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Adsorption and photo degradation for organic pollutants in wastewater using copper oxide based on waste cotton impregnated with sodium hydroxide (CuO/NaOH/CW) composites

Ali A. Hassan [a, *], Ibtehal K. Shakir [b], Munaf Al-Lami [c]

a Chemical Engineering Department, Al Muthanna University, Muthanna, Iraq
b Chemical Engineering Department, College of Engineering, University of Baghdad, Baghdad, Iraq
c Chemical and Environmental Department, Budapest University, Budapest, Hungary

Abstract

This work prepared new composite (CuO/NaOH/CW) and compared with another composite (HNO_3/NaOH/CW) from cotton waste, sodium hydroxide, copper sulphate and nitric acid for the treatment of refinery wastewater. Dry weight analysis confirmed the attachment of 29 and 32 % NPs in the composites of copper oxide and nitric acid, and their observed slow-release behavior contributed to enhanced stability. The accessory of copper oxide to the cotton waste surface fibrils and their deep infiltration into the matrix were obviously established by characterization analysis. The composite material was evaluated for its adsorption and photodegradation capabilities for organic removal from refinery wastewater (RWW). Remarkably, the synthesized composites exhibited impressive waste cotton activities against organic pollutants, achieving reduction rates of 89.2%, 78.4%, and 55.4% for CuO/NaOH/CW, HNO_3/NaOH/CW, and NaOH/CW, respectively. The cotton waste based CuO composites demonstrated non-toxicity and catalytic behavior under UV light exposure, offering insights for potential applications in organic pollutant removal and environmental remediation.

Keywords: cotton waste; adsorption; nanoparticles; copper oxide; water treatment; photodegradation.

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1- Introduction

Crude oil undergoes refining processes to transform it into petroleum and other valuable by-products [1-2]. However, these refining processes generate large quantities of wastewater comprising cooling water, process water, storm water, and sewage [3-4]. Oil refineries necessitate significant water usage for various operations such as catalytic cracking units and crude distillation [5-6]. Many of the toxins present in oil refinery wastewater are highly hazardous and can cause serious health issues even at low concentrations [7]. Hence, there is a growing interest in developing cost-effective methods for wastewater treatment [8-9].

One approach involves utilizing non-conventional agricultural by-products, mainly composed of cellulose, for adsorptive treatment of wastewater [10-11]. Indeed, activated carbon is renowned for its effectiveness in wastewater treatment due to its high surface area and adsorption capabilities [12-13]. However, its costliness has spurred research into alternative, low-cost organic adsorbents derived from various natural resources, agricultural wastes, and industrial by-products such as peat, wood, barley and rice husk, sawdust, and biomass [14-15]. Cellulose, being one of the most abundant natural polysaccharides, is a key component in many of these materials. It is highly abundant in cotton and wood, with cellulose accounting for about 95% of cotton and 50% of wood [16]. Cellulose is renowned for its strength and durability due to inter-molecular hydrogen bonds between hydroxyl groups and oxygen atoms on neighboring chains. However, unmodified cellulose lacks specific properties required for effective adsorption, such as variable physical stabilities and high metal ion removal capacity [17].

Cellulose composites prepared with different substances have shown promise in adsorption and oxidation treatment , offering improved elimination of organic pollutants from aqueous solutions [18-19]. Compared to activated carbon derived from charcoal , cellulose and metal oxide for eliminating organic compounds from wastewater [20]. Titanium dioxide (TiO_2) is widely used in photocatalytic processes due to its enhanced performance. However, the main drawback of TiO_2 is its high bandgap value, restricting its application to UV light absorption only [21]. To address this limitation, researchers are investigating visible-light-driven photocatalysts such as CuO, which has a relatively narrow bandgap and excellent photocatalytic performance [22-23]. Based on these considerations, the objective of this study is to prepare and characterize a composite adsorbent

*Corresponding Author: Email: ali.kazem2207d@coeng.uobagdad.edu.iq

based on CuO nanoparticles with waste cotton. The synthesized CuO/NaOH/CW composite, along with bare waste cotton and CuO photodegradation and compared with HNO_3/NaOH/CW by using nitric acid, will be employed for the adsorption and photocatalytic degradation of organic content in RWW under UV light.

2- Experimental section

2.1. Material and organic measurement

The wastewater contaminated with organic compounds that the discharge of refinery oilfields in the South of Iraq. RWW was stored at 5°C in a polypropylene container for treatment using oxidation technologies. The specifications of RWW are listed in Table 1. All materials used in this study were of analytical grade and utilized without any additional purification. Waste cotton was collected from tailoring workshops and underwent cutting and shredding processes.

The organic removal efficiency was estimated using Eq. 1:

$$\mathbf{Y_{OCRE}} = \frac{A_o - A_t}{A_o} \times 100\% \quad (1)$$

Where A_o and A_t is the organic compounds before and after treatment (in ppm).

2.2. The preparation of composites

The preparation of copper oxide solution [24] with some modification. The cotton waste was washed with hot and cold water in sequence until the water's tint continued reliable. Rendering to the lecture, after cleaning, the cotton waste was immersed in a 5% sodium hydroxide solution and constantly stirred [25]. After treating the CW with sodium hydroxide, hemicellulose and lignin scums were detached by frequently cleaning and washing it with ionic water until the normal pH. To produce alkane cotton, the cotton waste with sodium hydroxide was then dry at 70 °C in an oven set for one day. So as to attain a well-mixed solution, the cotton waste with sodium hydroxide was then saturated in solution from 5/20 mL of concentrated nitric acid and 20 mL of ionic water correspondingly. The solution was then heated to 40 °C while being continually stirred for one day. After that, it was frequently cleaned with water that had been pH solution.

2.3. Characterization

The information outlines various analytical techniques for characterizing the composite adsorbent material. FTIR technique (FTIR-2000, Bruker) was employed using Attenuated Total Reflectance mode to analyze the functional groups present in the composite adsorbent. FE-SEM was utilized to examine the surface morphology and structure of both the bare CW (presumably referring to the substrate material) and the composite adsorbent. X-ray Diffraction (model MDK 2TESLA) experiments were performed to validate the successful synthesis of nanoparticles and their incorporation into the CuO/NaOH/CW composite. TGA (PerkinElmer TGA4000) was performed using a TA Instruments Q-500 to investigate the thermal stability and decomposition behavior of the composite adsorbent. UV-DRS (Shimadzu UV-1800) was employed for the band gap present in the copper oxide.

Table 1. The wastewater properties

Parameters	Values	Parameters	Values
Organic compounds	162.4(ppm)	Specific gravity	0.997
Turbidity	24.2NTU	Total dissolved solids	231456 (ppm)
Oxygen dissolved content	.041 (ppm)	Iron	0.23 (ppm)
pH	6.780	Viscosity	1.0210 m Pa/S

2.4. Adsorption/photodegradation procedure

The trials were approved in a batch reactor with 150 mL of polluted wastewater. The RWW was equipped with a photodegradation system that is a UV chamber equipped with 8 UV lamps. The trials were conducted at different temperatures with change times from 30 to 120 min. Before the addition of reagents, the pH of the solutions was adjusted using dilute NaOH or H_2SO_4 solutions. The setup included the addition of the adsorbent material to the reactor, which facilitated the photo-degradation process of the refinery wastewater under UV irradiation. Fig. 1 likely depicts a schematic representation of the experimental setup, including the placement of the reactor, UV chamber, and other essential components for conducting the adsorption and photodegradation experiments.

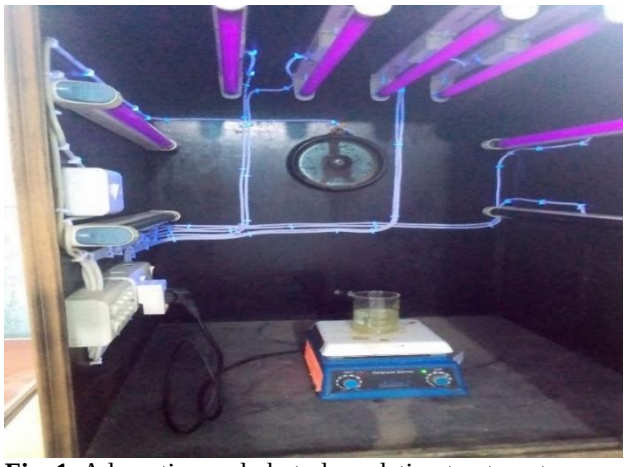

Fig. 1. Adsorption and photodegradation treatment

2.5. Dry weight analysis for Cu and NO_3 determination

The analysis involved two methods firstly Atomic Absorption Spectroscopy (AAS), AAS was used to quantify the percentage of CuO attachment to the CW in the composites. Ion chromatography was employed to determine the concentration of nitrate ions attached to the CW in the composites. The penetration percentage of composites and cotton wastes were intended from their dry weights utilizing the subsequent Eq. 2:

$$\text{Penetration percent} = \text{Composite weight} - \text{CW weight} \times 100\% \quad (2)$$

2.6. Experimental design

This effort established the best of untried circumstances aimed at organic pollutants of RWW applying adsorption /photodegradation treatment. The Box-Bingham design (BBD) method was working aimed at this purpose. The self-governing variables measured were reaction time (30-120), pH (3-9), dose (0.5-1.5), temperature (25-70), and UV light (2-8).

3- Results and discussion

3.1. Morphological features of synthesized composite adsorbent

The FE-SEM images in Fig. 2 exemplify the morphology and cotton waste structure and Exisite composite. The waste cotton exhibits a smooth surface, as shown in Fig. 2 a and b, while the nanoparticles of copper oxide are visible in Fig. 2 c. The bimetallic composite, as depicted in Fig. 2 d – f, displays a polygonal and abrasive structure [26]. This change in structure resulted in the composite photocatalytic materials having a larger specific surface area, which is conducive to the photocatalytic reaction.

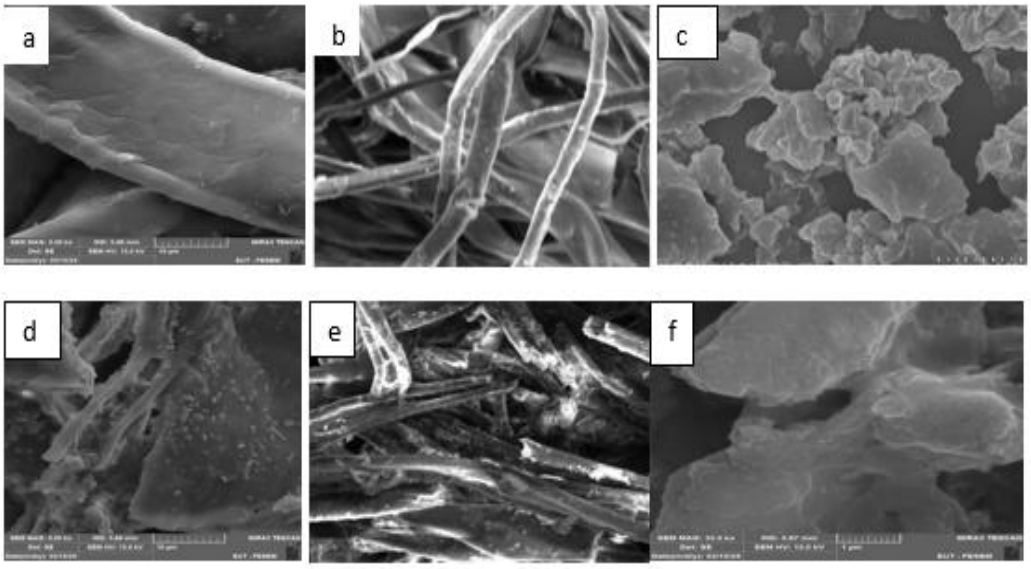

Fig. 2. (a) Cotton waste at 10µm, (b) Cotton waste at 25µm, (c) copper oxide, (d) CuO/NaOH/CW at 10µm, (e) CuO/NaOH/CW at 25µm, and (f) CuO/NaOH/CW at 1µm

Some CuO entered the interlayer of bentonite, while the rest was loaded onto the surface, consistent with XRD analysis. EDX analysis in Fig. 3 confirms the absence of copper in waste cotton, whereas CuO/NaOH/CW exhibits high copper concentrations that are clear in Table 2 for comparison between CW and CuO/NaOH/CW [27]. XRD patterns in Fig. 4 a reveal distinct features [28]. The presence of copper is evident in the XRD profile of waste cotton, with diffraction peaks at 43.32° and 53°. Additionally, CuO/NaOH/CW shows three peaks below $2\theta = 30$ and eleven peaks in the range of $2\theta = 30°–80°$, indicating the presence of both CW and CuO components.

The broadness of CuO peaks suggests nanoscale dimensions. FTIR spectra in Fig. 4 b reveals changes in waste cotton composition at different stages. Alkali treatment reduces hydrogen bonding, evidenced by decreased peak intensity between 3200 and 3400 cm^{-1}. Absorption peaks at 1529 cm^{-1} and 1226 cm^{-1} correspond to C=C stretching and CO stretching vibrations, respectively. Furthermore, the absorption peak at 3343 cm^{-1} indicates increased OH groups in cellulose after acid treatment [29].

The TGA results in Fig. 5 demonstrate the thermal behavior of the samples. CW exhibits characteristic weight loss stages attributed to cellulose degradation. Notably, the charred residue of CuO/NaOH/CW surpasses that of pure CW due to the presence of CuO, which withstands high temperatures [30]. Initially, in the first section, the CW material exhibited no discernible changes upon heating treatment until approximately 250°C, as evidenced by the absence of mass reduction in the thermogram [31].

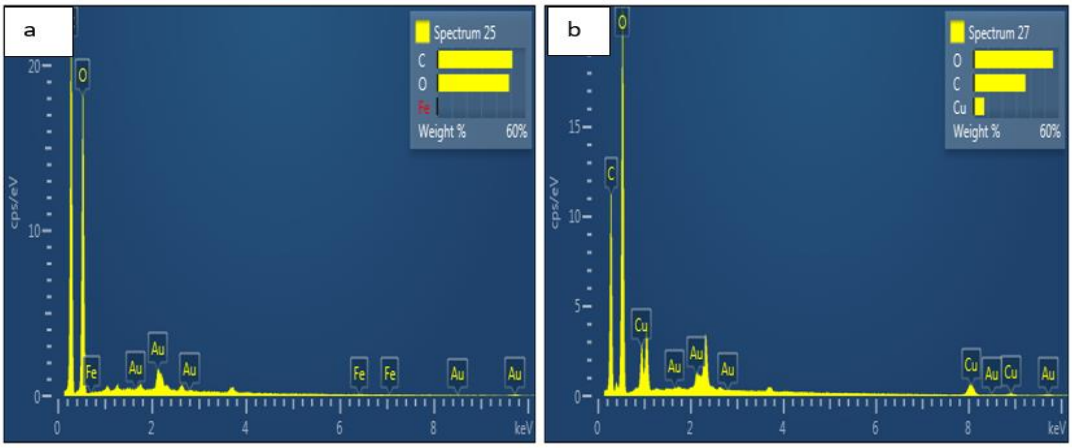

Fig. 3. (a) EDX for waste cotton, (b) EDX for CuO/NaOH/CW

Table 2. EDX for CW and CuO/NaOH/CW

Element	CW		CuO/NaOH/CW	
	Wt%	Atomic %	Wt%	Atomic %
C	51.02	58.16	36.56	45.70
O	48.86	41.81	55.96	52.53
Fe	0.14	0.03		
Cu			7.48	1.77
Total:	100.00	100.00	100.00	100.00

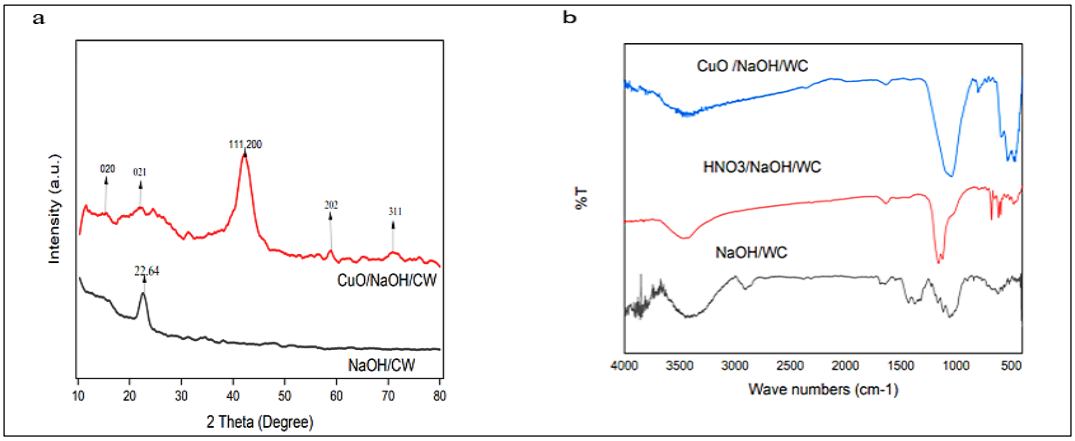

Fig. 4. (a) XRD patterns and (b) FTIR of CW and composite adsorbent

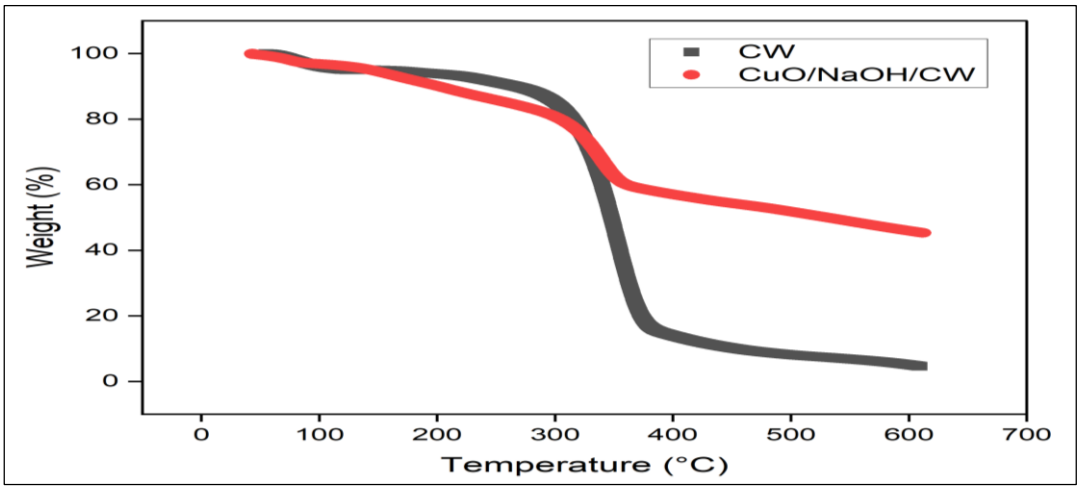

Fig. 5. TGA heating of CW and CuO/NaOH/CW

3.2. Modeling of composite adsorbent

The recovery of organic by way of function Oxidation time, pH, waste cotton, temperature, and UV lamps of waste cotton oxidation with change oxidation time, pH, amount, temperature and UV light irradiation.

Forty-sixty experiments were conducted according to the design of experiments using the Box–Bingham technique-performing ranges listed in Table 3 as follows:

Table 3. Results of the RSM experiments

Run no.	Oxidation time X_1	pH X_2	CW X_3	Temperature X_4	UV Lumps X_5	$Y_{NaOH/CW}$ (%)	$Y_{HNO3/NaOH/CW}$ (%)	$CuO_{/NaOH/CW}$ (%)
1	30	3	1	48	4	35.1	57.8	69.5
2	120	3	1	48	4	38.9	63.1	72.4
3	30	9	1	48	4	23.1	46.8	57.1
4	120	9	1	48	4	29.2	52.7	62.7
5	75	6	0.5	25	4	22.8	47.1	57.1
6	75	6	1.5	25	4	33.5	57.3	67
7	75	6	0.5	70	4	30.4	54.1	64.1
8	75	6	1.5	70	4	33.6	57.1	67.1
9	75	3	1	48	2	31.1	54.9	64.6
10	75	9	1	48	2	18.9	43.8	53.1
11	75	3	1	48	8	47.8	72.1	81.3
12	75	9	1	48	8	28.1	51.2	62.3
13	30	6	0.5	48	4	32.4	54.1	65.9
14	120	6	0.5	48	4	39.5	62.8	73
15	30	6	1.5	48	4	40.4	63.2	73.9
16	120	6	1.5	48	4	44.2	67.2	78.2
17	75	6	1	25	2	28.5	52.8	62
18	75	6	1	70	2	34.6	58.6	68.1
19	75	6	1	25	8	40.5	64.2	74
20	75	6	1	70	8	55.4	78.4	89.2
21	75	3	0.5	48	4	41.3	64.8	74.8
22	75	9	0.5	48	4	19.5	44.1	54.1
23	75	3	1.5	48	4	47.5	71.5	81
24	75	9	1.5	48	4	30.1	53.6	64.3
25	30	6	1	25	4	25.6	50.1	59.1
26	120	6	1	25	4	34.1	57.6	68.2
27	30	6	1	70	4	36.5	61.2	71.1
28	120	6	1	70	4	47.9	71.6	81.4
29	75	6	0.5	48	2	19.8	43.3	54.2
30	75	6	1.5	48	2	35.8	59.3	69.3
31	75	6	0.5	48	8	39.2	62.8	73.3
32	75	6	1.5	48	8	48.7	72.2	82.2
33	30	6	1	48	2	31.2	55.1	65.2
34	120	6	1	48	2	39.3	62.8	73.1
35	30	6	1	48	8	41.5	65.3	74.8
36	120	6	1	48	8	47.6	71.1	81.3
37	75	3	1	25	4	44.9	68.2	78.6
38	75	9	1	25	4	30.5	54	64.8
39	75	3	1	70	4	44.7	68.2	79.2
40	75	9	1	70	4	30.4	54.1	63.9
41	75	6	1	48	4	37.8	61.3	71.5
42	75	6	1	48	4	38.1	61.5	72.1
43	75	6	1	48	4	39	62.5	73.4
44	75	6	1	48	4	37.9	61.4	71.5
45	75	6	1	48	4	38.6	62.1	72.1
46	75	6	1	48	4	38.9	62.4	72.4

Examining Table 4 shows that the model is significant since the P-value is less than 0.05 and the F test is high for the oxidation by CuO /NaOH/CW [32] ,which demonstrated the high meaning of the regression model. The constant of multiple correlations for the CuO/NaOH/CW model was 89.2 % aimed at organic removal in refinery wastewater.

The main belongings plots reveal the best combination of serious limits aimed at attaining the best oxidation presentation, as exemplified in Fig. 6. Each plot highlights the best combination of limits for specific performance metrics. Previous authors has consistently designated that organic removal in wastewater increases with elevated levels of cotton amount , temperature, UV

light, and reaction time [33], Adsorption efficiency often decrease as pH increases. This might be as a result of variations in the adsorbent's and/or organic compounds surface charges at higher pH values, which lowers their attraction for one another and decreases adsorption [34].

Table 4. ANOVA for organic removal by CuO /NaOH/CW

Foundation	DOF	Seq. SS	Adj. MS	Fisher Value	P–test Value
1-Model	20	2483.56	124.178	5.65	0
Linear	5	148.13	29.626	1.35	0.278
X_1	1	9.3	9.302	0.42	0.521
X_2	1	55.04	55.038	2.5	0.126
X_3	1	12.61	12.613	0.57	0.456
X_4	1	18.05	18.052	0.82	0.374
X_5	1	52.95	52.948	2.41	0.133
Square	5	160.51	32.102	1.46	0.238
X_1^2	1	0.03	0.027	0	0.972
X_2^2	1	114.29	114.286	5.2	0.031
X_3^2	1	46.25	46.251	2.1	0.159
X_4^2	1	7.79	7.787	0.35	0.557
X_5^2	1	0.05	0.046	0	0.964
2-Way Interaction	10	63.93	6.393	0.29	0.977
X_1*X_2	1	1.6	1.599	0.07	0.79
X_1*X_3	1	1.86	1.855	0.08	0.774
X_1*X_4	1	0.16	0.16	0.01	0.933
X_1*X_5	1	0.35	0.354	0.02	0.9
X_2*X_3	1	4	4	0.18	0.673
X_2*X_4	1	0.57	0.573	0.03	0.873
X_2*X_5	1	14.06	14.063	0.64	0.432
X_3*X_4	1	11.62	11.615	0.53	0.474
X_3*X_5	1	9.61	9.61	0.44	0.515
X_4*X_5	1	20.1	20.102	0.91	0.348
Error	25	549.94	21.998		
Lack-of-Fit	20	547.46	27.373	55.34	0
Pure Error	5	2.47	0.495		
Total	45	3033.49			

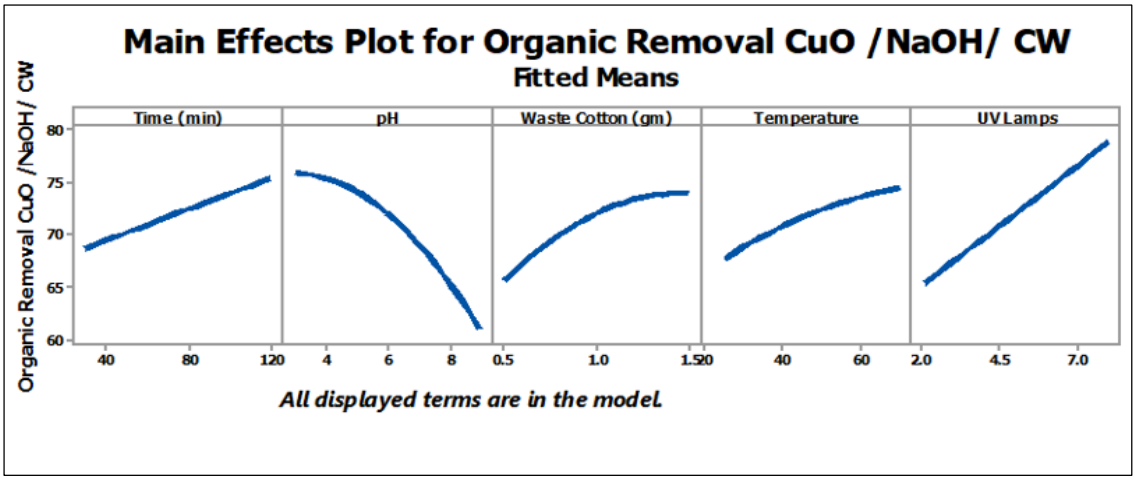

Fig. 6. Main effects plot for organic removal

3.3. Adsorption/photodegradation treatment

Studying the effect of irradiation time on composite adsorbents used for the adsorption/photodegradation of organic pollutants in RWW is crucial for optimizing the treatment process. This is because lengthy radiation exposure can improve the porosity and surface area of prepared adsorbent, thus providing more active sites for adsorption treatment [19] . Extended irradiation times better the photodegradation of organic contaminants in wastewater. The association between organic elimination and oxidation time along adsorption/photodegradation is obtainable in Fig. 7 a. The results were reliable with previous research [35]. At lower pH levels, the prepared composite surface may become protonated, subsequent in a positive charge of the surface.

This positive charge can promote electrostatic connections with negatively charged organic pollutants in RWW, leading to augmented adsorption onto the surface of the adsorbent. Moreover, certain functional groups on the prepared composite might become more protonated at the lower value of pH. This increase in oxidative potential can accelerate the breakdown of organic compounds, leading to more efficient removal from the wastewater [23]. The influence of pH on cotton adsorption organic by waste cotton, with sodium hydroxide and hydrogen

peroxide was investigated throughout a pH range of 3 to 9 with a contact time of 2 hours with all experiments performed. Fig. 7 b demonstrates that the greatest adsorption and oxidation efficiencies for NaOH/CW, HNO_3/NaOH/CW, and CuO/NaOH/CW were 41.3, 65.2, and 76.2 % respectively at 3 pH.

As a result, a higher dose of the composite adsorbent can lead to greater removal of organic pollutants from the wastewater, and increasing the dose of the composite adsorbent can result in more efficient utilization of the irradiation source (e.g., UV light). With a higher dose, more adsorbent particles are present in the wastewater, increasing the probability of interaction between the organic pollutants and the photocatalytic surface. Fig. 7 c indicates that organic compounds upsurges fast as waste cotton content upsurges because of the obtainability of more functional groups and thus additional redeemable surface places nearby to form developments with organic compounds. For NaOH/CW, HNO_3/NaOH/CW, and CuO/NaOH/CW (38.2 percent, 63.5 percent, and 72.4 %, respectively) [36].

Higher temperatures often lead to greater mobility of molecules, including both adsorbate molecules (organic pollutants) and adsorbent sites. This increased mobility can improve the diffusion of organic pollutants onto the adsorbent surface, leading to higher adsorption capacities and potentially greater removal efficiency. and higher temperatures can accelerate photodegradation reactions by increasing the rate of formation of reactive species (e.g., hydroxyl radicals) or by altering the energy levels of the photocatalytic materials [37].

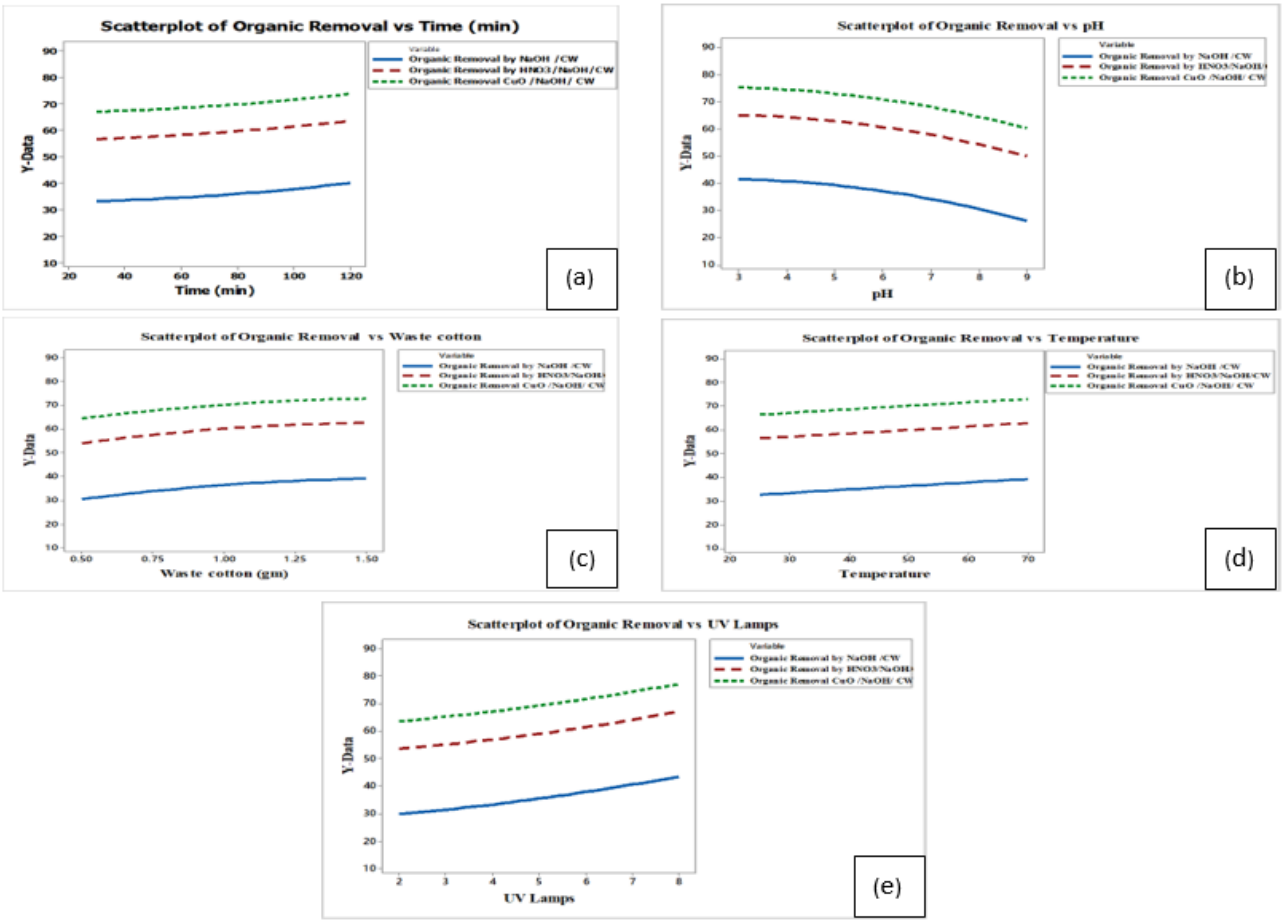

Fig. 7. The parameters effect on organic elimination (a) Time, (b) pH, (c) Dose, (d) Temperature, (e) UV lamps

Fig. 7 d the data exemplifies the percent elimination efficiency of organic compounds in refinery wastewater aimed at experiments showed at different temperatures, representative the positive effect of temperature. Exactly, the increase in temperature from 25°C to 70°C caused in improved elimination competence, the elimination competence increases from 31.4, 54.6 and 65.2 % to 37.4, 62.1, and 72.1 % at low and high temperatures for NaOH/CW, HNO_3/NaOH/CW, and CuO/NaOH/CW respectively. UV irradiation provides energy that can activate photocatalytic materials present in the composite adsorbent, leading to the cohort of reactive species such as free radicals (•OH). These reactive species are highly oxidative and can effectively degrade organic pollutants into smaller, less harmful molecules as shown in Fig. 7 e.

3.4. Optimization of working limits

The optimal experimental conditions for the CW, NaOH/CW, HNO_3/NaOH/CW, and CuO/NaOH/CW system to obtain the best values for working parameters such as cotton dose, pH, oxidation time, temperature, and

UV light. The measurement implications of the D-optimization are labeled in Fig. 8. The highest organic removal efficiencies were 89.2, 78.4, and 55.4% for CuO/NaOH/CW, HNO_3/NaOH/CW, and NaOH/CW respectively.

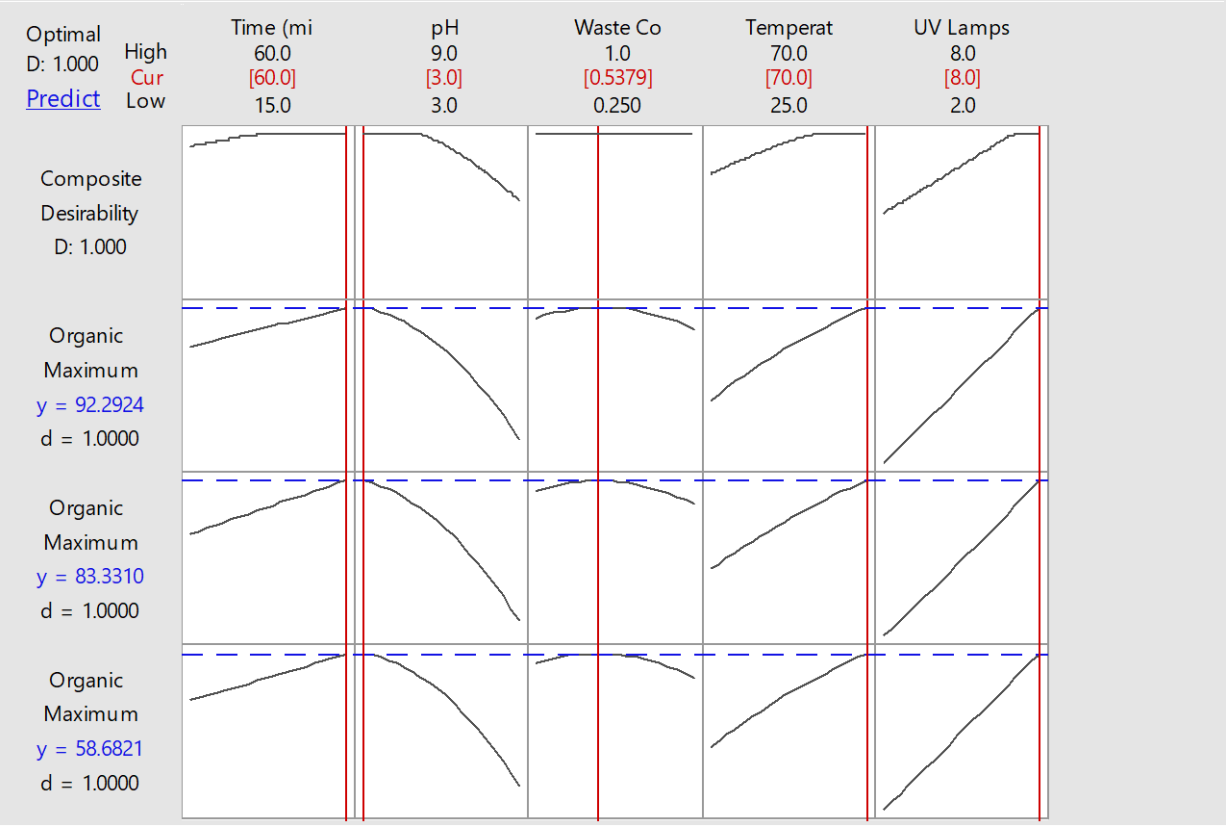

Fig. 8. Finest employed variables on refinery wastewater

3.6. The kinetic of oxidation

Photodegradation of organic compounds over CuO/NaOH/CW composite was investigated under different pH values and constant specific conditions: 1gm CW dose = 1 gm, and change reaction time (10-50 min) under UV light and ambient temperature. The pH of the solution was a crucial factor in the photo-oxidation treatment, significantly affecting the adsorbent surface charge. Many researchers have reported that most organic removal curves adhere to first-order or second-order kinetics. The first-order model is expressed as First-order kinetic Eq. 3 to be filled in.

$$ln\frac{Co}{c} = Kt \quad (3)$$

The kinetics model for Ex-site composite, as exemplified in Fig. 9, exposed a fitting correlation between oxidation time and the usual logarithm of the concentration ratio, revealing of a pseudo-first-order kinetic oxidation. The composite adsorbent showed a first-order squalor constant value of 0.0554 min^{-1} when pH solution was preserved at 3 [38].

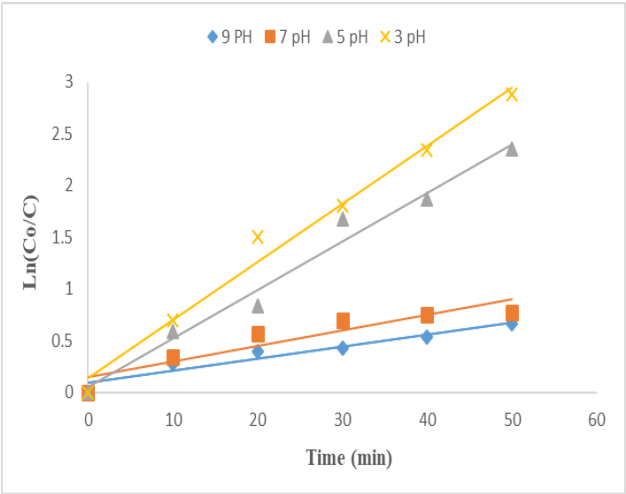

Fig. 9. Plot of –ln (C/Co) vs. time for organic elimination

4- Conclusion

In this study, CuO and CW were synthesized separately, and their adsorbent composite was prepared using the particle impregnation method. FE-SEM analysis demonstrated that the nanoparticles were effectively dispersed within the CW matrix and firmly attached to the CW pellicles. Furthermore, XRD results confirmed the crystallinity of CuO nanomaterial and revealed a type-I

cellulose structure in CW. The combination of these nanomaterials into CuO/NaOH/CW nanocomposite did not alter their crystal structures. Furthermore, we evaluated the waste cotton and catalytic properties of the CuO/NaOH/CW composite. These results highlight the potential of the new composite as a stable and cost-effective catalyst for organic degradation processes. The photocatalytic activity of the waste cotton in the composite suggests its potential for effectively removing organic and other pollutants from aqueous solutions. This indicates that these adsorbents could emerge as serious contenders for addressing environmental pollution challenges.

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الامتزاز والتحلل الضوئي للملوثات العضوية في مياه الملوثه بالنفط باستخدام أكسيد النحاس المعتمد على نفايات القطن المشربة بمركبات هيدروكسيد الصوديوم

علي عبدالحسن كاظم [١، *]، ابتهال كريم شاكر [٢]، مناف اللامي [٣]

١ قسم الهندسة الكيمياوية، جامعة المثنى، المثنى، العراق
٢ قسم الهندسة الكيمياوية، كلية الهندسة، جامعة بغداد، بغداد، العراق
٣ قسم الهندسة الكيمياوية والبيئة، جامعة بودابست للتكنولوجيا والاقتصاد، بودابست، هنغاريا

الخلاصة

النفايات القطنية (CW) هو بوليمر حيوي مهم بتطبيقات واسعة في مجالات الطب الحيوي والمتعلقة. هذه الدراسة تناولت القيود الكامنة فيه من خلال تشبيب جسيمات أكسيد النحاس (CuO NPs) في قطن النفايات تحت ضوء فوق البنفسجي .(CuO/ NaOH/CW) قارناها بـ HNO_3/NaOH/CW لمعالجة مياه الصرف الصناعي. تم تصنيع المركبات باستخدام نهج التركيب المركب ex–situ وتمت دراستها بشكل شامل باستخدام تقنيات تحليلية مختلفة. أكد تحليل الوزن الجاف على تثبيت ٢٩ و ٣٢ % من جسيمات النحاس في المركبات من أكسيد النحاس والحمض النيتريك، وساهم سلوكها في تعزيز الاستقرار. أظهر التحليل باستخدامFE–SEM ، FTIR، EDX، DRS، TGA، وتشتت الأشعة السينية دليلاً واضحًا على تثبيت جسيمات النانو على ألياف سطح قطن النفايات واختراقها العميق في المركب. تم تقييم المواد المركبة لقدرتها على الامتزاز وتحلل الضوء لإزالة الملوثات العضوية من مياه الصرف الصناعي. لاحظت المركبات المركبة المصنعة نشاطًا ملحوظًا ضد الملوثات العضوية، حيث بلغت معدلات الانخفاض ٨٩,٢%، ٧٨,٤%، و ٥٥,٤% لـCuO/NaOH/CW ، HNO_3/NaOH/CW، و NaOH/CW على التوالي. أظهرت مركبات أكسيد النحاس القائمة على قطن النفايات عدم السمية والسلوك الحفازي تحت تعرض ضوء فوق البنفسجي، مما يقدم رؤى لتطبيقات محتملة في إزالة الملوثات العضوية وتحسين البيئة.

الكلمات الدالة: النفايات القطنية، الامتزاز، المواد النانووية، اوكسيد النحاس، معالجة المياه والعوامل الموكسدة.