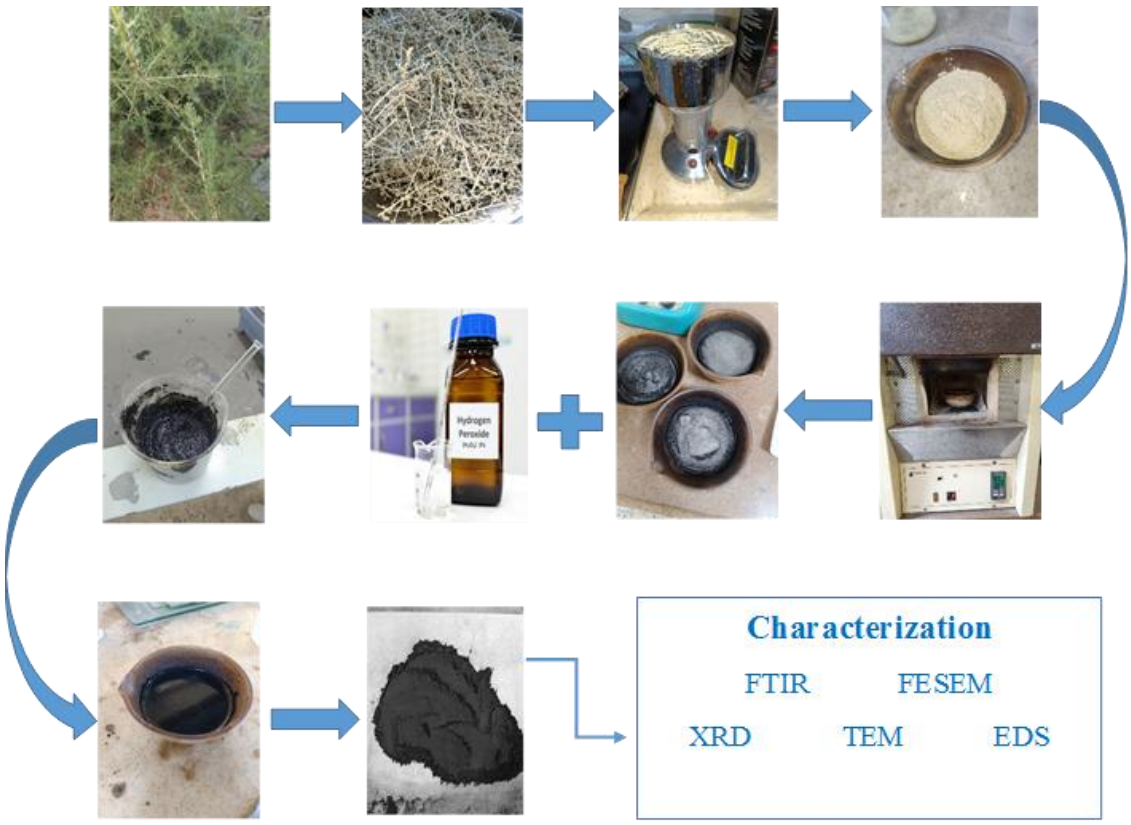

Figure 1. Shows the preparation of the adsorbent

Iodine adsorption

Mix 1g of activated charcoal with 15 mL, 5% of HCl in a conical flask, shake it until it is homogeneous, then put it on the fire until it boils for one minute, then cool the solution to room temperature, then add 0.1M, 50 mL of iodine solution to the existing mixture in the conical flask. After that, we filter using filter paper, then we take 25 ml of the filtrate and put it in a beaker. The starch was used as a guide. Then a burette was used to calibrate the filtrate using 0.1M of aqueous sodium thiosulfate (Lee et al., 2019).

Methylene blue indicator

A measurement of activated carbon surface area, indicates the capacity of activated carbon to absorb large particles. 1g of activated carbon and 25 mL of methylene blue (MB) at a concentration of (50 ppm) were mixed in a conical flask and placed in a vibrating water bath at (25°C) for 3 hours, after which the remaining (MB) concentration was measured and the (MB) index was calculated according to ref (Al-Mahmoud, 2019).

Preparation of Aqueous Solutions of phthalic and succinic acids adsorbates

After dissolving 47.2g of succinic acid in 1L of distilled water (0.4 M), the first solution was created by diluting it with more distilled water. The standard solution was used to prepare the range of concentrations for the succinic acid solution, which was (0.01 M - 0.05 M). Additionally, 0.83 g of phthalic acid was dissolved in a solvent of water - 5% ethanol (0.013 M), then solutions were made by diluting the first with distilled water. The range in concentrations of the phthalic acid solution was prepared from the standard solution, ranging from (0.001 M - 0.013 M).

Batch adsorption studies

Batch tests were conducted in sealed plastic containers with a capacity of 50 mL of working volume and using a rotary shaker. The initial concentration of succinic acid was evaluated (0.01, 0.02, 0.03, 0.04 and 0.05 M). The initial concentration of phthalic acid was also evaluated (0.001, 0.002, 0.003, 0.004 and 0.005 M), contact time (15, 30, 45, 60, 90, 120, 180 and 240 min.), adsorbent dose (0.5, 1, 1.5, 2 and 2.5 g), temperature difference (25, 35, 45 and 55 ºC) for both acids. During the current study, the amount of succinic acid and phthalic acid adsorbed was determined in millimoles per gram using the following mass balance equation (Alam et al., 2019):

$$Qe = \frac{Co-Ce}{m} \times V \qquad \textbf{Eq. 1}$$

Where C_o is the initial acid concentration in M, Ce is the equilibrium acid concentration in M, V is the volume of adsorbate in L, and m is the weight of the adsorbent in g. Qe is the quantity of acid adsorbed onto each unit weight of the adsorbent in mmol/g. The following equation was used to obtain the acid elimination %. (Shouman and Khedr., 2015):

$$Removal(\%) = \frac{Co-Ce}{Co} \times 100 \qquad \textbf{Eq. 2}$$

Characterization surface functions

-(FT-IR): of the raw material showed the presence of a broad band at elongation (3413 cm^{-1}) due to the vibration of the OH group in alcohols or carboxylic acids, and a band at (2924 cm^{-1}). The vibrational distortion belongs to alpha CH, and the band at (1100 cm^{-1}) belongs to the C-O group. Alkenes have a band at (1600 cm^{-1}) due to C=C stretching vibration as in (Figure.2). The positions of the beam of active groups such as OH changed and some of them disappeared in the FT-IR spectrum of activated carbon samples obtained after treating the raw material with hydrogen peroxide. There is a band at (2193 cm^{-1}) that belongs to C≡C, and a band at (1447 cm^{-1}). belongs to C-C as in (Figure.2). We discovered a shift in the location of the bands for many functional groups after the adsorption of succinic acid and phthalic acid on activated carbon, where a band appeared at (3181 cm^{-1}) belonging to the carboxyl OH group and a band at (1562 cm^{-1}) belonging to C-C stretching, a band at (568cm^{-1}) belongs to the aliphatic C-H as in (Figure.2).

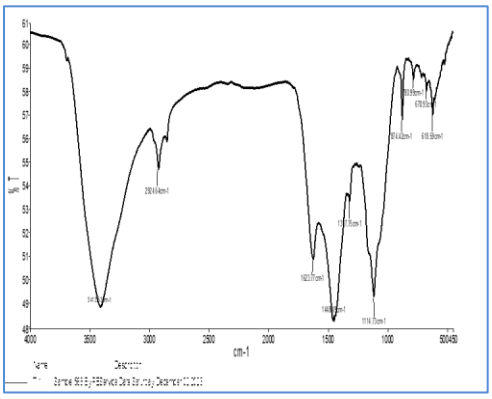

Fig. (3) FT-IR of (H_2O_2) before adsorption.

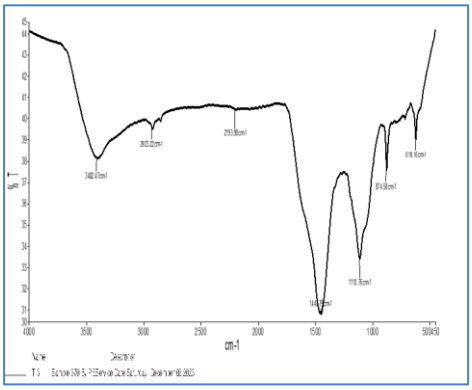

Fig. (2) FT-IR spectrum of the raw material.

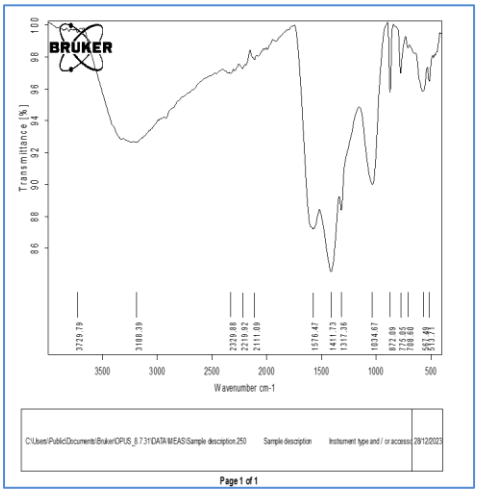

Fig. (4) FT-IR of (H_2O_2) after Succinic acid adsorption

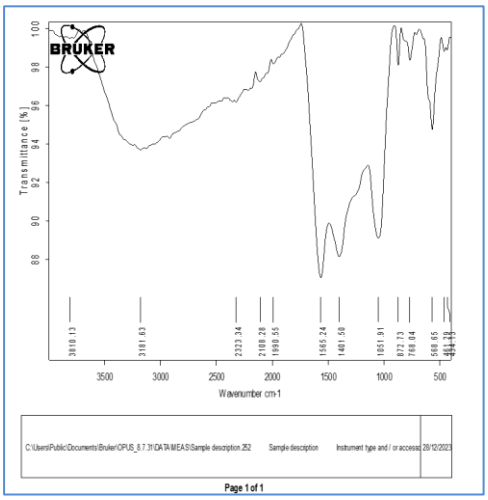

Fig. (5) FT-IR of (H_2O_2) after Phthalic acid adsorption.

-(X-RD): analysis: X-ray diffraction is a widely used method for material structural analysis that is easy to apply, non-destructive, and effective. Ascertain the structural characteristics, gauge the thin film's thickness, calculate the nanoparticles' sizes, etc.

Diffractions may happen when the x-ray wavelength interacts with the sample surface since it is similar to the crystal lattice parameter. Bragg low states that diffraction occurs at

$$d\sin\theta = n\lambda^2 \qquad \text{Eq. 3}$$

The planar crystal distance (d) and the diffraction angle (θ) for certain incident x-ray wavelengths (λ) are connected, hence the diffraction spectrum can provide information about the crystal structure (Myers, 1997).

XRD OF ACT: Powder XRD patterns of ACT prepared by burn a *Salsola* placed in an oven at 250°C for 2 h. Is shown in (Figure. 6) the strong and weak diffraction peaks emerged at 2θ = 28◦ and 2θ = 42◦,46◦, respectively. This result indicates the existence of graphite crystallite in *Salsola* active carbon, crystallite size of *Salsola* active carbon is 15.75 nm.

(Figure. 7) shows a typical XRD structure of activated carbon generated by chemical activation of H_2O_2 (after washing stage). The characteristic broad peaks of the k (002) and (100) planes of carbon are located approximately at 25◦ and 40.89◦, respectively (Zhang et al., 2018). Crystallite size of ACP active carbon is 1.91nm.

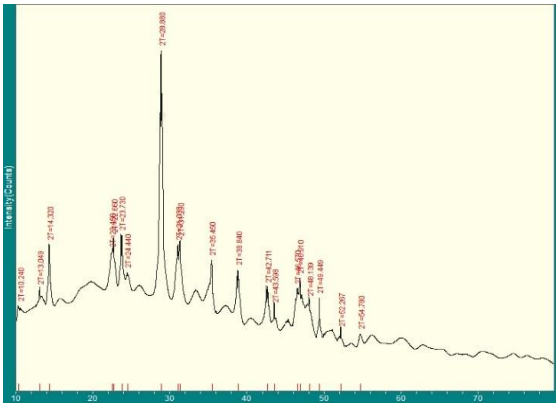

Fig.6. XRD for ACT.

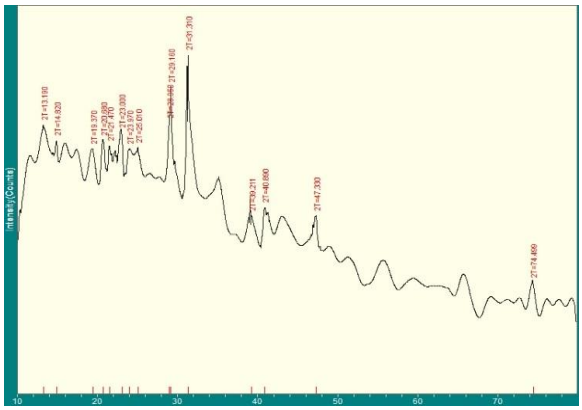

Fig.7. XRD for ACP.

- (FE-SEM) of ACT:

The microscopic structure and surface morphology of activated charcoal powder were examined using FE-SEM analysis, which was the outcome of a modified approach. Sample ACT possesses rich mesoporous structure and no cavities on the morphological surface, according to FE-SEM data. Graphite crystallite scale decreases, which might cause broadening or internal structure disordering to generate a greater specific surface area, make up the entire wall of activated carbon. The ultrafine particles that make up activated carbon have a porous structure. The greater the particular surface area, the lower the crystallinity.

(FE-SEM) of ACP:

First examined the ACP sample's surface with a 1000-times magnification using Fe-SEM. Multiple holes on the surface of Base ACP were found. However, a bigger diameter and more pores were produced by oxidizing the activated carbon with H2O2. Examining the samples at 5000 times magnification revealed that the duration of the H2O2 oxidizing treatment had an impact on the formation of pores with 30% H2O2 250 °C.

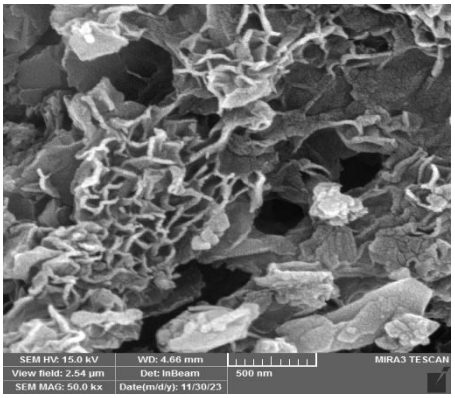

Fig.8. FE- SEM reading results of ACT.

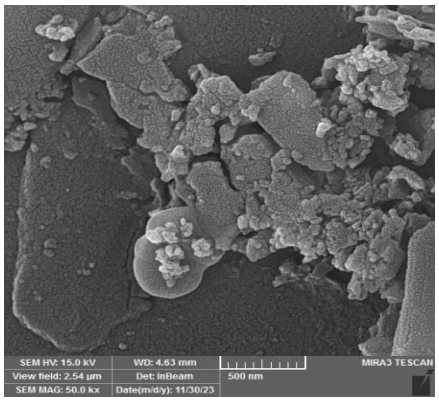

Fig.9. FE- SEM reading results of ACP

- (EDX):X-ray spectroscopy OF ACT, ACP:

EDX is investigating the elemental analysis of Sample activated charcoal Fig. (10_11). The C peak is seen by the EDS spectrum and other impurities can be observed (Scimeca et al., 2018).

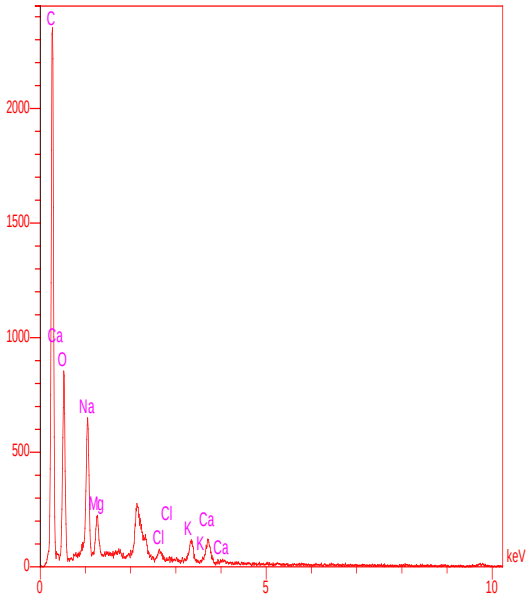

Fig.10. EDX Analysis of Carbon (ACT)

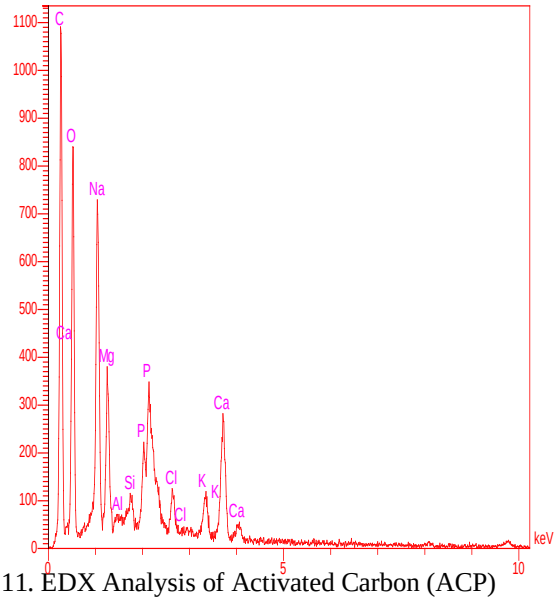

Fig. 11. EDX Analysis of Activated Carbon (ACP)

Table 1.EDX Analysis of Carbon (ACT).

Elements	Weight%
C	58.52
O	30.62
Na	5.62
Mg	1.68
Cl	0.65
K	1.34
Ca	1.58

Table 2.EDX Analysis of Carbon (ACP)

Elements	Weight%
C	46.30
O	33.94
Na	7.30
Mg	2.80
Al	0.16
Si	0.56
P	1.84
Cl	1.06
K	1.42
Ca	4.63

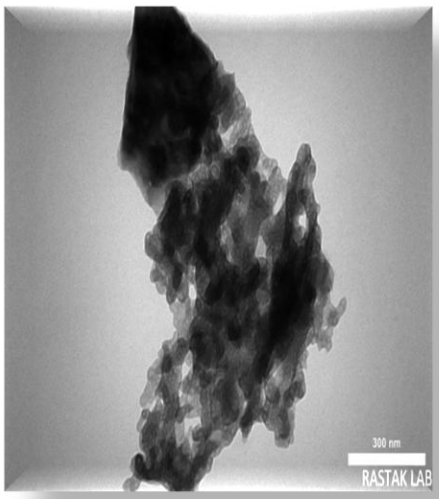

Fig.12. TEM of ACT.

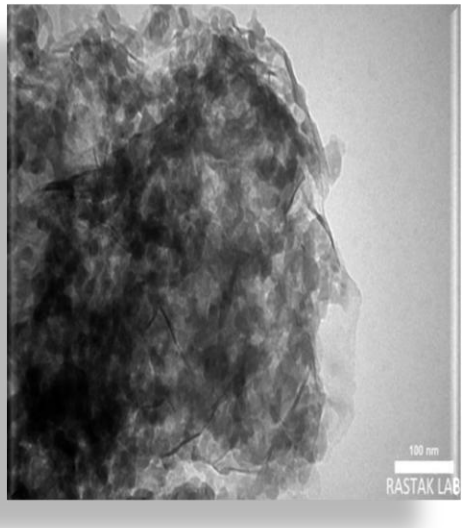

Fig.13. TEM of ACP

Iodine index

In (Figure. 14), the results of iodine values for all types prepared from activated carbon are shown. Activated carbon with hydrogen peroxide has the best iodine adsorption capacity, up to (578.18), and activated carbon models with iodine values ranging between 500 and 1500 are recommended for removing micro-pollutants (Alhamed, 2009).

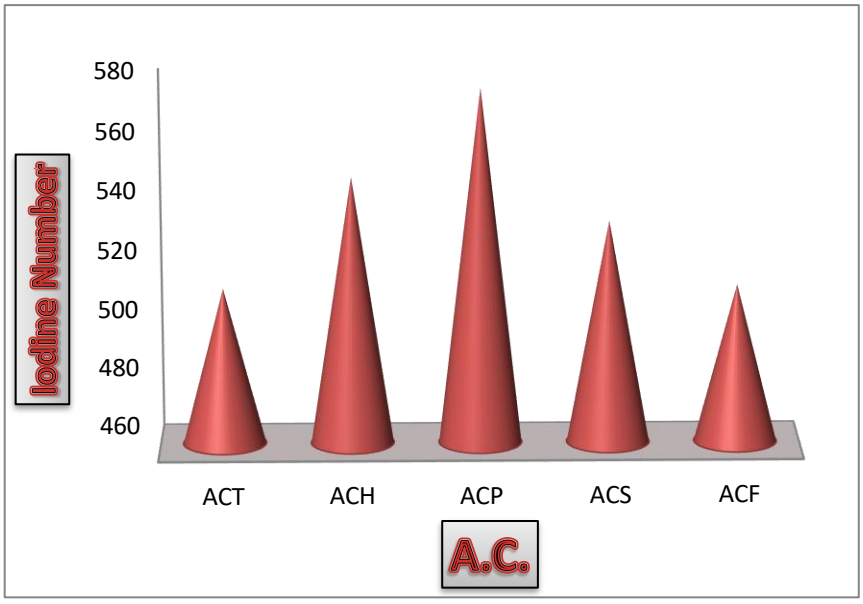

Figure 14 shows the iodine adsorption rates for each type of adsorbent coal.

Methylene blue index

In (Figure. 15), the results of the blue dye removal values for all types prepared from activated carbon are shown. Activated carbon with hydrogen peroxide has the best ability to adsorb dye and the percentage of removed particles is very high, which indicates that activated carbon has high effectiveness in removing both large and small particles.

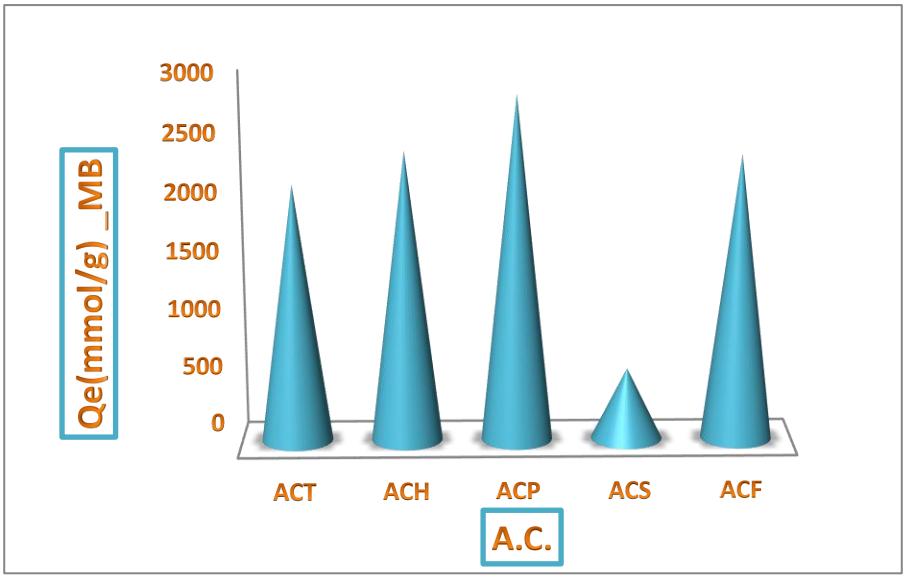

Figure 15 shows the amount of methylene blue dye adsorbed for each type of coal.

Influence of the operational parameters

Many variables, such as the initial acid concentration, the amount and kind of adsorbent, the temperature, the adsorbents nature, and the length of the contact period, all affect the adsorption.

Influence of initial concentration on adsorption

One of the key elements influencing the equilibrium concentration is the initial acid concentration. (Figure. 16) shows the effect of phthalic and succinic acid concentrations on activated carbon. The capacity of acid to adsorb on activated carbon increased as the initial concentration of acid increased. This suggests that the ability of acids to adsorb on activated carbon was significantly influenced by the initial concentrations of phthalic and succinic acids.

Influence of temperature on adsorption

Temperature is consident that one of the factors affecting the adsorption process. The effect of temperature on the adsorption of succinic acid and phthalic acid was studied using different temperatures ranging between (25, 35, 45 and 55 °C). The percentage of removal of succinic acid appears to increase at a temperature of 25°C to be 87%, then it decreases at 35°C, then it increases to be higher. The removal rate of succinic acid is 92% at 55°C. The percentage of phthalic acid removal also appears to increase at a temperature of 25°C to be 95%, then it decreases at 35°C, then it increases so that the highest removal percentage of phthalic acid is 98% at a temperature of 55°C, as shown in (Figure. 17).

Influence of contact time on adsorption

Batch adsorption studies have also been conducted at different contact times (15, 30, 45, 60, 90, 120, 180 and 240 min) by taking initial concentration of succinic acid 0.01 M and phthalic asid 0.001M with 0.5 g adsorbent dose of activated charcoal in 50 mL succinic acid solution ,50mL phthalic acid solution and at 25°C temperature. Effects of contact time on removal of succinic acid and phthalic acid by activated charcoal are presented in (Figure. 18). Since the duration of the contact between the adsorbent and the adsorbate depends on the type of system being employed, it is crucial to the adsorption process. These figures show that at first, the absorption of acid is extremely quick, but it gradually slows down and eventually reaches equilibrium. It is evident that the adsorbed amount of acid does not substantially vary any more after 90 minutes of contact with activated charcoal, reaching equilibrium at that time for acid in the concentration range under study. It so agrees well with the worth of the literature (Khamseh et al., 2023).

Influence of adsorbent dose on adsorption

Another crucial variable for adsorption system optimization is the adsorbent dosage. Using various doses of AC ranging from 0.5 to 2.5 g, the impact of adsorbent dose on the adsorption of succinic acid and phthalic acid has been studied. Figure.19 shows how the amount of adsorbent rises with the removal of succinic acid and phthalic acid. 62% of the succinic acid was removed when 0.5 g of activated carbon was used. The clearance efficiency trend tended to climb to 88% as the dose rose to 2.5g. Phthalic acid removal effectiveness was 82% when 0.5 g of activated charcoal was used; however, removal efficiency rose to 97% when the dose was increased to 2.5 g. Greater surface area and the availability of more adsorption surface sites can be the cause of an increase in adsorption with an increase in adsorbent dosage. However, by increasing the adsorbent from 0.5 to 2.5 g, the adsorption capacity of phthalic acid drops from 0.082 to 0.019 mmol/g, whereas the adsorption capacity of

succinic acid decreases from 0.62 to 0.16. (Figure. 20) illustrates this decrease in adsorption capacity, which is essentially caused by unsaturated adsorption sites. Adsorption capacity decreases with large adsorbent concentrations, which may be caused by overlapping adsorption sites on the adsorbent surface. For adsorption and thus for 2.5 g, the adsorbent has an extra surface area.The adsorbent found that the optimal percentage for removing succinic acid and the adsorption capacity are 88% and 0.16 mmol/g, respectively, while the optimum percentage for removing phthalic acid and the adsorption capacity are 97% and 0.019 mmol/g, respectively.

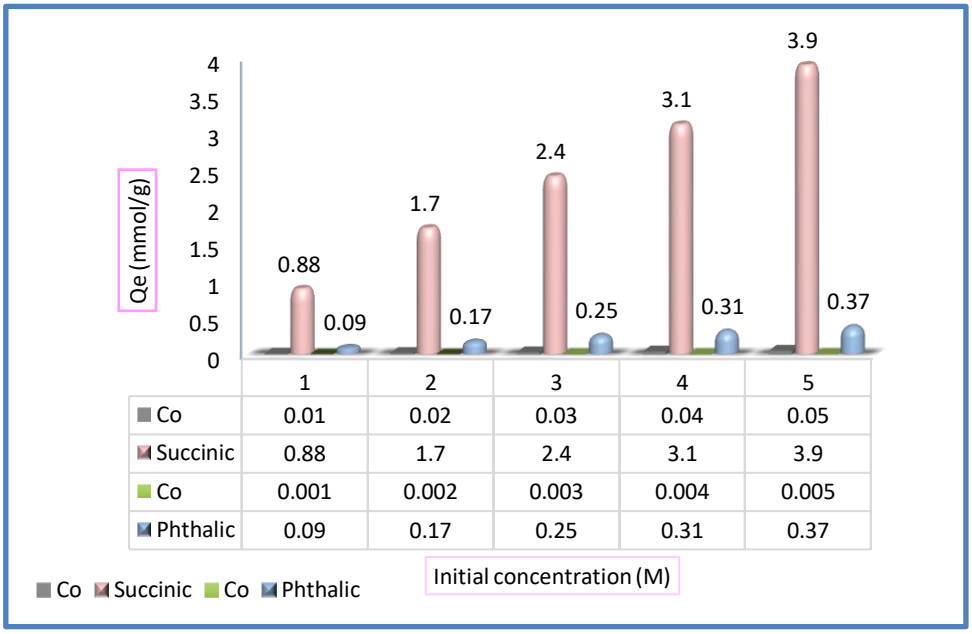

Figure 16. Shows the adsorbed amount of succinic acid and phthalic acid at different concentrations (T=25°C), (D=0.5g)

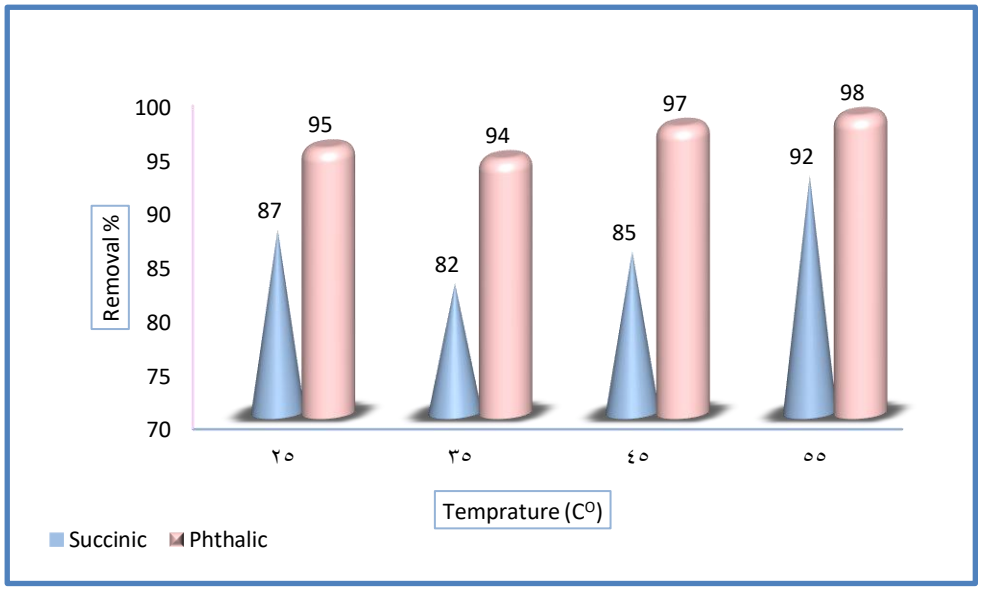

Figure 17. Shows the removal rates of succinic acid and phthalic acid at different temperatures (0.01M Succinic acid), (0.001M Phthalic acid)

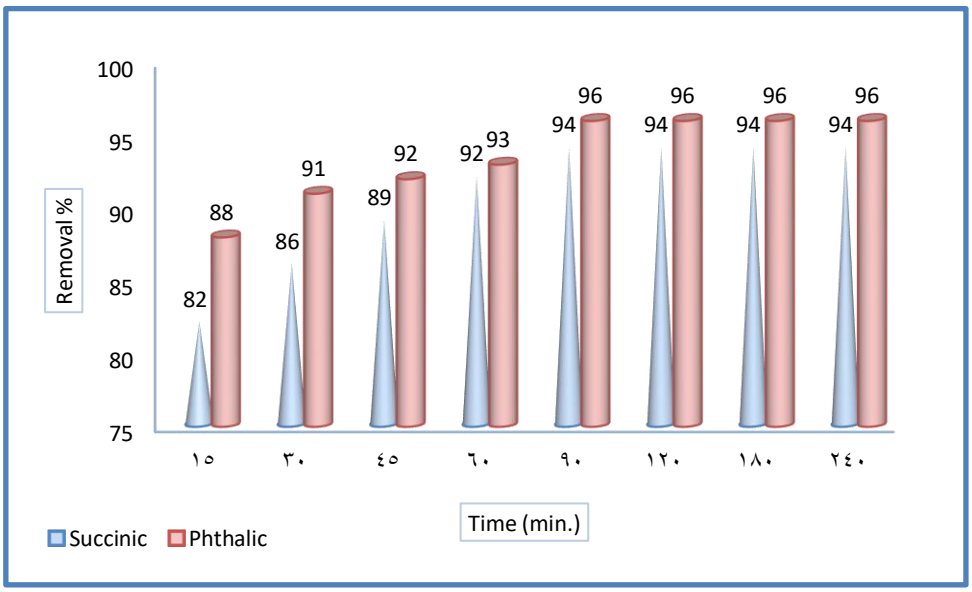

Figure 18. Shows the removal rates of succinic acid and phthalic acid at different times. (D=0.5g), (0.01M Succinic acid), (0.001M Phthalic acid)

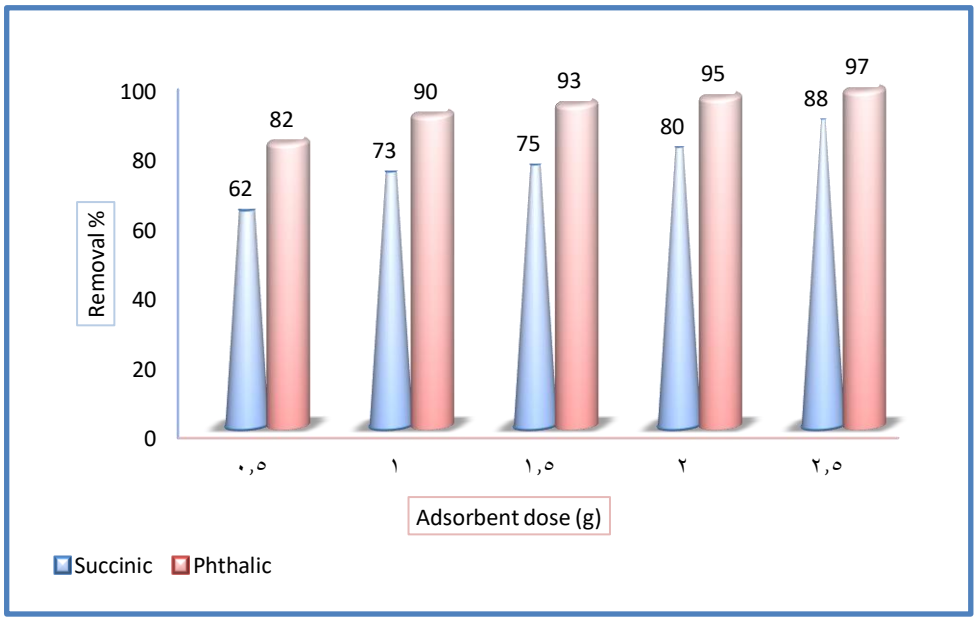

Figure 19. Shows the removal rates of succinic acid and phthalic acid at different charcoal doses. (T=25°C), (0.01M Succinic acid), (0.001M Phthalic acid)

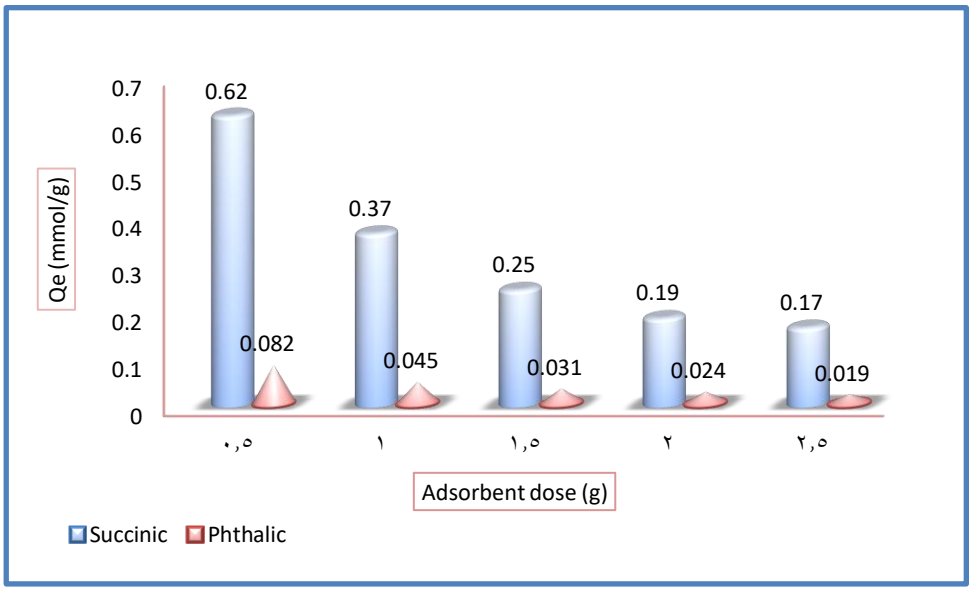

Figure 20. Shows the adsorbed amount of succinic acid and phthalic acid in different doses of charcoal. . (T=25°C), (0.01M Succinic acid), (0.001M Phthalic acid)

Adsorption isotherm

Langmuir isotherm adsorption

(Figure. 21). displays the outcomes of the Langmuir model for the elimination of phthalic acid and succinic acid from AC. The Langmuir isotherm is followed by the correlation coefficients that were reported and provided significant positive evidence for the adsorption of phthalic and succinic acid onto AC. The high correlation coefficients R demonstrated the Langmuir model's linear form's applicability to AC. R^2 = 0.9829 for phthalic acid and R^2 = 0.9052 for succinic acid. This implies that a decent model of the adsorption system is provided by the Langmuir isotherm (Sirhan et al., 2023).

Freundlich isotherm adsorption

From the (Figure. 22). and table 3, it was found that Freundlich adsorption constant value 1/n is greater than one. The high correlation coefficients R demonstrated the Freundlich model's linear form's applicability to AC. R^2 = 0.9862 for phthalic acid and R^2 = 0.9962 for succinic acid. This suggests that the Freundlich isotherm provides a good model of the adsorption system.

Table 3. Shows the Langmuir and Freundlich constants for the adsorption of succinic acid and phthalic acid.

Adsorbents	Langmuir constants			Freundlich constants		
	R^2	Q_o	K_L	R^2	N	k_f
Succinic acid	0.9052	6.1	142.8	0.9962	1.5	6.6
Phthalic acid	0.9829	0.5	2040.8	0.9862	2.04	48.9

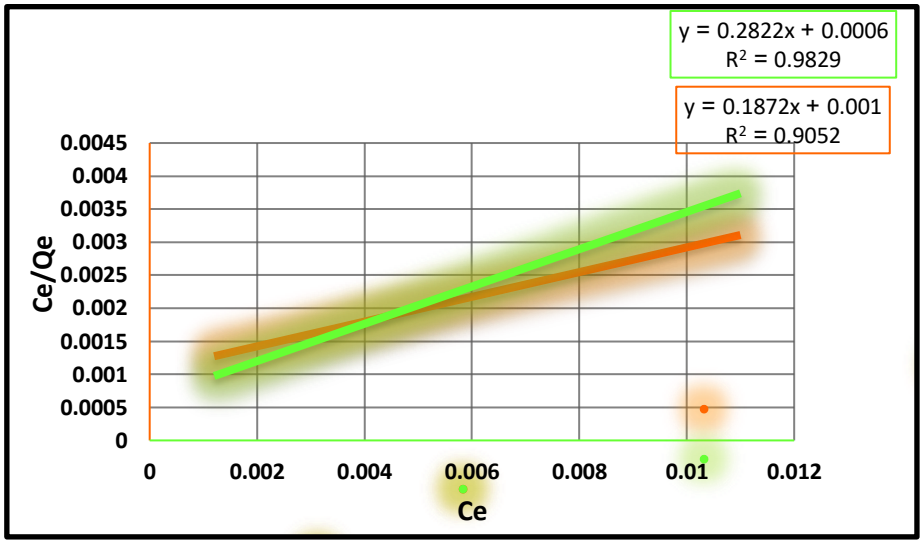

Figure 21 shows the Langmuir isotherm for the adsorption of succinic acid and phthalic acid

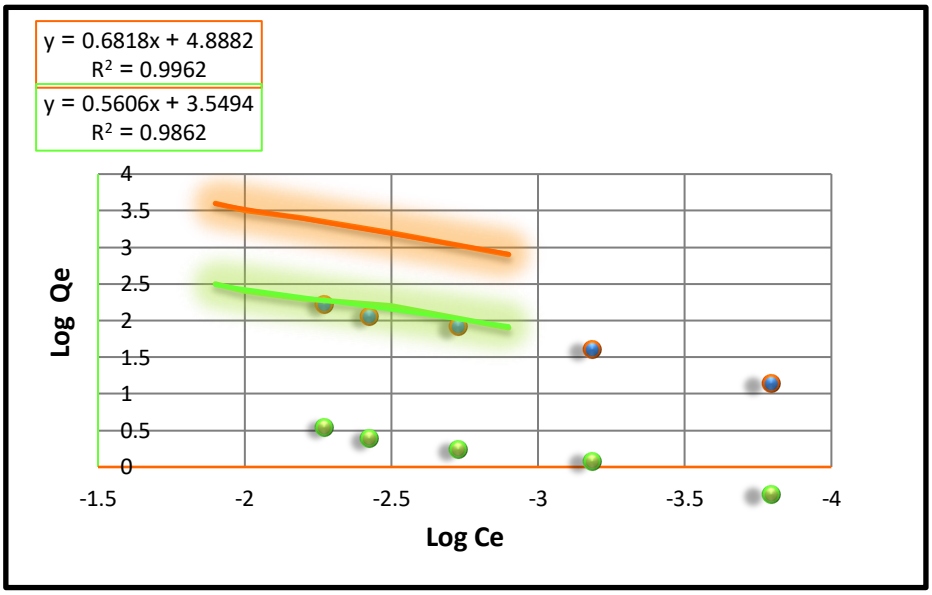

Figure 22 shows the Freundlich isotherm for the adsorption of succinic acid and phthalic acid

Thermodynamic

The thermodynamic functions of the adsorption processes (succinic acid and phthalic acid) from aqueous solutions were estimated using carbon activated with hydrogen peroxide. The values of enthalpy of adsorption (ΔH) and entropy of adsorption (ΔS) were calculated using the Vant Hoff equation (Efan, and Sirhan, 2022 and Hamooshy and Hussein, 2021).

$$LnK = \frac{\Delta S}{R} - \frac{\Delta H}{RT} \qquad \text{Eq. 4}$$

$$K = \frac{Qe}{Ce} \qquad \text{Eq. 5}$$

The plot of Ln K versus 1/T in (Figures 23–24) was used to determine the straight line equation's slope and intercept, and the values of ΔH and ΔS were derived from the equation's slope and intercept, respectively. The value of the free energy ΔG was also determined using the Kipps mathematical equation (Alalaw et al., 2022).

$$\Delta G = \Delta H - T \cdot \Delta S \qquad \text{Eq. 6}$$

Table (4) shows that all adsorption processes emit heat because the heat of adsorption (ΔH) is negative and all values are less than (40 kg/mol), indicating that the adsorption is physical. . It is indicated by negative (ΔG) values

that spontaneous adsorption activities take place. When ΔS is positive, it means that the molecules that have been adsorbed are not as well-organized on the adsorbed surface as they are in solution.

Table 4. Shows the thermodynamic values for succinic acid and phthalic acid.

T (K)	Succinic acid			Phthalic acid		
	ΔH (KJ/mol)	GΔ (KJ/mol)	ΔS (J/mol.k)	ΔH (KJ/mol)	GΔ (KJ/mol)	ΔS (J/mol.k)
298		-29.3			-45.9	
308		-30.3			-47.4	
318		-31.3	98.4	-28.3	-48.9	153.8
328	-14.1	-32.3			-50.5	

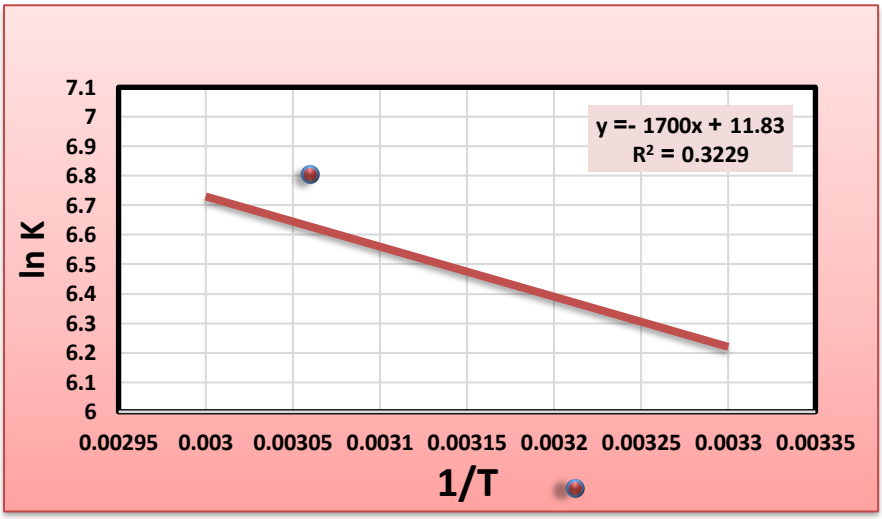

Figure 23 Van't Hoff relationship for the removal of succinic acid on ACP

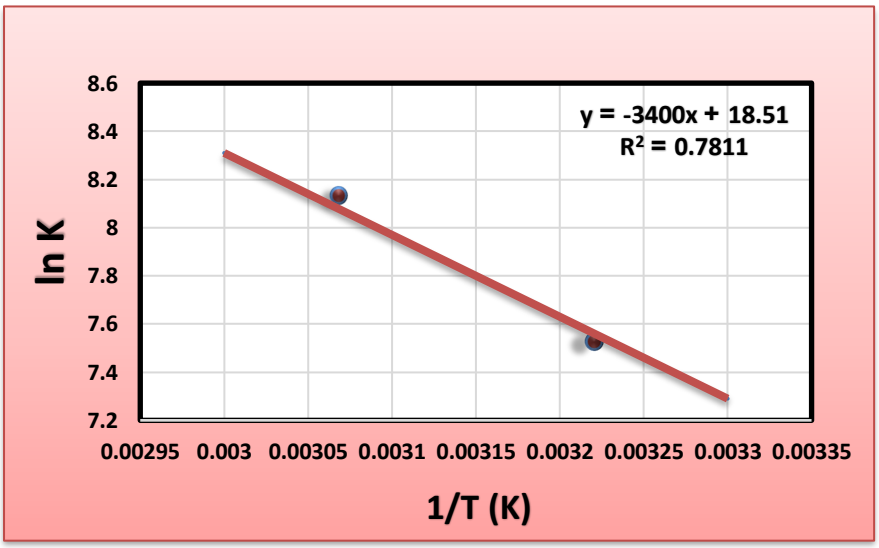

Figure 24. Van't Hoff relationship for the removal of Phthalic acid on ACP

Conclusions

The *Salsola* plant was used to prepare carbon and treated it with hydrogen peroxide to increase its efficiency in the adsorption process. It was diagnosed using FT-IR, EDX, FE-SEM, XRD, TEM techniques. The removal percentage of succinic and phthalic acids was determined, and the removal percentage on the adsorbent surface activated with hydrogen peroxide for phthalic acid was 97% higher than succinic acid, which was 94 %. Also, the amount adsorbed for the acids increased with increasing time, and the contact time was 90 minutes. The adsorption process was also subject to the Freundlich and Langmuir equations.

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