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Kinetic Pathways for Uranium Adsorption from Contaminated Wastewater Using Activated Carbon Derived from Corn Cob as a Biosorbent

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Abstract

With the continuous development of the nuclear industry, the amount of uranium containing wastewater discharged from the production process is increasing, which poses a great threat to the environment and human health. Therefore, it is an urgent task to find safe, environmentally friendly and efficient water treatment agents. This study evaluated the kinetic behavior and adsorption performance of corncobs-derived activated carbon for uranium removal from water. The activated carbon was produced through pyrolysis and characterized using ESEM (Environmental scanning electron microscopy) , EDX (**Energy-dispersive X-ray spectroscopy**), and FTIR (Fourier transform infrared spectroscopy) to analyze its structural properties. Batch kinetic experiments investigated the influence of pH, contact time, temperature, particle size, and adsorbent dosage on uranium adsorption. Under optimized conditions, the adsorbent achieved 88.3% uranium removal with a maximum capacity of 7.27 mg/g. Kinetic analysis revealed that the adsorption process followed pseudo-first-order kinetics, while equilibrium data aligned with the Langmuir isotherm model. The study also noted a correlation between uranium removal and organic pollutant degradation, as indicated by decreasing COD (Chemical oxygen demand) and BOD (Biological oxygen demand) levels initially. However, beyond 60% uranium removal, COD and BOD values rose, suggesting the need to optimize contact time and dosage for kinetic efficiency. Elution with 1M HCl recovered 78.5% of uranium, demonstrating the adsorbent's reusability. These findings highlight the potential of agricultural waste-based adsorbents for kinetically controlled heavy metal and organic pollutant remediatio

. **Keywords:** Activated carbon, corn-cobs waste; adsorption; uranium removal; Kinetics.

1. Introduction

Activated carbon produced pore structure carbonaceous adsorption material and had a large specific surface area. Because of its robust adsorption capacity, abundant supply of raw materials, and renewable benefits, biomass activated carbon has emerged as the preferred adsorbent. The activated carbon adsorption method can perform advanced treatment, adsorb a variety of heavy metals, including lead and mercury, and has cheap operating costs and simple equipment. In addition to breaking down contaminants in soil and sewage, activated carbon can also eliminate organic or inorganic materials from the atmosphere[1]. The activated carbon from corn cobs has a wide range of applications such as a treatment agent, after converting it to biochar that adsorbs ammonia nitrogen in swine wastewater[2] adsorption of brilliant green dye from wastewater[3] and applied as ethylene absorber for 'Gros Michel' banana packaging to delay fruit ripening[4]

According to[5] uranium is a heavy metal that is highly radioactive and chemically poisonous. Finding a cost-effective and efficient way to extract U (VI) from an aqueous solution is therefore crucial [6- 11] To separate and preconcentrate components from environmental samples, the adsorption technique has been employed extensively **[12-13]**. Currently, a lot of research has been done on active carbon (AC), one of the numerous low-cost and eco-friendly adsorbents **[14-18]**. Additionally, because of its porosity and surface area, AC has a high adsorption effectiveness, making it a popular choice for treating waste solutions **[19]**. Cotton stalks[20] hazelnut shells[21], rice husks[22], peanut shells[23] , bamboo shoots[24] and coconut shells[25] are among the waste materials from which many scientists have recently investigated the use of AC.

The water column carries heavy metals, which eventually sink to the bottom as silt. Sediments contribute to pollution due to their activity and metal remobilization process. Metal Environmental pollutants have the potential to bioaccumulate in water bodies. Surface water is exposed to liquid heavy metals, including carbonates, sulfates, fulvic acid, humic organic compounds, and amino acids, along with insoluble salts or complexes. These salts and chemicals are not thought to be harmful to this aquatic species. Some of them sink and get trapped in sediments. Water's pH is lowered by acid rain or alkaline precipitation. Acid crashes caused by the buildup of heavy metals in the water column render aquatic life toxic [26] Uranium has the potential to irritate the intestinal lining when ingested. Additionally, it can enter the circulation through the lungs and remain in the liver, kidneys, bone, or any number of other tissues for years, irradiating any tissues in

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the vicinity. It is quite likely that exposure to U could have neurological health effects. Additionally, it affects blood cells that are part of the immune system and can damage the kidneys when they are discharged through the urine. It can either cause cancer directly or worsen cancers brought on by other toxins. Uranium's chemical toxicity is comparable to that of other heavy metals such as nickel and lead, when combined with its radioactive effects [27].

The adsorption kinetics of uranium (VI) ions onto corn cob has been widely investigated, with studies confirming that the process typically follows **pseudo-second-order (PSO) kinetics,** suggesting chemisorption as the dominant mechanism [28-29]. Researchers have observed an initial rapid adsorption phase due to abundant surface functional groups (–OH, –COOH) on corn cob, followed by slower uptake as equilibrium is reached [30] **Intra-particle diffusion models** often reveal multi-stage adsorption, indicating that both surface binding and pore diffusion contribute to U(VI) removal[31] .The activation energy (Ea) for the process typically ranges between **8–40 kJ/mol**, supporting a mixed physisorption-chemisorption interaction[32].

Agricultural residues, which are often underutilized, present an environmentally sustainable option for adsorbent production. The valorization of such residues into activated carbons, hydrothermal car-bons, and biochars is an innovative approach for enhancing uranium adsorption.[33]

Optimization studies show that **pH 4–6**, moderate temperatures (25–45°C), and higher adsorbent dosages enhance U(VI) uptake[30-34] Compared to commercial adsorbents, corn cob exhibits a competitive adsorption capacity (**50–200 mg/g**), attributed to its porous structure and ion-exchange properties[31] . The **Elovich model** further confirms heterogeneous surface interactions, while thermodynamic studies indicate a **spontaneous ($\Delta G° < 0$) and endothermic ($\Delta H° > 0$)** process[35] . Some researchers have modified corn cob with acids or nanoparticles to improve kinetics, achieving faster equilibrium times (Sarı & Tuzen, 2014). Overall, corn cob's cost-effectiveness, rapid kinetics, and high efficiency make it a promising biosorbent for uranium-contaminated wastewater treatment.

This work proposed a straightforward and affordable approach for activating synthesized activated carbon from Corn Cobs by examining the adsorption equilibrium and kinetics of uranium ions in aqueous systems.

Although activated carbon is widely applied for pollutant removal, natural materials which are relatively cheaper and Eco-friendly have also been successfully employed as adsorbents for heavy metal removal from aqueous solutions and wastewaters due to their availability, low-cost, unique chemical composition and renewability. The reduced running cost has been the focal point for research on application of natural materials.

2. Materials and Methods

2.1. Materials and Reagents

All reagents and chemicals used in this study were of analytical grade, and all solutions were prepared using distilled water to ensure purity. The uranium source, uranyl nitrate hexahydrate ($UO_2(NO_3)_2.6H_2O$), served as the primary adsorbate. Key analytical reagents, including Arsenazo I [3-(2-arsenophenyl) diazinyl C16H13AsN2O11S2], HNO_3 (nitric acid), and NaOH (sodium hydroxide), were procured from Aldrich Company. Additionally, 4,5-dihydroxynaphthalene-2,7-disulfonic acid was obtained from Sigma-Aldrich. The experiments utilized a spiked (simulated) wastewater sample containing uranium, along with the synthesized activated carbon adsorbent derived from corn cobs, which served as the primary adsorption material.

2.2. The preparation of Corncob-Derived Activated Carbon Sorbent.

The synthesized activated carbon from Corn Cobs samples used in this study was prepared according to [2], with some modifications. The biomass of agricultural wastes was ground, sieved, and dried overnight at 70 ^{O}C before pyrolysis. After being dried, the biomass was transferred into crucibles, covered with lids, and placed in the muffle furnace. Under a steady stream of nitrogen gas, the furnace was heated to 450 ^{o}C (with a heating ramp of 2 ^{o}C/min) and kept there for two hours. As seen in Figure 1, the furnace was then turned off, and the crucibles were let to cool to room temperature. After that, the carbonized materials were washed with 0.1 N HCl and distilled water, until the pH of water become from 6.8 to 7. Then it was dried in oven at 105 ° C overnight. Then it was collected in an airtight plastic container and used for analysis, as well as, for adsorption experiments. A carbon sample weighing around 100g was dried at 70°C at a constant weight before being pulverized in a porcelain mortar and screened "with homogenous particle size segments of 60, 80, and 120 mesh.

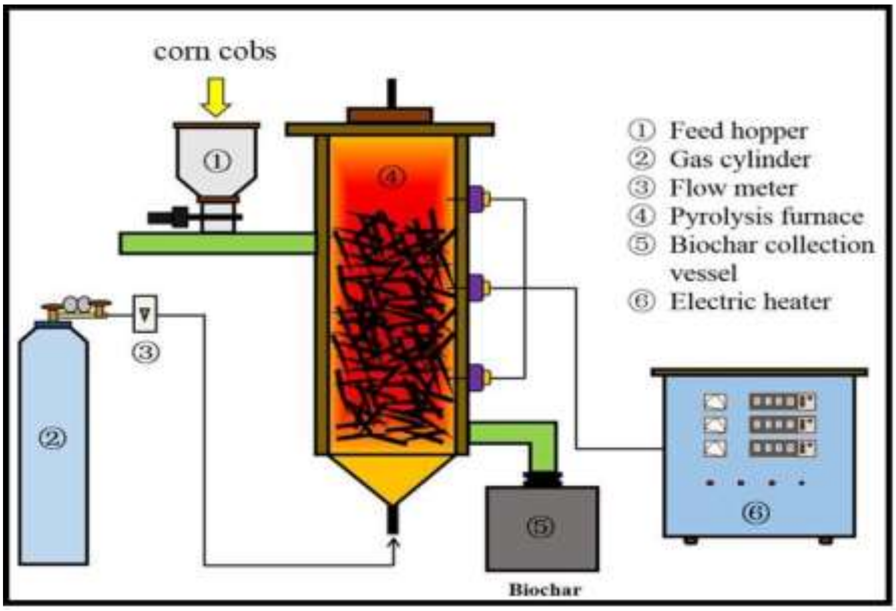


Figure (1): Flow diagram for activated carbon synthesis from Corn Cobs samples

2.3. Instrumentation and Characterization Techniques

The corn cob-derived activated carbon samples, both before and after uranium adsorption, were analyzed using field-emission scanning electron microscopy (FE-SEM) coupled with energy-dispersive X-ray spectroscopy (EDX) at 30 kV acceleration voltage, 14x to 1,000,000x magnification, and 1 nm resolution. Elemental analysis (C, H, N, S) was performed by the Microanalytical lab (Cairo university). Fourier-transform infrared (FTIR) spectroscopy (PerkinElmer 2000) analyzed KBr pellets in transmission mode (400–4000 cm^{-1}, . Uranium (VI) concentration was determined via Arsenazo I spectrophotometry (Jasco V-530 UV-Vis, λ = 596 nm,). Samples were prepared by mixing 1 mL of solution with 2 mL Arsenazo I and 5 mL buffer, then diluted to 25 mL with distilled water. Absorbance was measured at 596 nm against a reagent blank (Marczenko & Lenarczyk, 1976).

2.4. Adsorption Workability

Simulated wastewater samples were prepared by spiking with heavy metals and uranium nitrate (as a representative radioactive element). A 1000 mg/L uranium (VI) stock solution was prepared using $UO_2(NO_3)_2 \cdot 6H_2O$. Adsorption experiments were conducted using 0.2 g of adsorbent (corn cob-derived activated carbon) in 20 mL of 100 mg/L uranium solution (pH 1–7) shaken at 120 rpm for 60 min. Key variables investigated included initial concentration (25–150 mg/L), contact time (5–60 min), adsorbent dosage (0.1–0.5 g), temperature (25–65°C), solution volume (20–100 mL), and particle size (60–120 mesh). pH adjustments were made with 0.1 M HNO_3 or NaOH. Post-adsorption, samples were filtered, and residual uranium concentrations were analyzed.

The adsorption capacity (q_e, mg/g) was calculated as:

$$q_e = (C_i - C_v)V/m \qquad (1)$$

where C_i and Cv are initial/final concentrations (mg/L), V is solution volume (L), and m is adsorbent mass (g).[37]

2.5. Kinetic Models:

The adsorption kinetics was analyzed using pseudo-first-order and pseudo-second-order models to understand the rate-controlling mechanisms. The pseudo-first-order model of Lagergren is expressed as;[36]

$$log(q_e - q_t) = log\, q_e - {}^{k_1}/_{2.303}\ t \qquad (2)$$

where q_e and q_t represent the adsorption capacities (mg/g) at equilibrium and time t, respectively, and k_1 is the rate constant (min^{-1}). The pseudo-second-order model proposed by Ho and McKay follows the Eq. 3:

$$^{t}/_{q_t} = {}^{t}/_{q_e} + {}^{1}/_{k_2 q_e^2} \qquad (3)$$

where k_2 being the second-order rate constant (g·mg⁻¹·min⁻¹). The suitability of these models was evaluated by comparing the correlation coefficients (R^2) and the agreement between experimental and calculated q_e values.

2.6. Adsorption Isotherms

For isotherm analysis, four models were employed to describe the equilibrium adsorption behavior. Equilibrium data were analyzed using Langmuir, Freundlich, Dubinin-Radushkevich (D-R), and Temkin isotherm models to describe adsorbate-adsorbent interactions.

The Langmuir isotherm, assuming monolayer coverage, was applied in the linear form (Eq. 4):

$$C_e/q_e = 1/k_L Q_L + C_e/Q_L \qquad (4)$$

where Q_l is the maximum adsorption capacity (mg/g) and K_l is the Langmuir constant (L/mg) related to adsorption energy.

The Freundlich isotherm, suitable for heterogeneous surfaces, was represented as in Eq. 5:

$$log(q_e) = log\, K_F + \frac{1}{n} log\ (C_e) \qquad (5)$$

where K_F indicating adsorption capacity $(mg/g\cdot(L/mg)^{1/n})$ and n representing adsorption intensity.

The Dubinin-Radushkevich (D-R) model is represented in Eq. 6 as follow: [37]

$$q_e = k_{DR} \exp(-K_{DR}\, \varepsilon^2) \qquad (6)$$

where $\varepsilon = RT \ln(1+1/C_e)$, was used to determine the nature of adsorption as physical or chemical based on the mean free energy. Finally, the Temkin isotherm in Eq. 7 accounted for the effects of adsorbent-adsorbate interactions;

$$q_e = \frac{RT}{B} lnAT + \frac{RT}{B} lnCe \qquad (7)$$

where q_e refers to the equilibrium metal/g/g sorbent sorption capacity, Ce to the balance metal concentration in mg/L. The equilibrium binding constant (AT), universal gas constant(R), solution temperature(T), and sorption heat (bT) are determined.[37]

2.7. Uranium Elution Studies

A series of elution experiments were conducted using two eluent solutions: 1.2 M sodium chloride and 1 M hydrochloric acid, targeting a uranium loading of 84.7 % adsorbent. The elution process maintained a constant flow rate of 1 mL/min, resulting in a residence time of approximately 20 minutes as the solution passed through the uranium-saturated activated carbon. Effluent samples were collected in 10 mL aliquots for subsequent uranium concentration analysis.The experimental setup utilized glass chromatography columns (60 cm length × 1 cm internal diameter) packed with corn cob-derived activated carbon. A measured quantity of dry adsorbent was carefully loaded into each column to achieve a consistent bed height of 3 cm for all trials.

2.8. Determination of BOD&COD

BOD Standard Method:

In 1936, the American Public Health Association (2005) recognized BOD5 as a standard method to estimate the bio- degradability of compounds present in wastewater. The technique consists of placing the samples contaminated, possibly by organic matter in special bottles containing a mixture of previously aerated water, nutrients, and an unknown microbial inoculum, with approximately 105 cells/mL . First, the measurement of initial dissolved oxygen is carried out, then, the bottles are hermetically closed and incubated in darkness at 20 °C for 5 days. The determination of final dissolved oxygen according to ISO 5815: "Water quality determination of biochemical oxygen demand after the nth day (BODn**)**

COD Standard Method:

In the standardized method described in International Standards, ISO 6060- and ISO 15705–2002, organic matter (i.e., potassium biphthalate) is oxidized in the presence of potassium dichromate and sulfuric acid, in 2h reflux at a temperature of 150 °C (open or closed). HgSO4 are added to eliminate the presence of chloride ions and silver salts to catalyze the reaction. In the "open reflux" procedure, the excess of dichromate can be measured by titrating the K2Cr2O7 that was not reduced, using a solution of ferrous ammonium sulfate (Mohr's salt), with ferroin as an indicator. the initial reaction involves biphthalate, which reacts with dichromate: After this reaction, dichromate (K2Cr2O7) is replaced by oxygen (O2). After digestion (reflux), the excess of non-reduced dichromate is titrated with an iron solution (Fe2+), In the "closed reflux" procedure, the excess of dichromate is detected via spectrophotometric methods at a wavelength of 420 nm or the increase of trivalent chromium ions (Cr(III)) at a wavelength of 600 nm.**[38]**

3.Results and Discussion

3.1. Chemical Composition of the Studied Spiked Wastewater Sample

Table (1): characterization of spiked wastewater sample.

3. Element	4. Conc mg/L	5. Element	6. Conc mg/L
7. BOD	8. 68	9. Mo	10. 0.15
11. COD	12. 158	13. Cd	14. n.d
15. Mn	16. 17.31	17. B	18. n.d
19. Fe	20. 101.04	21. Ba	22. 0.11
23. Ca	24. 284.55	25. As	26. 5.78
27. Cr	28. n.d	29. Pb	30. n.d
31. Co	32. n.d	33. Mg	34. 851.96
35. Cu	36. 13.6	37. U	38. 102
39. Ni	40. 9.34	41. REEs	42. 140
43. Zn	44. 5.85	45.	46.

3.1.2 Characterizations of Activated Carbon from Corn Cobs

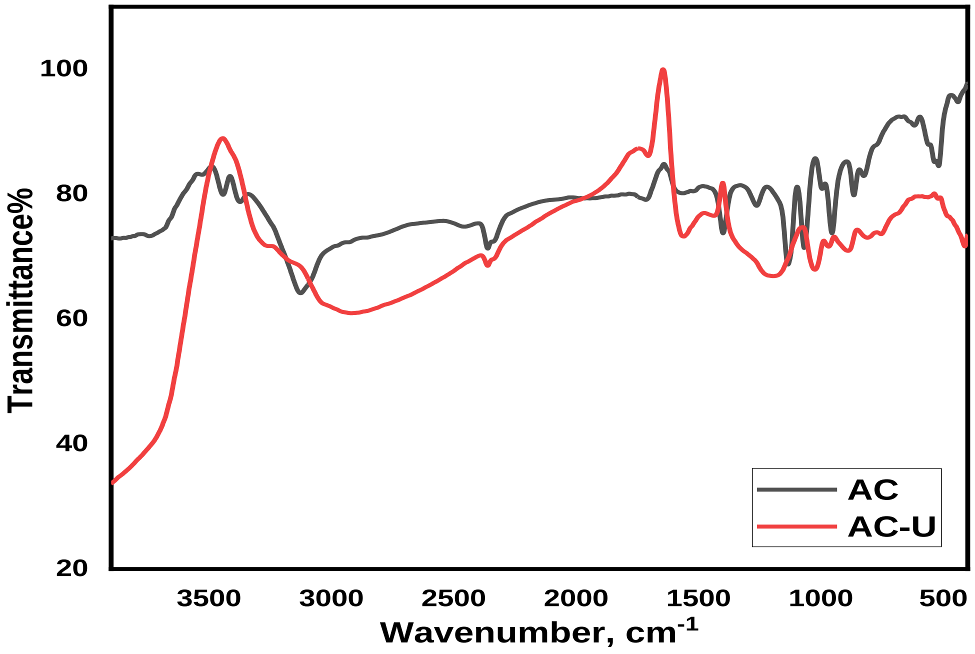
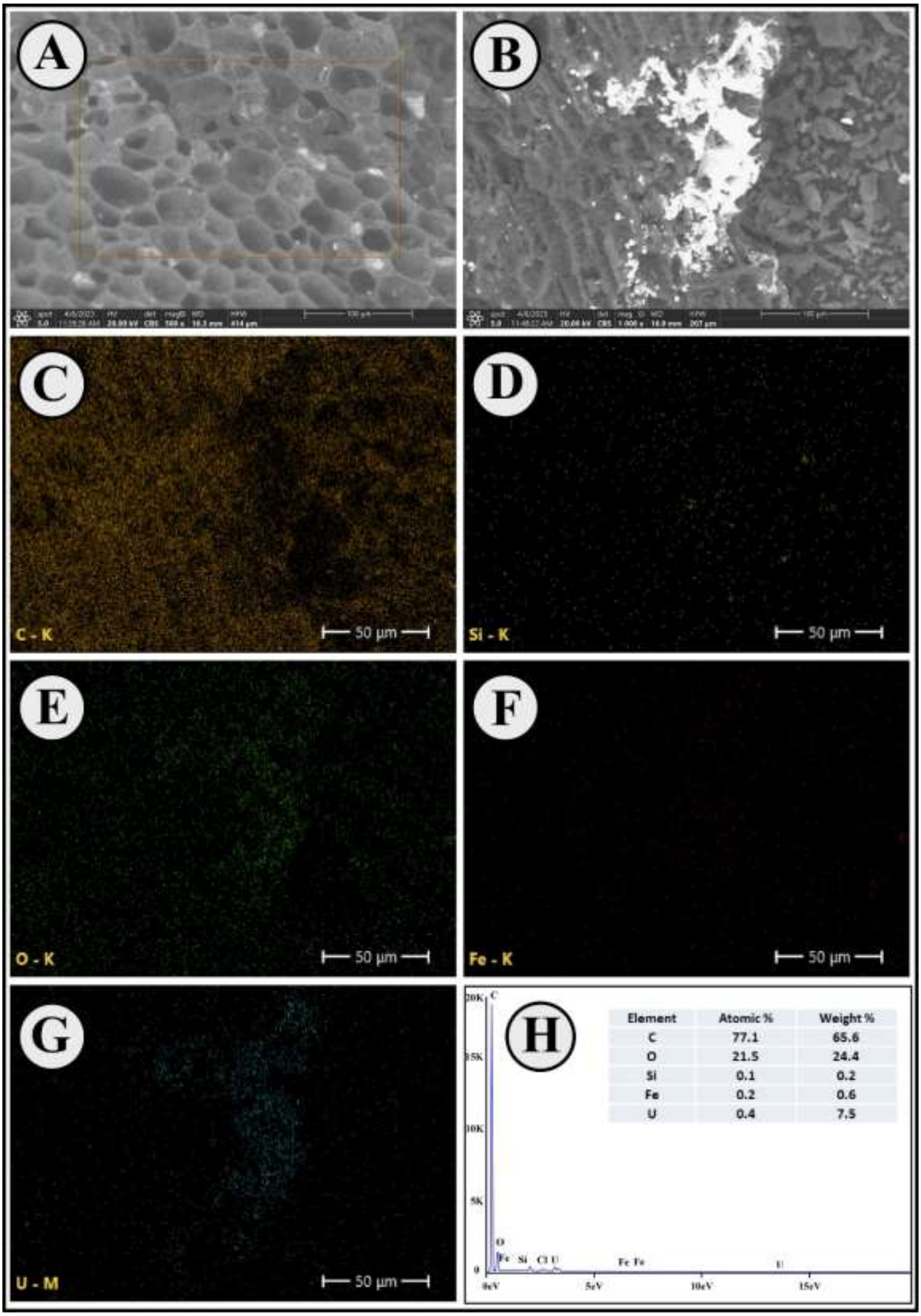


Figure (2): IR Spectroscopy of modified activated carbon prepared from corn cobs before (AC), and after (AC-U) treatment with wastewater sample containing uranium



Element	Atomic %	Weight %
C	77.1	65.6
O	21.5	24.4
Si	0.1	0.2
Fe	0.2	0.6
U	0.4	7.5

Figure (3): EDX, ESEM, and mapping of the activated carbon prepared from corn cobs appearing the intricate, porous formation after uranium adsorption.3A before U loading&3B for AC-U loaded.

3.1.3. Adsorption Experiments

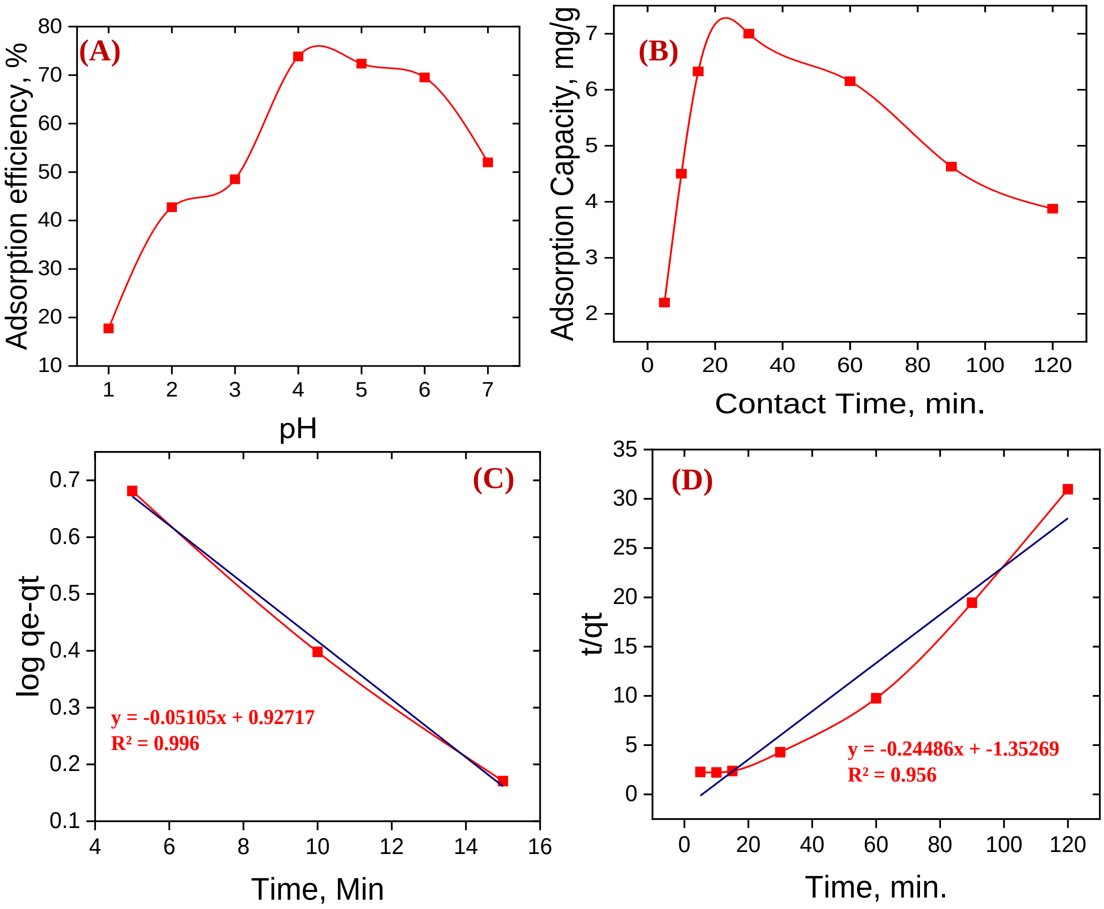


Figure (4): (A): Effect of pH upon uranium adsorption on activated carbon material applied conditions of U concentration 102 mg/L in 20 mL Solution of U, 0.2 g biomass, 120 mesh, 35 ºC temp, pH 4, Shaking, 125 rpm), (B): Effect of contact time on the effectiveness of activated carbon for uranium adsorption, (Concentration 102 mg/L in 20 mL Solution of U, 0.3 g biomass, 120 mesh, temp 35 ^{O}C, pH 4, Shaking, 125 rpm), (C): Pseudo-first order reaction of uranium adsorption upon activated carbon, and (D): Pseudo-second order reaction on uranium adsorption of activated carbon material

Table (2): Kinetic parameters of uranium adsorption upon activated carbon from corn cobs according Lagergren and Ho & McKay models

Kinetic model					
Pseudo first order			Pseudo second order		
q_1, (mg/g)	K_1 (min^{-1})	R^2	q_2, (mg/g)	K_2 (g/mg.min)	R^2
8.46	0.011757	0.996	4.084	0.04432	0.956

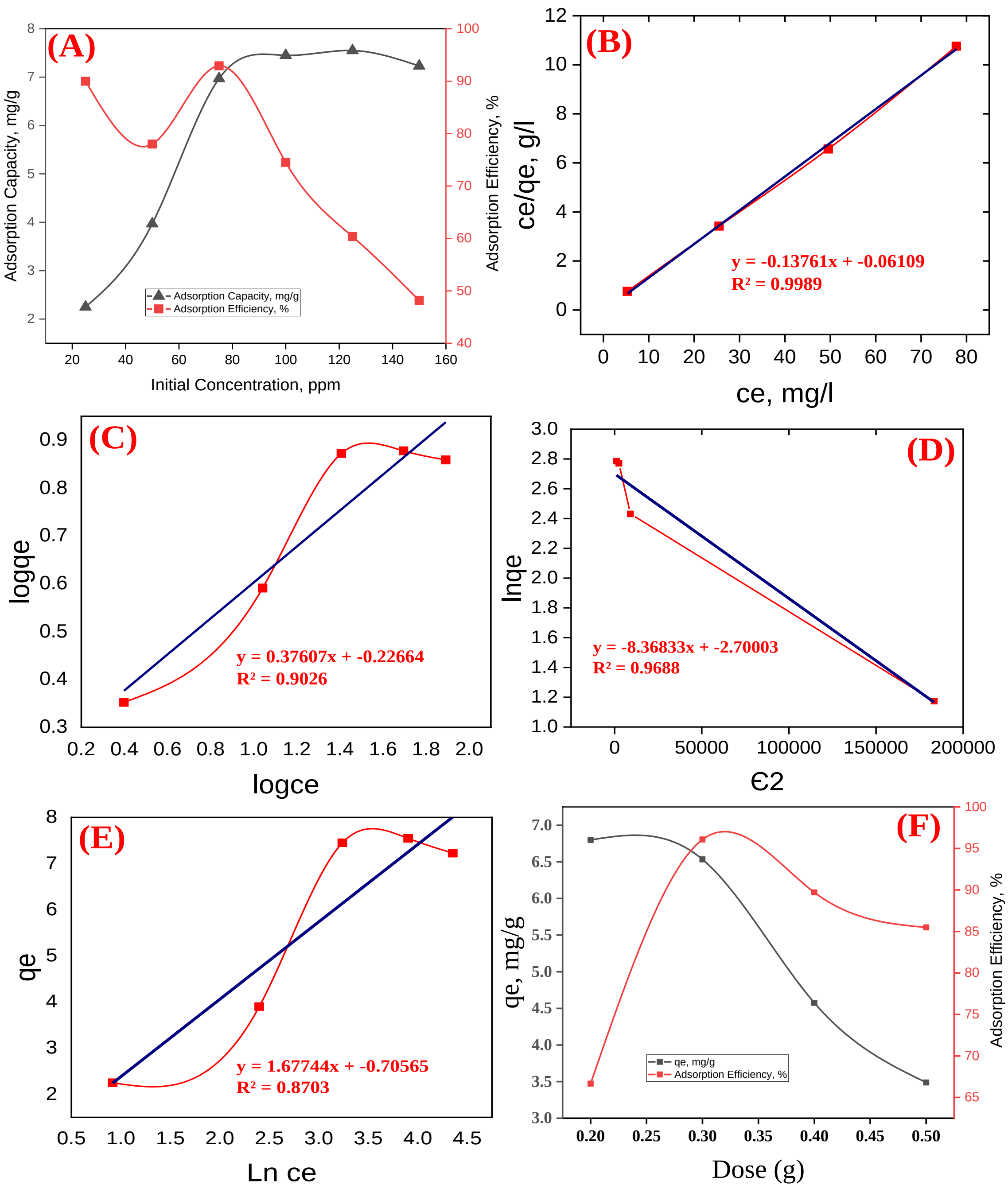


Figure (5): (A): Effect of the initial uranium concentration upon the adsorption efficiency and adsorption capacity by activated carbon, (Various concentrations, mg L^{-1} in 20 mL solution of U, 0.2 g carbon, 120 mesh, temp 35 °C, pH 4, 125 rpm), (B): Langmuir isotherm, (C): Freundlich isotherm, (D) D-R isotherm (E), Temkin isotherm, of uranium adsorption upon activated carbon synthesized from corn cobs, and (F): Effect of activated carbon material dosage upon uranium adsorption efficacy and adsorption capacity, (Concentration 102 µg g^{-1} in 20 mL Solution of U, various biomass dose, 120 mesh, 45 ^{O}C temp, pH 5, Shaking, 125 rpm).

Table (3): Parameters of uranium adsorption by Langmuir isotherm, Freundlich isotherm, D-R isotherm, Temkin isotherm at room temperature

47. **Isotherm model**	48. **Parameters**	49. **Value**
50. Langmuir isotherm	51. Q_L (mg/g)	52. 7.27
	53. K_L	54. -2.2526
	55. R^2	56. 0.9989
57. Freundlich isotherm	58. K_F (mg/g)	59. 1.685156
	60. n	61. 2.659
	62. R^2	63. 0.9026
64. D-R isotherm	65. Q_{DR} (mg/g)	66. 14.88
	67. K_{ad} (mol^2/KJ^2)	68. 8.369 X 10^{-3}
	69. E (KJ/mol^2)	70. 0.00773
	71. R^2	72. 0.9688
73. Temkin isotherm	74. B (KJ/mol)	75. 1.67744
	76. A_T (L/g)	77. 1.522983
	78. b_T	79. 1476.996
	80. R^2	81. 0.8703

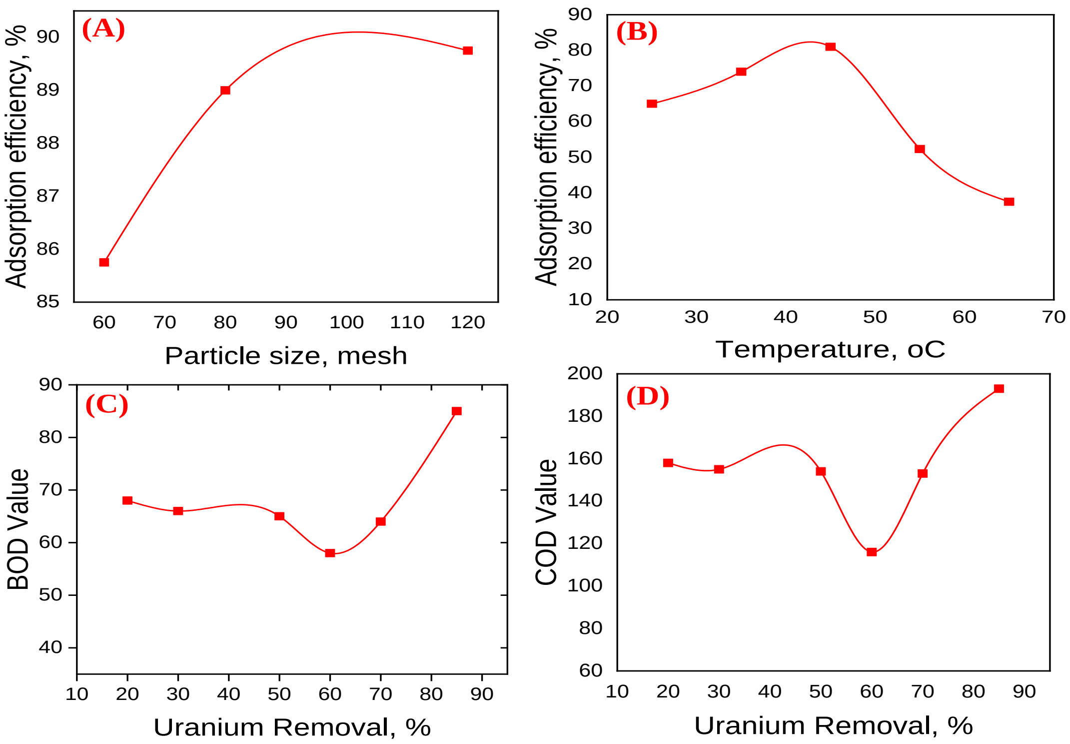


Figure (6): (A): Effect of particle size upon uranium adsorption efficiency using activated carbon, (Concentration 102 µg g^{-1} in 20 mL Solution of U, 0.3 g biomass, temp 35 °C , various grain size, pH 4, Shaking, 125 rpm), (B): Effect of temperature on U adsorption efficiency by activated carbon, (Concentration 102 µg g^{-1} in 20 mL Solution of U, 0.2 g biomass, 120 mesh, various temp, pH 4, Shaking, 125 rpm), (C): Effect of BOD results on different removal percentages with optimum condition of (PH=4, contact time=15 min, particle size 120 mesh, conc 102 mg L^{-1}, and (D): Effect of COD results at different removal percentages with optimum condition of (PH=4, contact time=15min, particle size 120 mesh, conc 102 mg L^{-1}).

Table (4): Statistical parameters analysis

82. Parameter	83. N	84. Mean	85. SD	86. Sum	87. Min	88. Max	89. Correlation 90. coefficient 91. (Pearson)
92. pH	93. 7	94. 4	95. 2.16025	96. 28	97. 1	98. 7	99.
100. Adsorption eff., %	101. 7	102. 53.81286	103. 20.1876	104. 376.69	105. 17.75	106. 73.84	107. 0.6883
108. Contact Time, min.	109. 7	110. 47.14286	111. 44.3337	112. 330	113. 5	114. 120	115.
116. Adsorption Capacity, mg/g	117. 7	118. 4.95357	119. 1.66129	120. 34.675	121. 2.2	122. 7	123. -0.0533
124. Dose (g)	125. 4	126. 0.35	127. 0.1291	128. 1.4	129. 0.2	130. 0.5	131.
132. Adsorption eff., %	133. 4	134. 84.48529	135. 12.6514	136. 337.9411	137. 66.666	138. 96.07843	139. 0.51122
140. Temperature, ºC	141. 5	142. 45	143. 15.81139	144. 225	145. 25	146. 65	147.
148. Adsorption eff., %	149. 5	150. 61.96	151. 17.3806	152. 309.8	153. 37.5	154. 81	155. -0.69775
156. Particle size, mesh	157. 3	158. 86.66667	159. 30.5505	160. 260	161. 60	162. 120	163.
164. Adsorption eff., %	165. 3	166. 88.16667	167. 2.12623	168. 264.5	169. 85.75	170. 89.75	171. 0.85954
172. Uranium Removal, %	173. 6	174. 52.5	175. 24.4439	176. 315	177. 20	178. 85	179. 0.27236
180. COD Value	181. 6	182. 154.83333	183. 24.4084	184. 929	185. 116	186. 193	187.
188. Uranium Removal, %	189. 6	190. 52.5	191. 24.4439	192. 315	193. 20	194. 85	195. 0.41197
196. BOD Value	197. 6	198. 67.66667	199. 9.13601	200. 406	201. 58	202. 85	203.

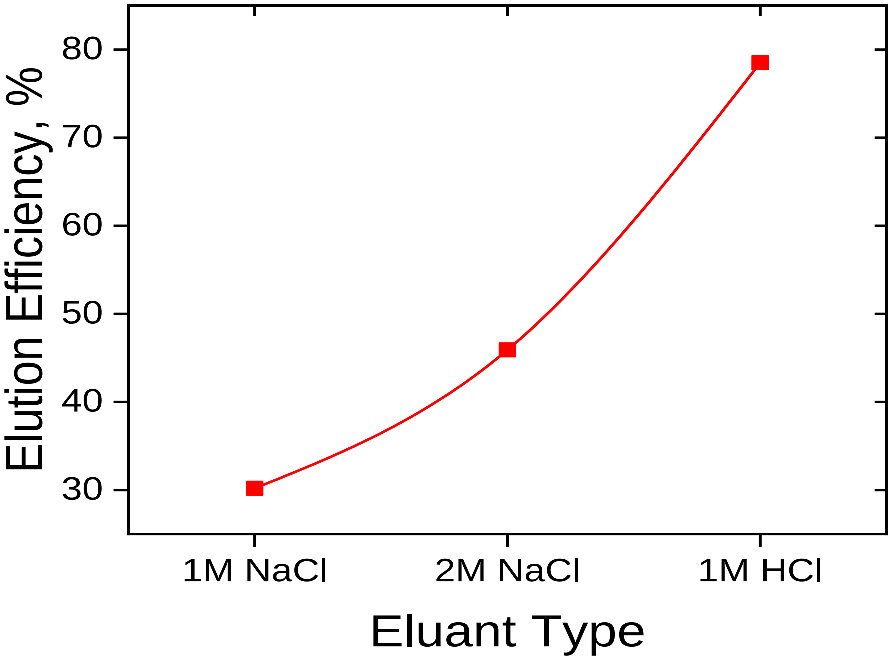


Figure (7): Effect of eluant type upon uranium elution efficiency from the loaded activated carbon synthesized material

3.2. Discussion

3.2.1. Chemical Composition of the Studied Wastewater Sample

The results (Table 1) show the concentrations of several elements in a prepared spiking wastewater sample, with magnesium (851.96 mg/L) and calcium (284.55 mg/L) being the most prevalent, indicating their probable role as key components. Iron (101.04 mg/L) and uranium (102 mg/L) are also present in significant concentrations. Manganese, copper, nickel, and zinc are trace metals in smaller proportions, while molybdenum and barium occur in extremely low concentrations. Some others such as lead, chromium, and cadmium, are not detected. Rare earth elements (REEs) have a total concentration of 140. Also, BOD and COD values were measured.

3.2.2. Characterizations of Activated Carbon from Corn Cobs

Infrared Spectroscopy

The obtained results (Fig. 2), show The FTIR analysis reveals significant differences between pure activated carbon (AC) and uranium-loaded activated carbon (AC-U), confirming successful uranium adsorption and surface interactions.[39] The most notable changes occur in the O-H (3400–3200 cm^{-1}) and C=O (1700–1600 cm^{-1}) regions, where AC-U exhibits increased absorption and new peaks, indicating uranium binding to hydroxyl and carbonyl functional groups. The emergence of distinct bands in the 900–800 cm^{-1} range further supports the presence of uranyl (UO_2^{2+}) vibrations, confirming chemisorption. [40]The overall decrease in transmittance across the spectrum suggests enhanced surface interactions, likely due to uranium complexation with oxygen-containing groups (e.g., carboxyl, phenolic, or ether moieties). These findings align with known uranium adsorption mechanisms, where UO_2^{2+} ions form inner-sphere complexes with carbon's oxygenated sites. [41]

Environmental Scanning Electron Microscopy (ESEM)/Energy Dispersive X- Ray (EDX) Scrutiny of the Activated Carbon Samples

Figures 3 The SEM image of the synthesized corn cob-derived activated carbon (Fig. 3A) reveals a highly macroporous structure, which is advantageous for biosorption due to enhanced surface accessibility. The STEM-elemental mapping (Fig. 3C-G) further demonstrates the uniform distribution of key compositional elements (C, Si, Fe, and O), suggesting a homogeneous biosorbent matrix. This uniformity aligns well with the consistent distribution of adsorbed uranium ions, indicating effective and stable uptake across the material. Additionally, EDX analysis (Fig. 3H) confirms the biosorbent's composition, primarily carbon (77.1%) and oxygen (21.5%), with trace amounts of silicon (0.1%) and iron (0.2%). The detectable presence of uranium (0.4%) in the EDX spectrum corroborates the material's successful adsorption capacity, underscoring its potential as an efficient sorbent for uranium removal from aqueous solutions.

3.3.3. Adsorption Experiments Discussion

Effects of pH

The effect of pH on uranium adsorption by using activated carbon was studied by varying the pH from 1 to 7, while keeping all the other parameter fixed at: initial uranium concentration of 102 µg U g^{-1}, contact time of 30-minute, temperature of 45 °C, dose of 0.3 g and particle size of 120 mesh. The obtained results present in Figure 4A show that the adsorption efficiency increases with increasing pH till 4 then decrease with increasing pH while the pH 4 is the optimum for uranium adsorption, where the adsorption efficiency reached 73.9 % which could be attributed to less availability of H^+ to compete with other metal ions such uranium for adsorption sites of biomass. **[42-43]**

The Effect of Contact Time

The effect of contact time on uranium adsorption using synthesized activated carbon material was studied by varying the contact time from 5 to 120 min, while keeping all parameter fixed. The obtained results shown in Figure 4B, indicate that with the increase in the contact time, the uranium adsorption efficiency increased from 21.56 % at 5 min and reach its maximum at 15 min to 85.35 % while the maximum adsorption capacity achieved at 30 min after that equilibrium was attained of about 7mg/g. Therefore 30 min would be chosen as the optimum contact time. These results agree with[16]

Kinetics of Uranium Adsorption

The results of adsorption kinetics parameters of uranium adsorption upon activated carbon from corn cobs according Lagergren and Ho & McKay models are listed in Table 2 and Figures 4 C and D which proved that the correlation coefficient of pseudo first order is 0.998 while that pseudo second order is 0.956 while the calculated adsorption capacity from the pseudo first order is 8.46 mg/g and 4.084 mg/g for the second order suggesting that pseudo first order can express well the uranium adsorption. These data are confirmed by the experimental values (7 mg/g), for the investigated concentration being close to the theoretical obtained applying pseudo first order.

Effect of Initial U Concentration

The intensity of the uranium concentration was adjusted at different intervals between 25 and 150 mgL^{-1} to examine the influence of the initial uranium concentration. Based on the results shown in Fig. 5A, it is evident that uranium adsorption efficiency improves with uranium starting concentration with starting concentration of 75 mgL^{-1}, it reaches its maximum effectiveness of 92.93 % while the maximum adsorption capacity is achieved at uranium initial concentration of 125 mgL^{-1} which reaches 7.55 mg/g. Moreover, no improvement in adsorption efficiency was seen with any further concentration increase above the initial concentration. The following could be the cause of this: Uranium ions are free to travel throughout the solution when the uranium concentration is low when there is no binding sites left. Nevertheless, most of the binding sites fill with uranium ions when the uranium concentration rises. Furthermore, competition for free-binding sites arises with any increase in uranium concentration. These results are in line with those published by[44]

Uranium Adsorption Isotherm Using Activated Carbon

The results illustrated in Figures 5B to E and presented in Table 3 outline the parameters for uranium adsorption based on various isotherm models at room temperature, emphasizing how well they correlate with experimental data. The Langmuir isotherm demonstrates the highest equilibrium adsorption capacity, with a value of 7.27 mg/g and a strong correlation coefficient of 0.9989, closely aligning with the observed practical adsorption capacity of 7 mg/g. The Freundlich and D-R models also represent the adsorption process, showing moderate correlation coefficients of 0.9026 and 0.9688, respectively. In contrast, the Temkin model displays a lower correlation (R^2 = 0.8703). The energy of adsorption serves as an essential measure of the type of adsorption processes occurring. Based on the D-R isotherm, the mean free energy (E) is calculated to be 0.00773 KJ/mol^2, which is significantly lower than 8 KJ/mol. This indicates that the adsorption process is primarily physical, relying on weak van der Waals forces instead of chemical bonding. Similarly, for the Temkin isotherm, the adsorption energy constant (B = 1.67744 KJ/mol) further suggests a physical adsorption mechanism. These findings reinforce that uranium adsorption onto the examined adsorbent is mainly driven by physical interactions, corroborating the outcomes from the kinetic study.

Effect of Adsorbent Dose:

The effect of adsorbent dosage on uranium adsorption using prepared activated carbon material has been studied by varying the adsorbent dosage from 0.2 to 0.5 g, while keeping all the other parameter fixed. The results are in Figure 5 F, indicate that with the increase in the adsorbent dosage, the uranium adsorption efficiency increased and reached its maximum at 0.3 g, attaining 84.75 % and about 6.6 mg/g adsorption capacity and after that decreased to 85.5 % at 0.5 g. However, further increase of adsorbent dosage does not exhaust uranium adsorption. This may be due to the overlapping of adsorption sites because of overcrowding of adsorbent particles. In addition, the number of ions bound to the adsorbent and the number of free ions remain constant even with further addition of the dose of adsorbent,**[45-46].**

Effect of Adsorbent Particle Size:

The effect of particle size on uranium adsorption using prepared activated carbon from corn cobs was studied by varying the particles size from 60 to 120 mesh, while keeping all the other parameter fixed. The obtained data in Figure 6 A, show that the particle size of 120 mesh is the most effective size, where the efficiency of uranium adsorption reached 89.8 % and with increasing the diameter of the adsorbent partial the extraction adsorption efficiency decreased to reach 85.75 % at the particles 60 mesh this is because the surface area increases with the small size of the partial which causes many adsorbent bindings site available.

Effect of Temperature:

The effect of the temperature on uranium adsorption was studied at the temperatures from 25 to 65 ^{o}C and keeping the other factor fixed. When the experimental adsorption temperature increased from 25˚C to 45 ˚C, the adsorption capacity of uranium increased with the increase of equilibrium concentration and eventually tended to be stable. The obtained results in Figure 6 B, shows that the adsorption capacity of activated carbon increased with the increase of temperature from 25 to 45 with 65 to 81 % respectively, and decrease with increase the temperature which show that the reaction is exothermic. These results agree with[47]

Summing up, the optimum condition applied on the adsorbent activated carbon prepared from corn cobs to adsorb uranium from a simulated spiked wastewater sample are as following: the adsorbent dosage 0.3 g, 20 mL solution, initial uranium concentration 102 mg/L contact time 30 min, pH of 4, temperature of 45 °C and particle size of 120 mesh. On the other hand,[48] achieved uranium adsorption efficiency of 92.9 % using activated charcoal applied the optimum adsorption conditions of 75 mg/L uranium initial concentration, 0.2 gm adsorbent dose, 40 ml standard uranium synthetic solution, 15 min as contact time, and at 35°C temperature. This research result shows that the adsorption efficiency reached about 88.3 % with deviations about 4.6 % compared with results obtained when using of activated charcoal in the adsorption of uranium from standard synthetic solution, this deviation is due to other ions in the wastewater sample such as iron competes uranium.

Studying the Effect of COD & BOD Results at Different Removal Percentages with Optimum Conditions.

BOD is defined as the amount of dissolved oxygen needed by aerobic biological organisms in a body of aqueous solution to break down the organic material present in an aqueous sample, at a specific temperature and specified period. The effect of BOD on different removal percentages was studied. Chemical oxygen demand (COD) is the total amount of oxygen consumed by strong oxidants present in the aqueous solution during the decomposition and chemical oxidation of organic/inorganic matter. The COD values at different removal percentages of U was studied, the obtained data in Fig 6D. It has been shown that there is a significant reduction in BOD and COD values with increasing the uranium removal percentages till reaching 60% then an increase in their values The untreated effluent has an extremely high organic content measured in terms of COD, & BOD. This has an adverse environmental impact. The values of BOD&COD were obtained from the water &air lab in the national research center.

The increase in both BOD and COD values with increasing of uranium removal percentages may be due to increasing in the contact time between the polluted aqueous solution and the activated carbon, so increasing the amounts of AC in the aqueous solution enhancing the degradation, which leads to increasing of COD and increasing BOD accordingly. Therefore, optimizing the uranium removal from aqueous solution, the contact time used, and the dose of activated carbon is essential, simultaneously, due to their effect on increasing the BOD and COD.

Results of Statistical Analysis

The statistical analysis reveals how different parameters affect uranium adsorption efficiency and capacity.

1- **pH** demonstrates a moderate positive correlation ($r = 0.6883$, $p = 0.0874$), indicating a noticeable but statistically insignificant influence on uranium adsorption efficiency.
2- **Contact time** shows a negligible correlation ($r = -0.0533$, $p = 0.9097$), suggesting no meaningful relationship with adsorption capacity.
3- **Adsorbent dose** presents a moderate correlation ($r = 0.51122$, $p = 0.48878$), but the high p-value indicates that this relationship lacks statistical significance.
4- **Temperature** exhibits a negative correlation ($r = -0.69775$, $p = 0.19017$), implying that higher temperatures may reduce adsorption efficiency, although this result is also not statistically significant.
5- **Particle size** has a strong positive correlation ($r = 0.85954$, $p = 0.3415$), suggesting a significant potential impact on adsorption efficiency, though the limited sample size affects the reliability of this statistic.
6- Finally, the chemical parameters **COD** and **BOD** show weak correlations with uranium removal ($r = 0.27236$, $p = 0.60156$ and $r = 0.41197$, $p = 0.4171$, respectively), indicating minimal direct effects.

Elution of Activated Carbon Loaded by Uranium from the Spiked Wastewater Sample

In the present work, the elution system is studied by using 1, 2 M sodium chloride solution. This eluant solution passed through the loaded activated carbon material and saturated with uranium adsorption at a flow rate of 1 mL/min which corresponds to a contact time of about 20 min. The obtained eluant solution was collected every 10 mL for uranium analysis. The results obtained are plotted in Fig. 7. Which revealed that 1M HCl is the most suitable eluting agent thus the elution efficiency reached about 78.5 % in one cycle.

Conclusion

This study showcases the effective use of activated carbon derived from corn cobs for removing uranium from water, positioning it as a cost-effective and environmentally friendly option for wastewater treatment. By optimizing critical factors such as pH, contact time, temperature, particle size, and adsorbent dosage, the process achieved a uranium removal efficiency of 88.3% in simulated conditions. The adsorption process was best described by the Langmuir isotherm model and pseudo-first-order kinetics, indicating that it involves monolayer adsorption and reaches equilibrium quickly. Further analysis confirmed the physical nature of the adsorption through isotherm and thermodynamic studies. Moreover, elution tests identified 1M HCl as the most effective solution for recovering the adsorbed uranium, demonstrating the potential for reusing the activated carbon. Overall, the results emphasize the promise of using agricultural waste-based activated carbon for sustainable remediation of heavy metals in contaminated water systems. By transforming agricultural solid waste such as corn cob waste into a valuable product like an affordable adsorbent, a significant portion of it can be utilized and its economic value maximized while also contributing to waste reduction

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