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Efficient Removal of Organic and Inorganic Pollutants from Hospital Wastewater Using Flash Graphene in Batch Experiments

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ABSTRACT

Hospital wastewater contains a variety of organic, inorganic, and heavy metal contaminants. In this study, wastewater samples were collected from Al-Sader Medical City Hospital in Al-Najaf, Iraq, and the removal efficiency of pollutants was evaluated using flash graphene (FG) as an adsorbent. Flash graphene was synthesized from Iraqi orange peel using a novel carbon-based method known as flash Joule heating (FJH). The data obtained demonstrate the presence and subsequent reduction of various contaminants in hospital wastewater—such as total suspended solids (TSS), phosphate (PO_4^{3-}), pH, total dissolved solids (TDS), dissolved oxygen (DO), total organic carbon (TOC), nitrate (NO_3^-), chloride (Cl^-), cobalt (Co), copper (Cu), and chemical oxygen demand (COD)—after treatment with flash graphene. Based on biological and chemical standards, the concentrations of heavy metals such as copper and cobalt exceeded the permissible limits set by Iraqi water quality regulations. In addition, elevated levels of total hardness and chloride were also observed, exceeding national water quality standards. These findings suggest that hospital wastewater is a significant source of environmental pollution and should be carefully considered when formulating strategies to assess environmental and public health risks. Flash graphene, characterized by an average pore diameter of 18.534 nm and a specific surface area of 11.168 m²/g, proved to be an effective adsorbent for removing organic pollutants (BOD, COD, TOC), inorganic contaminants (TDS, DO, PO_4^{3-}, NO_3^-, Cl^-, Co, Cu), and mixed pollutants such as TSS. This study proposes that adsorption using flash graphene could serve as a more cost-effective alternative to conventional hospital wastewater treatment systems. The volume and composition of toxic substances and liquid waste generated by hospital operations pose significant risks to both human health and the environment. In many developing countries, untreated hospital wastewater is often discharged directly into the environment, including rivers and other water bodies, which exacerbates environmental pollution.

1. INTRODUCTION

Wastewater represents one of the most significant threats to aquatic ecosystems. According to the World Health Organization, health-related pollution arises from the activities of healthcare centers, hospitals, medical laboratories, and pharmacies [1]. Liquid medical waste contains pharmaceutical products and materials, organic and inorganic chemicals, and toxic substances [2].

In recent decades, the volume and complexity of pollutants in hospital wastewater have increased due to the expansion of medical services, rising patient numbers, and inadequate waste treatment and disposal practices [3]. Pollution occurs when pollutants are discharged into rivers, such as physical, chemical, and biological pollutants resulting from industrial, sanitary, or domestic wastewater, and the presence of these chemicals impacts the vitality of living organisms [4]. Water pollution is one of the most serious threats to the health of all living organisms, including humans. Moreover, polluted water may contain heavy metals, dangerous and toxic compounds, and disease-causing organisms, making it unfit for drinking [5].

Suppose hospital waste is not properly treated through physical, chemical, and biological processes prior to discharge. In that case, it can severely contaminate lakes and other water bodies and contaminate the water upon reaching the riverbed. Additionally, the presence of heavy metals affects water quality [6].

Hospitals contribute to the progress of medical science and research and are vital to the well-being of humanity. By providing ongoing assistance to meet complex health problems, they contribute to health services [7]. Nevertheless, these operations are linked to the production of significant amounts of wastewater [8, 9]. Additionally, hospitals produce a substantial amount of biomedical waste (BMW) [10]. The hospital's size significantly impacts the waste management procedures, the services and facilities provided, and the kinds and amounts of Hospital wastewater (HWW) created.

Hospital wastewater (HWW) differs significantly from domestic wastewater, as it contains hazardous and potentially infectious substances. The wastewater released by radiology, diagnostic labs, surgical rooms, and infectious wards [11] includes radioactive elements, hazardous organic pollutants, harmful bacteria and viruses, and pharmaceutical substances, including psychiatric drugs, antibiotics, and other pharmaceutical compounds. The many harmful microorganisms found in HWW emphasize the possible risk to public health that HWW discharge to the receiving water poses [12, 13]. Therefore, to reduce the negative effects of hospital effluents on the environment, adequate treatment is essential [14]. The typical characteristics of HWW are highlighted in Table 1. Al-Sadr Teaching Hospital in Najaf is a major healthcare facility in the region. Environmental engineers have a daunting issue in managing the massive amounts of wastewater generated by the hospital's ever-increasing development of pharmaceutical and healthcare operations [7]. Generally speaking, HWW has higher concentrations of nitrogen, ammonia, chemical oxygen demand (COD), and biochemical oxygen demand (BOD) than home wastewater [13, 14].

COD is the number of oxygen equivalents used in a potent oxidant's chemical oxidation of organic matter. In contrast, the amount of oxygen microorganisms require to decompose organic matter in aerobic conditions at a specific temperature and time is known as BOD [15, 16]. Therefore, BOD can be defined as the wastewater's biodegradable portion, whereas COD measures both biodegradable and non-biodegradable organic molecules. The biodegradability index is the ratio of wastewater BOD to COD [16, 17]. Additionally, HWW has a lower biodegradability index than municipal wastewater, which makes it challenging for traditional biological systems to handle [13, 14, 18].

Many organic compounds present in HWW are highly toxic and possess very low drinking water equivalent limit (DWEL) values, a significant environmental concern [19].

Over the years, a variety of treatment technologies have been employed to treat HWW, including advanced oxidation processes like photocatalysis and the Fenton process, biological techniques like the adsorption-built wetlands (CWs), membrane bioreactors (MBR), moving bed bioreactors (MBBR), and activated sludge processes (ASP) [19]. In addition to its high susceptibility to disease outbreaks, hospital wastewater poses a serious risk to public health due to the complex pollution load it places on ecosystems and water supplies, due to the presence of pharmaceutically active compounds and other recalcitrant organic compounds [1].

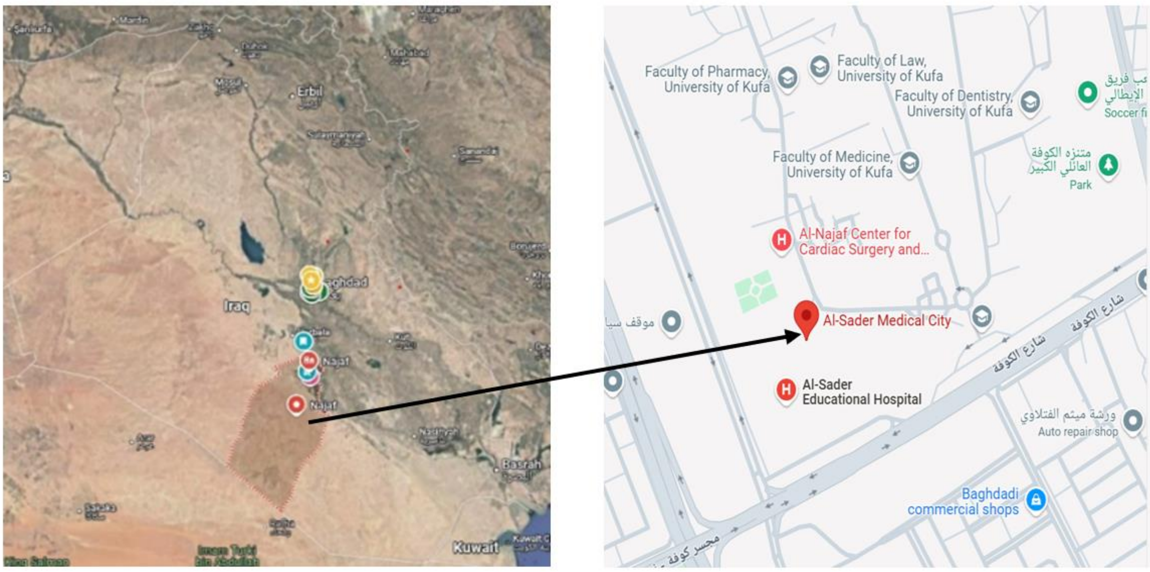
This study provides insight into the occurrence, persistence, and removal of BOD, COD, total suspended solids (TSS), PO_4, pH, TDS, DO, TOC, NO_3, and Cu.

Graphene is a two-dimensional material composed of a single layer of sp^2-hybridized carbon atoms arranged in a hexagonal lattice. Graphene has captivated scientists because of its distinct shape, chemical makeup, mechanical, electrical, and thermal characteristics, and enormous specific surface area [14].

Using two distinct online platforms, this study presents a novel technique that uses a short electrical pulse combined with a powerful radiation burst to transform several inexpensive carbon species into desired graphene flakes quickly. These resources include coal, petroleum coke, tires, charcoal, food scraps, carbon black, and other plastic waste. The entire process takes less than a second. The resulting product is referred to as FG [13, 14]. This technique uses FJH to rapidly create graphene from carbon-containing materials. The synthesis of FG does not require a furnace, solvents, reactive gases, or additional purification steps. If certain carbon sources are used, graphene can be produced from carbon for as little as \$30/metric ton due to its low electric energy requirements and exceptional ease of scale production [14]. For various reasons, scientific efforts to use graphene as an adsorbent are still in their infancy in Iraq; nevertheless, the preparation time is the most significant [20]. Cost-effective graphite produced from fruit was used to create a new adsorbent [21].

2. METHODOLOGY

2.1 Study area



(a) (b)

Figure 1. a) The city of Al-Najaf, Iraq, b) Al-Sader Medical City Hospital (sampling stations)

The study was conducted at the University of Baghdad, College of Engineering, in the Environmental Engineering department /Iraq. The study samples were collected from Al-Sader Medical City Hospital, which is located in Najaf, Iraq, approximately 160 kilometers (99 miles) south of Baghdad. The hospital coordinates are Latitude 32.01789° N and Longitude 44.37256° E. One of the key healthcare institutions in the province was established in the 1980s. The hospital has a capacity of 597 beds, making it a cornerstone of medical services in the region, as shown in Figure 1.

2.2 Adsorbent flash graphene

The FJH technique is an advanced and efficient method for synthesizing FG from carbon-based materials as an adsorbent. FJH is a new way to make a lot of high-quality FG_S [22]. Flash graphene is sourced from orange peel activated carbon that is prepared by chemical and physical activation. For more details about the preparation process, see our previous work [23]. This method employs a quartz tube with two electrodes, where a rapid discharge of electric current, controlled by a mechanical relay, produces 1 gram of FG per batch. The process utilizes a two-capacitor bank of (470 µF per capacitor) charged by a 210 V direct current source, with a 460 × 2-volt voltage. It requires no additional purification steps, solvents, or reactive gases, making it cost-effective and environmentally friendly. Figure 2 shows the flash graphene synthesis process.

Figure 2. Flash graphene synthesis process

The FG characteristic is an average pore diameter of 18.534 nm and a specific surface area of 11.168 m²/g. It is suitable for various applications in water treatment, spectroscopy, environmental science, and materials engineering, addressing significant industrial and scientific demands through its surface, which contains hydrophilic functional groups. The rapid, cost-effective synthesis and superior physical and chemical properties make FG highly suitable for water and wastewater treatment, pollutant adsorption, nanomedicine, and advanced material science applications.

Given the current widespread discharge of industrial wastewater into the environment, it is strongly advised that cost-effective adsorbents be used for water treatment because they are not only affordable but also readily available locally, technically feasible, and engineeringly applicable [24].

2.3 Wastewater

Al-Sadeer Medical City Hospital is a general and teaching hospital that provides all kinds of physical and surgical services. The Iraqi Ministry of Health acquired it. The hospital operates a referral system at a rate of more than 2500 references per month. It is considered one of the most important hospitals in Al-Najaf, Iraq. The hospital has an old treatment plant for its own discharged wastewater. As wastewater was generated from different hospital departments, and the wastewater flow ranged from 70 to 78 L/h during the research period, the wastewater was discharged within the hospital sewage network connected to the sewer system.

The samples were taken periodically at a rate of 80 liters of wastewater from the final discharge point (main hole). As the research conducted an actual wastewater sample to achieve the realistic status of wastewater specification, the initial wastewater specifications varied according to the discharged wastewater specification at the sampling time. The samples were immediately transported after treatment to the service laboratory. This study aims to examine the wastewater treatment plant at the Al-Sadr Medical Teaching City Hospital in Al-Najaf and the consequences of hospital waste released from the facility. All of the locations under study had a pH of 8.2. The average values of TDS, DO, BOD_5, COD, TOC, PO_4, NO_3, Cl, TSS, Co, and Cu were 1730, 5.3, 5.3, 40, 8, 3.518, 0.94, 480, 1050, 0.14, and 0.481 mg/L, respectively, as shown in Table 1.

Table 1. Initial concentration from the main hole in the hospital

Samples	pH	TDS	DO	BOD	COD	TOC %	PO_4	NO_3	Cl	TSS	Co	Cu
Original	8.2	1730	5.3	5.3	40	8	3.518	0.94	480	1050	0.14	0.481

The findings showed that the hospital's BOD_5, COD, TSS, TDS, PO_4, NO_3, and CL concentrations exceeded the Iraqi reuse threshold, indicating that hospital wastewater needs treatment before municipal sewage disposal. A novel adsorbent was developed, utilizing cost-effective fruit-derived graphite [25]. The recent advances in graphene-based nano-carriers for drug delivery applications are a significant development in Nanomedicine [26].

2.4 Sample collection

Collecting samples of wastewater discharged from Al-Sader Medical City Hospital's main septic tank began in the summer of 2024 to evaluate its quality. Samples were collected between 12 p.m. and 2 p.m. at 10 to 25cm below the surface water in the collection basins. The sample was collected directly from a sewage water tank in Al-Sader Hospital in a 1-liter glass container and directly transported to the lab with an ice box container for laboratory chemical analysis in the field; the air temperature was 35℃, the water temperature was 27℃, and add for dissolve oxygen container (KI and $MnSO_4$) reagent for fix the oxygen value and the COD and TOC sample, add H_2SO_4.

2.5 Batch

This experimental work was conducted to treat AL-Sadeer Medical City Hospital wastewater using Flash graphene, which was locally prepared for batch experiments to treat the hospital wastewater. The wastewater was taken from AL-Sadeer Medical City Hospital on Kufa Street in Najaf City, Iraq.

Batch experiments were carried out using conical flasks of 250 cm^3 in size and filled with 100 cm^3 of real medical wastewater from AL-Sadder Medical Hospital in AL-Najaf City in Iraq. Sixteen experiments were conducted for batches of heavy metals, and organic and inorganic removal from real medical wastewater was done. In these experiments, the effect of different parameters, such as contact time, pH, adsorbent dose, and agitation speed, was studied to determine the best conditions and to find equilibrium data for the treatment process.

Removal efficiency were examined through different adsorbent dosages (0.5, 1, 1.5, and 2) gm, different periods (15, 30, 60, 90, and 120) min, pH (5, 7.3, and 8.5), different agitation speed (100, 150, 200 and 250) rpm, and constant initial concentrations with value as shown in Table 1 and compared the result with Iraqi standard where Table 2 is the specifications Iraqi standard for water and Table 3 is the classification of rivers in terms of pollution. The experimental work procedure is shown in Figure 3.

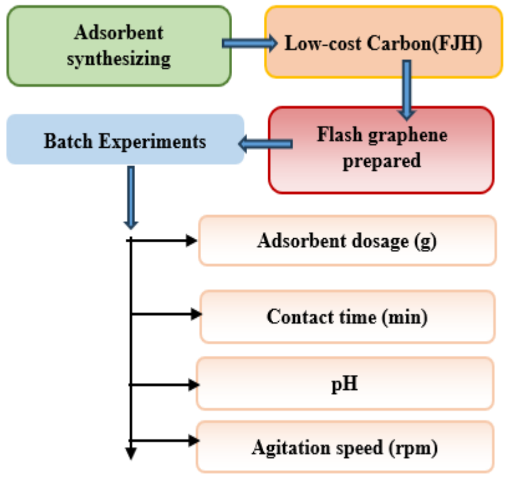


Figure 3. The experimental work procedure

Table 2. Specifications of the Iraqi standard for water

Properties	Iraqi Environmental Legislation (mg/L) (1967)	WHO Environmental Legislation (mg/L) (2011)
pH	6.5-8.5	6.9-9.5
BOD	5	low 5
COD	100	low 3
TSS	30	10_20
TDS	1500	1000
PO_4	3	0.5
NO_3	50	50
Cl	250_350	45_250
Cu	0.05	2
Co	0.05	This has not established a specific guideline for the value of cobalt in drinking water. This decision is due to the limited data on the health effects of cobalt at concentrations typically found in drinking water.

Table 3. Classification of rivers in terms of pollution

Classification of a River	BOD_5 (mg/L)
Very clean	1
Clean	2
Fairly clean	3
Questionable cleanliness	5
Bad	More than 10

In this study, an insight into the occurrence, persistence, and removal of BOD_5, COD, TSS, PO_4, pH, TDS, dissolved oxygen (DO), Total organic carbon (TOC), NO_3, Cl, Co, and Cu from hospital wastewater by flash graphene. To choose the optimal performance of the selected parameter values, these numbers for the lowest pollutant concentration are based constructively on the literature review of previous adsorption batch mode studies in scientific research [27]. Comparing the choosing parameter in Table 1 with the Iraqi standard in Tables 2 and 3, we note that it exceeds the limiting value.

3. RESULTS AND DISCUSSION

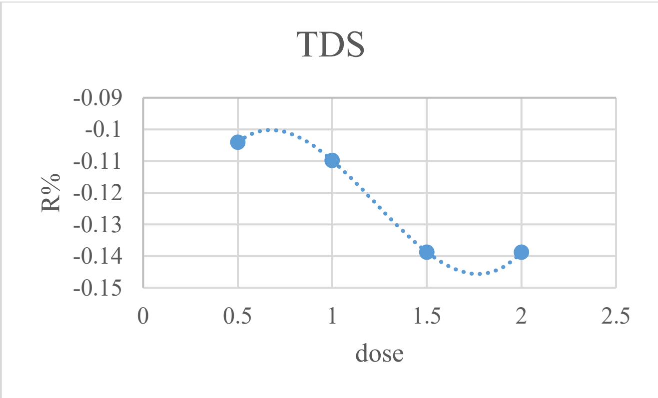
3.1 Effect of adsorbent dosage

Different quantities of flash graphene sorbent were added to four 250 ml conical flasks for each adsorption test run. Each of the four samples was a water sample at room temperature with consistent time, rpm, and pH values. There were four dosage-weighted levels: 0.5, 1, 1.5, and 2 g. As an adsorbent, 100 milliliters of actual medical wastewater were placed inside each conical flask for 60 minutes at 8.2 pH and 200 rpm. Table 4 displays the remedial outcomes of this project. One crucial adsorption characteristic is the adsorbent's surface area. When the adsorbent has a large surface area, its sites are more reactive to metal-ion interaction [28]. The active locations that the pollutants will occupy are largely determined by surface area. As a result, a material's ability to absorb additional contaminants is increased when its surface area grows [29].

As shown in Figures 4(f) and (h), the best removal was at 2 g of flash graphene for PO_4 and Cl. It is evident that as the sorbent dose has increased, so has the removal efficiency. While TDS, COD, TOC, NO_3, Co, and Cu were removed at 0.5 g from flash graphene, as clear in Figures 4(a), (d), (e), (g), (j) and (k), respectively, that prove the efficient of small amount of flash graphene for remove the mention pollution. While 1 g of flash graphene is sufficient for the removal of BOD_5 and TSS, as shown in Figures 4(c) and (i), respectively, and finally, 1 g of flash graphene is enough to reduce DO, as shown in Figure 4(b). As the sorbent dose in the solution increased, more sorption sites became available, which is why this behavior was anticipated. Additionally, it demonstrated that the amount of flash graphene in the solution stays constant even after the sorbent dose is added, since the total sorption sets the amount of this pollutant to the sorbent after a specific sorbent dose.

Table 4. Effect of adsorbent dosage

Dose	TDS	DO	BOD	COD	TOC	PO_4	NO_3	Cl	TSS	Co	Cu
0.5	1910	2.4	0.24	ND	ND	32.87	0.9	440	62	ND	0.205
1	1920	2.16	0	ND	ND	18.99	0.92	440	16	ND	0.216
1.5	1970	1.92	0	8	1.6	11.9	0.85	440	16	ND	0.295
2	1970	2.2	1	ND	ND	2.26	4.18	400	106	ND	0.205



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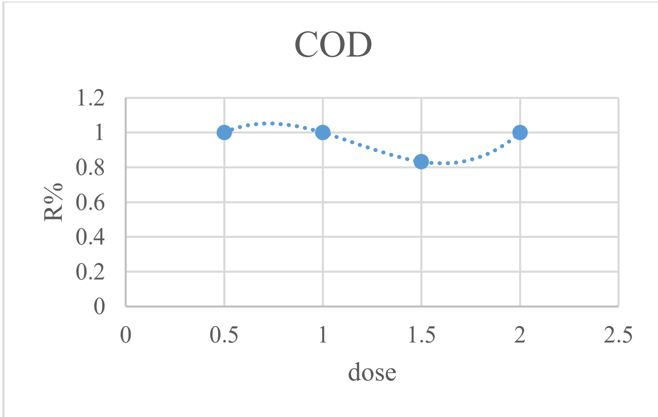

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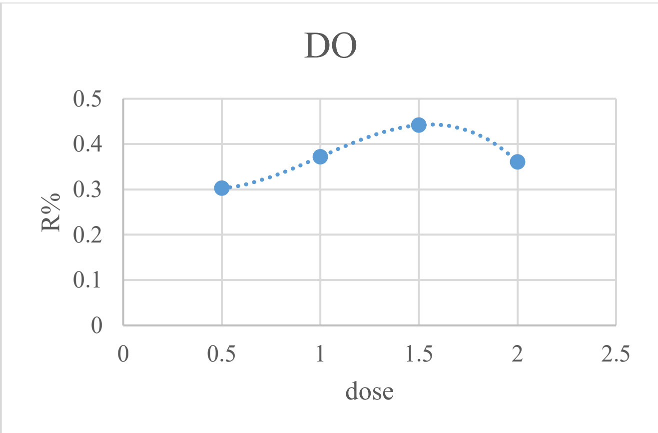

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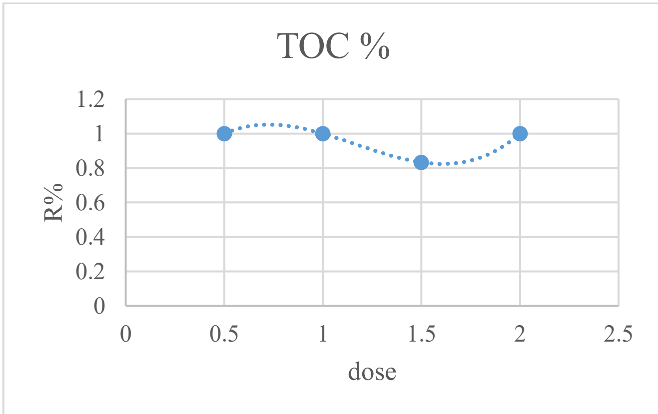

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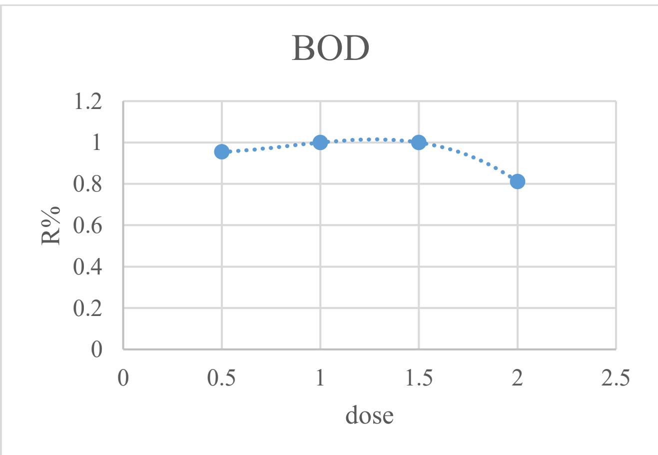

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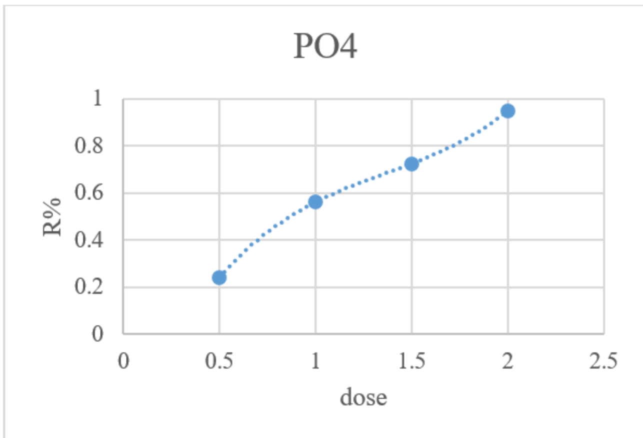

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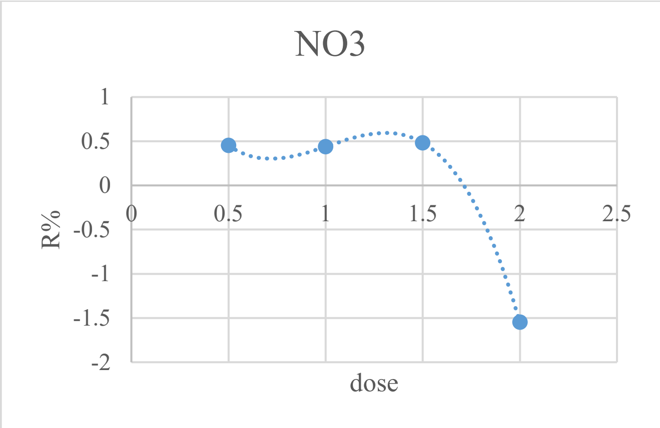

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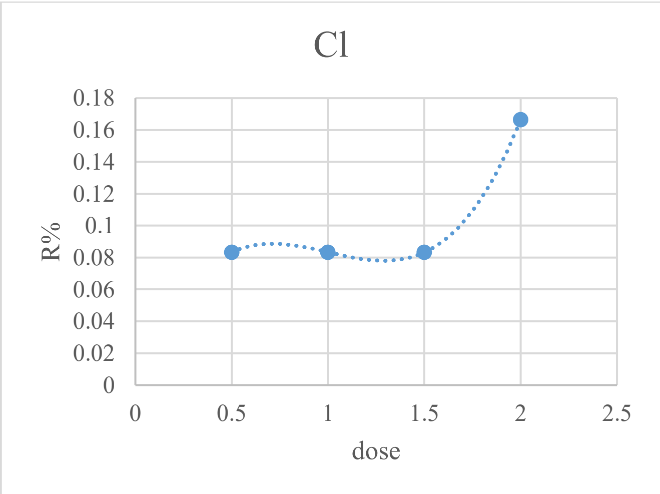

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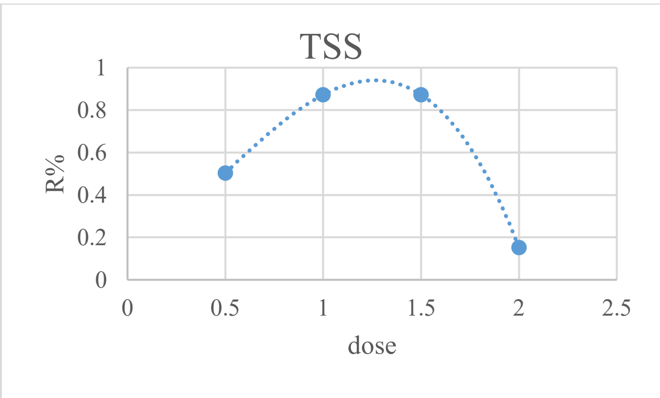

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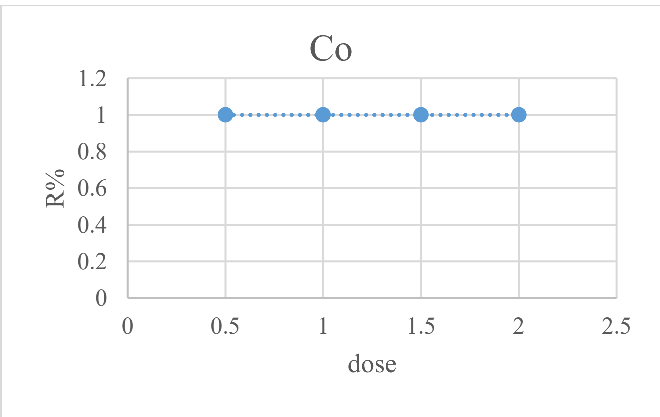

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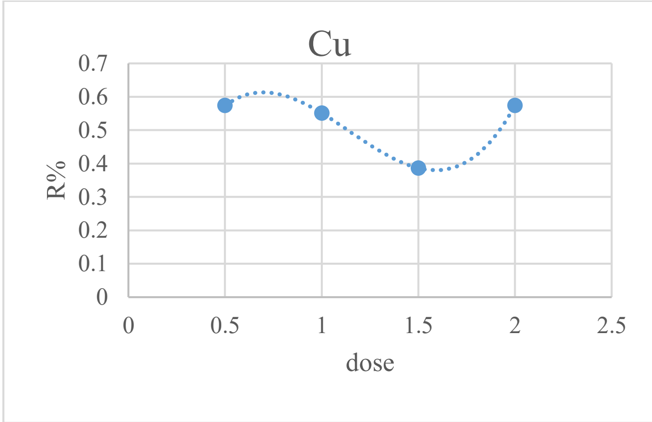
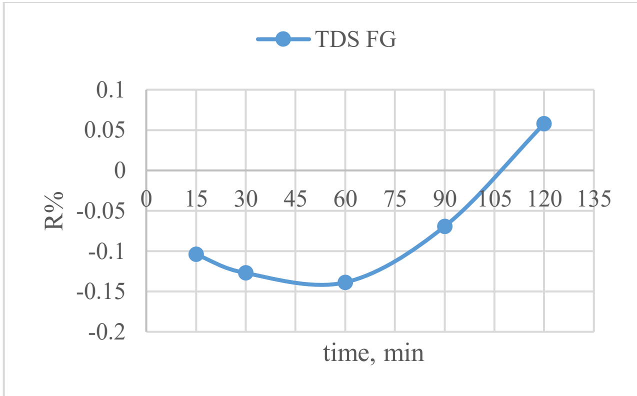


(k)

Figure 4. Effect of adsorption dose (a) TDS, (b) DO, (c) BOD, (d) COD, (e) TOC, (f) PO_4, (g) NO_3, (h) Cl, (i) TSS, (j) Co, (k) Cu

3.2 Effect of contact time



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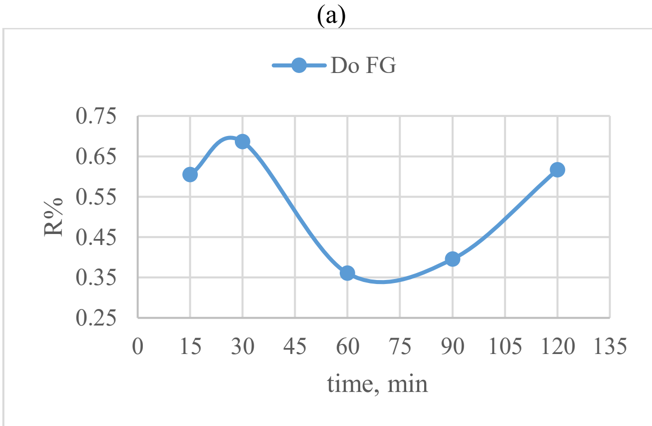

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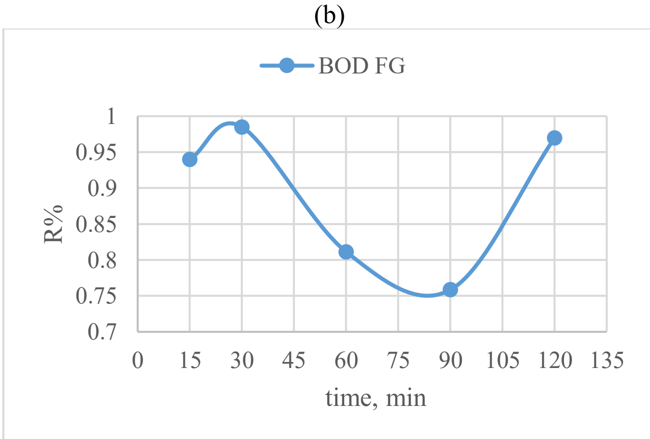

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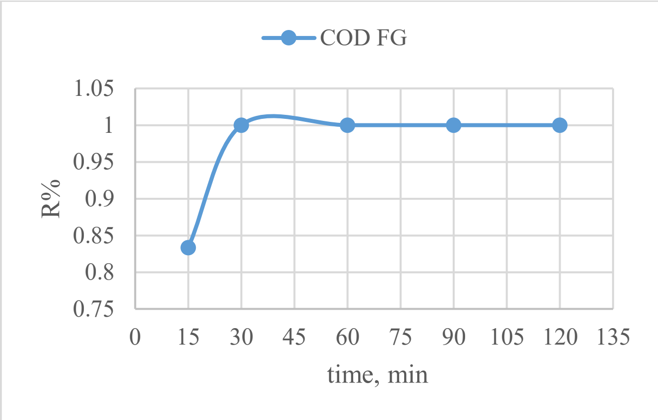

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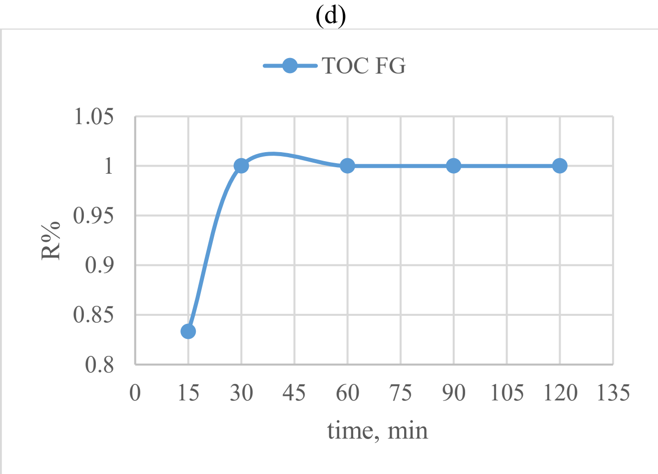

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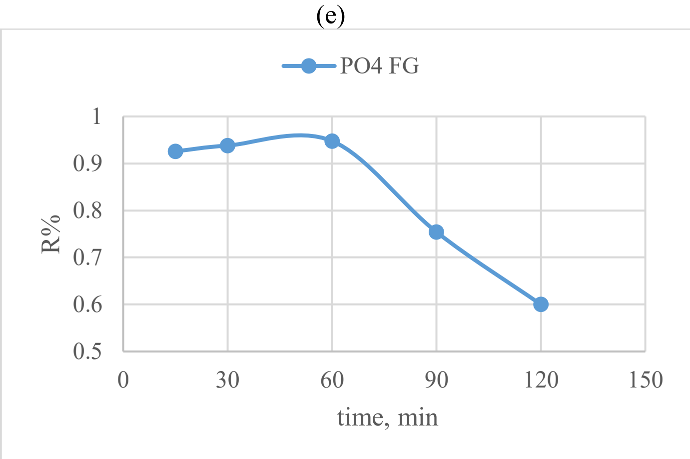

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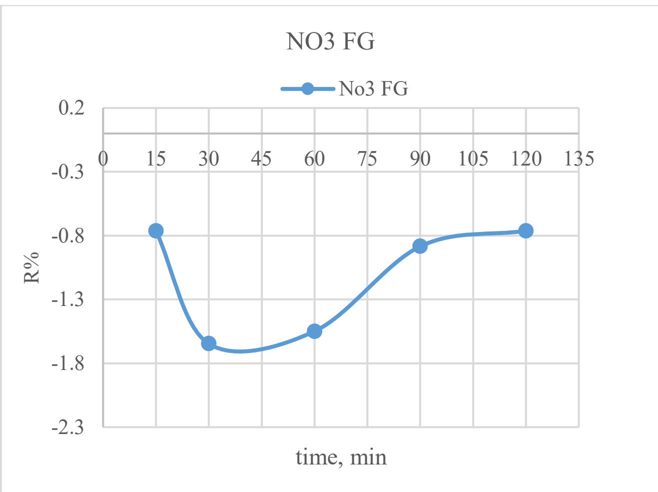

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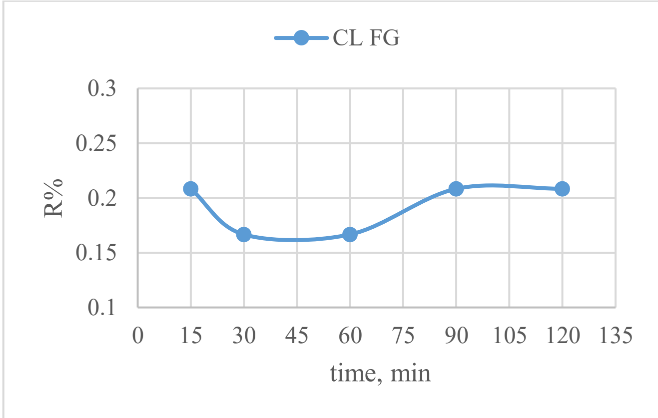

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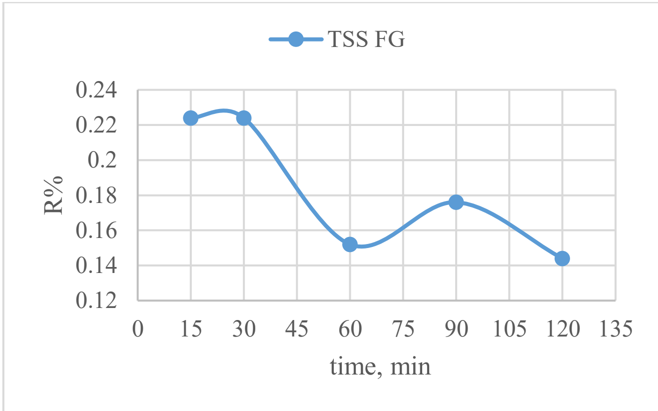

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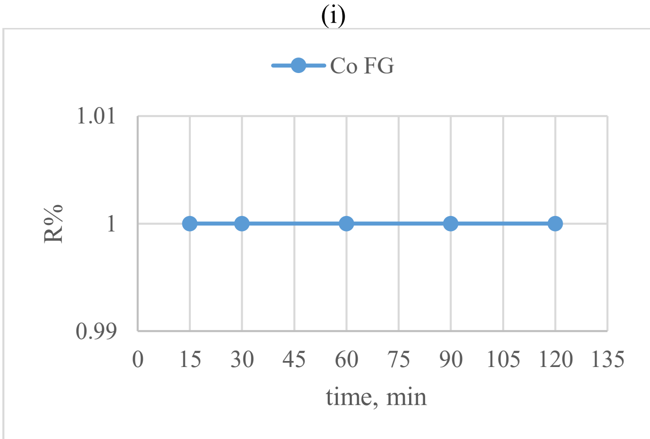

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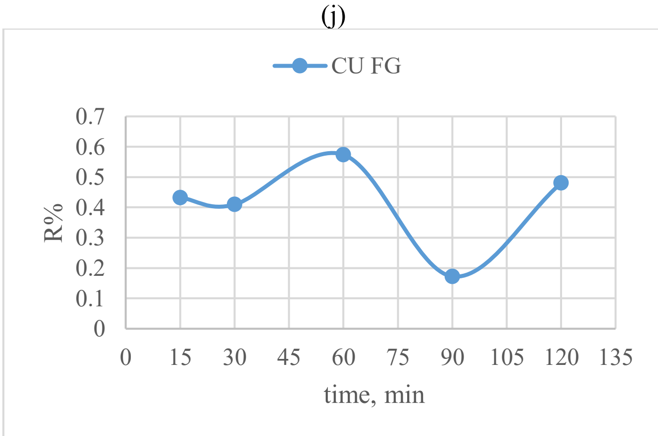


(k)

Figure 5. Effect of contact time (a) TDS, (b) DO, (c) BOD, (d) COD, (e) TOC%, (f) PO_4, (g) NO_3, (h) Cl, (i)TSS, (j) Co, (k) Cu

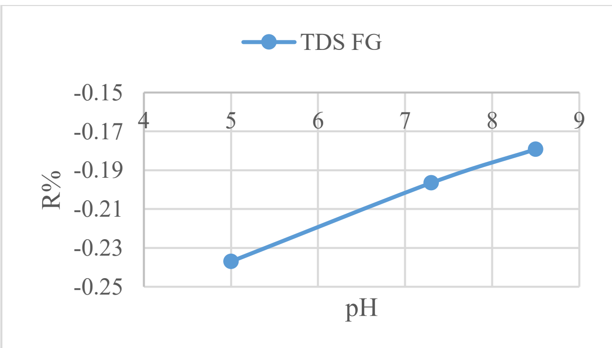
Table 5. Effect of contact time

Time min.	TDS	DO	BOD	COD	TOC %	PO_4	NO_3	Cl	TSS	Co	Cu
15	1910	1.36	0.32	8	1.6	3.21	2.89	380	97	ND	0.273
30	1950	1.08	0.08	ND	ND	2.68	4.34	400	97	ND	0.284
60	1970	2.2	1	ND	ND	2.26	4.18	400	106	ND	0.205
90	1850	2.08	1.28	ND	ND	10.63	3.09	380	103	ND	0.398
120	1630	1.32	0.16	ND	ND	17.3	2.89	380	107	ND	0.25

The equilibrium time should be determined to achieve equilibrium concentrations [30]. Medical real wastewater solutions taste the effect of contact time by choosing five different times (15, 30, 60, 90, 120 min) (Table 5). Under 2 g from the adsorbent flash, graphene was added to 100 ml of the solution at room temperature with 8.7 pH and a shaking speed of 200 rpm. The result value is described in Figure 5. At contact time of 15 min, Cl and TSS were removed as shown in Figures 5(h) and (i), and at 30 min, Do, BOD, COD, and TOC was removed as shown in Figures 5(b), (c), (d), and (e). Also, at 60 min, PO_4 and Cu were removed, as shown in Figures 5(f) and (k). This figure demonstrates how the percentage of these pollutants removed rose noticeably as contact time increased. The sorption rate was high in the beginning and gradually decreased. A decrease in sorption sites on the surface of the flash graphene was most likely the cause of the slower sorption [31].

3.3 Effect of pH

The solution's pH impacted the adsorbent surface's electrical charge and the adsorbate molecule's ionic forms [32]. The solution's initial pH is the most important single parameter influencing the sorption capacity. The effect of pH value was tested with three different values of 5, 7.3, and 8.5 and a fixed condition of 60 min shaking time with 2 g of flash graphene and 200 rpm shaking speed. Table 6 shows the removal result after adsorption by flash graphene. From Figures 6(a) to (e) and (h, I, and k), higher removal efficiency was observed at a pH value of 5, while PO_4 was removed at a pH value of 7.3, as shown in Figure 6(f). Also, NO_3's best pH value at 8.5 is clear in Figure 6(j).



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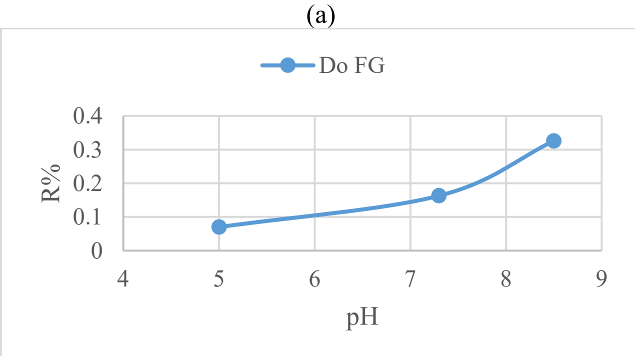

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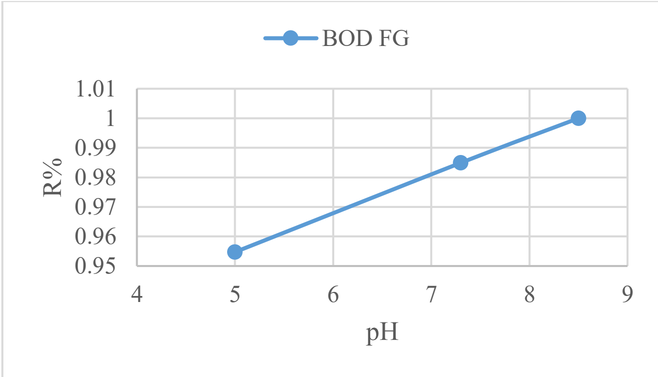
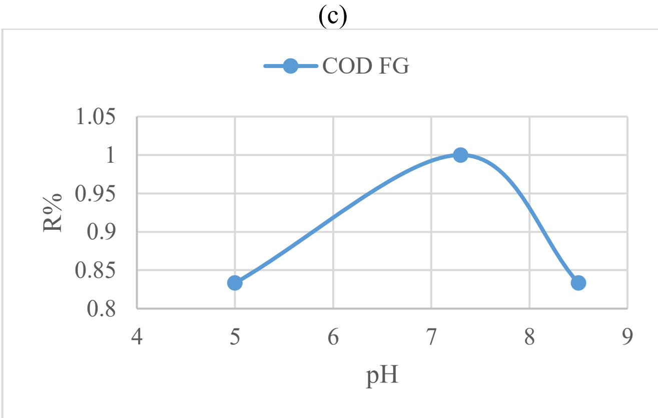
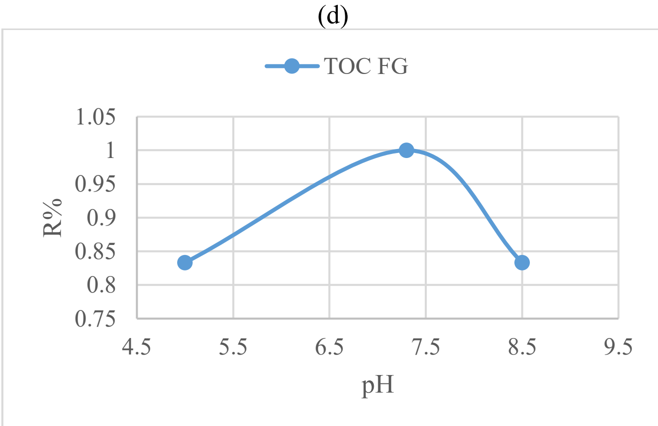


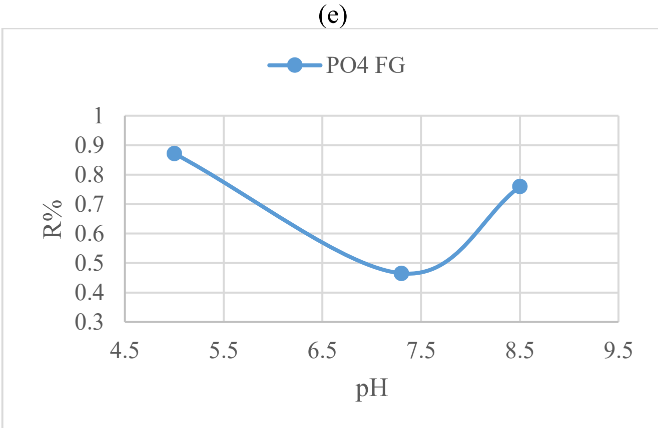
(c)



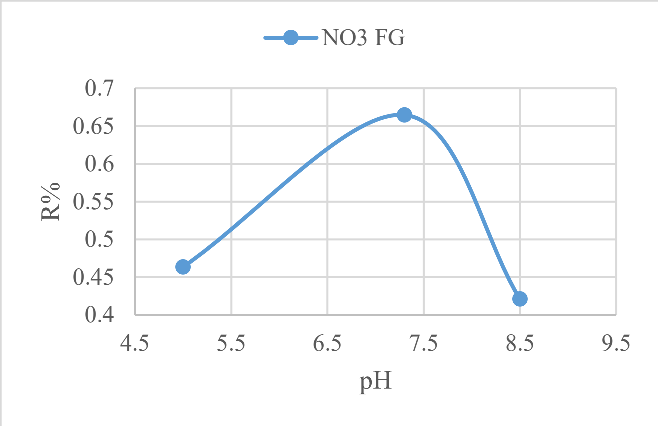
(d)



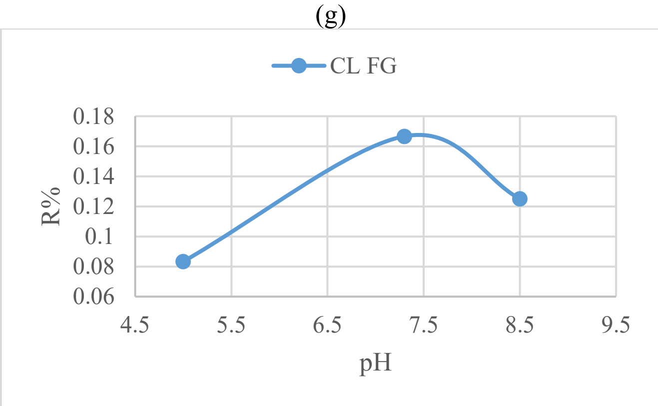
(e)



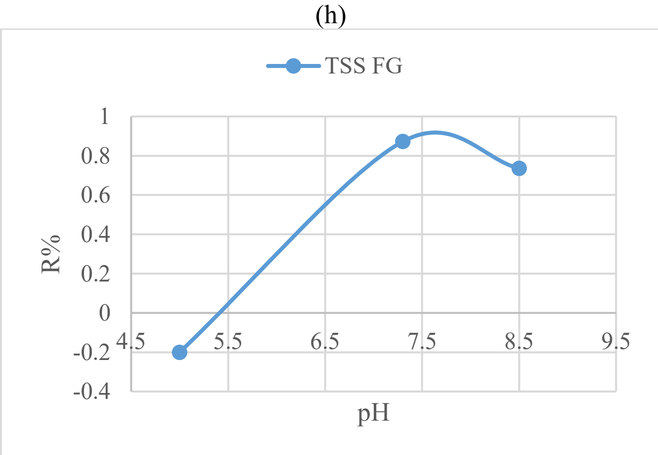
(f)



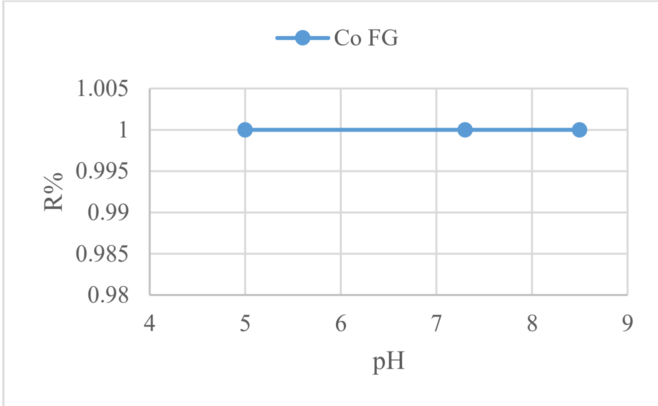
(g)



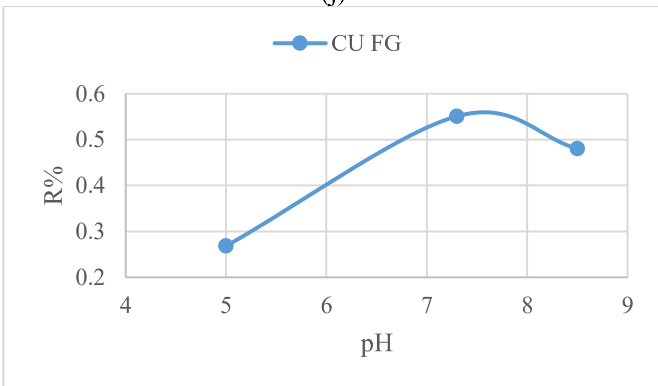
(h)



(i)



(j)



(k)

Figure 6. Effect of pH value (a) TDS, (b) DO, (c) BOD, (d)COD, (e) TOC%, (f) PO_4, (g) NO_3, (h) Cl, (i)TSS, (j) Co, (k) Cu

3.4 Shaking speed

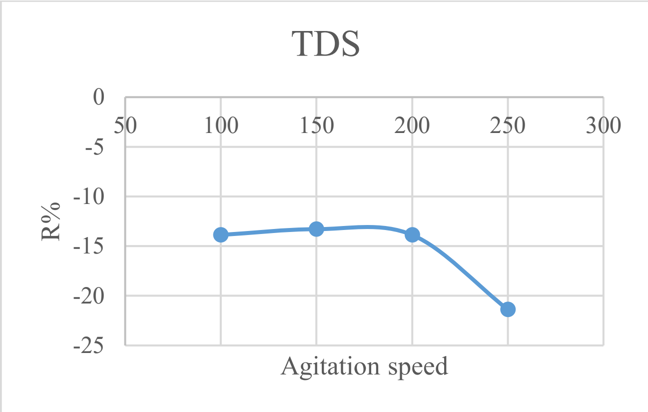
Four different shaking speeds were examined by adding 2 g of flash graphene to 100 mL of real medical wastewater in a 250 mL conical flask with 7.3 pH and a shaking time of 60 minutes, as shown in Table 7, which shows the removal percentage. At a shaking speed of 150 rpm, TDS, DO, and Cl were removed, as shown in Figures 7(a), (b), and (h), while BOD and TSS were removed at 250 rpm shaking speeds, respectively, as is clear in Figures 7(c) and (i). Furthermore, NO_3, Cu, and COD are removed at a shaking speed of 100, as shown in Figures 7(f), (d), and (k), which shows a notable reduction in values.

Table 6. pH value

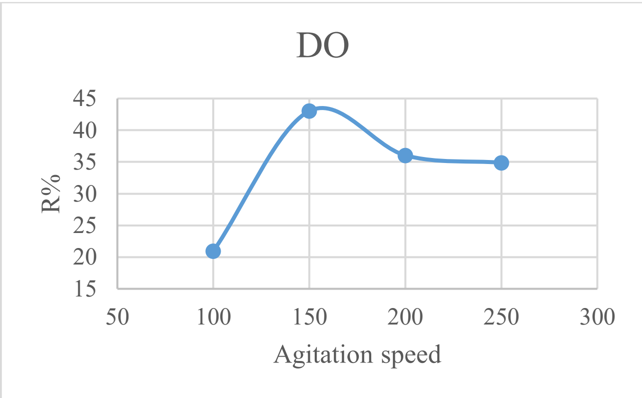
pH	TDS	DO	BOD	COD	TOC %	PO_4	NO_3	Cl	TSS	Co	Cu
5	2140	3.2	0.24	8	1.6	5.54	0.88	440	150	0	0.352
7.3	2070	2.88	0.08	0	0	23.13	0.55	400	16	0	0.216
8.5	2040	2.32	0	8	1.6	10.41	0.95	420	33	0	0.25

Table 7. Effects of shaking speed

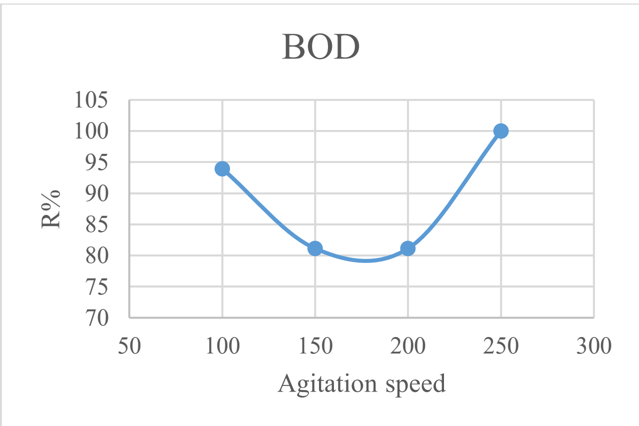
Time min.	TDS	DO	BOD	COD	TOC %	PO_4	NO_3	Cl	TSS	Co	Cu
100	1970	2.72	0.32	ND	ND	19.1	0.51	480	100	ND	0.136
150	1960	1.96	1	40	8	30.54	1.22	360	108	ND	0.205
200	1970	2.2	1	ND	ND	2.26	4.18	400	106	ND	0.205
250	2100	2.24	0	16	3.2	15.5	0.66	440	50	ND	0.159


TDS
0
-5
-10
-15
-20
-25
50
100
150
200
250
300
R%
Agitation speed

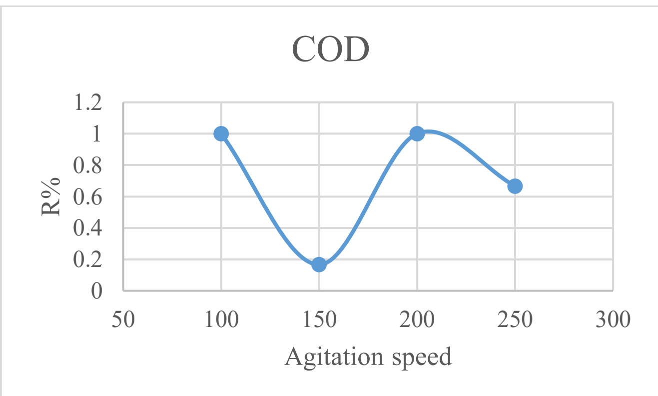
(a)


DO
45
40
35
30
25
20
15
50
100
150
200
250
300
R%
Agitation speed

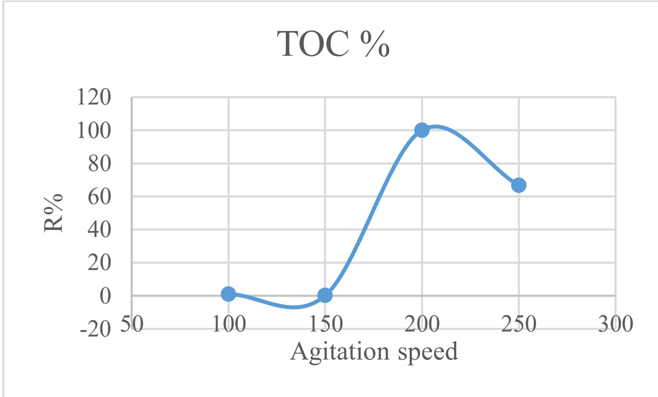
(b)


BOD
105
100
95
90
85
80
75
70
50
100
150
200
250
300
R%
Agitation speed

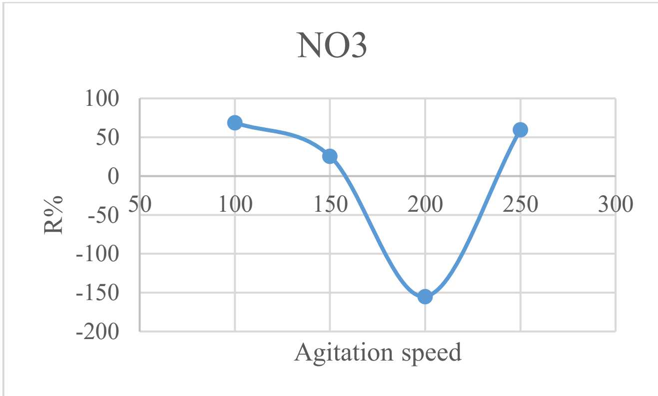
(c)


COD
1.2
1
0.8
0.6
0.4
0.2
0
50
100
150
200
250
300
R%
Agitation speed

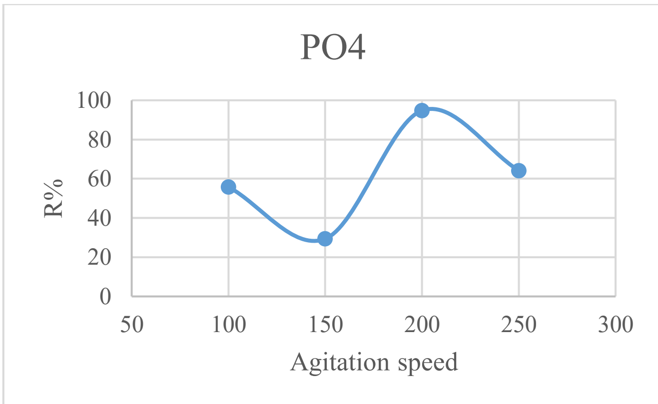
(d)


TOC %
120
100
80
60
40
20
0
-20
50
100
150
200
250
300
R%
Agitation speed

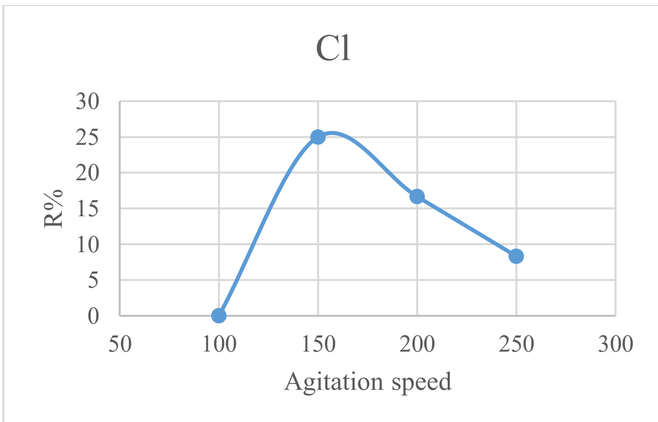
(e)


NO3
100
50
0
-50
-100
-150
-200
50
100
150
200
250
300
R%
Agitation speed

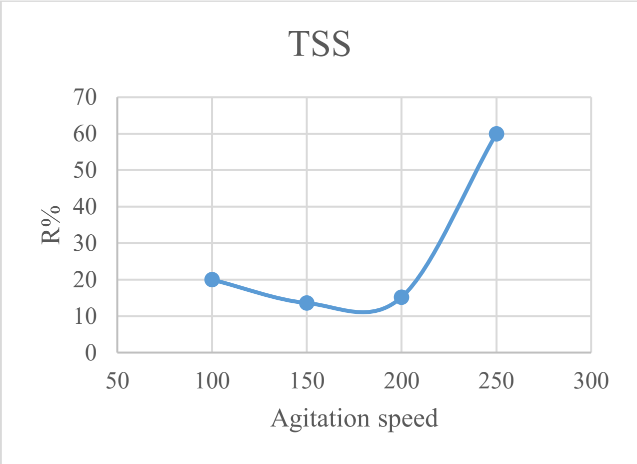
(f)


PO4
100
80
60
40
20
0
50
100
150
200
250
300
R%
Agitation speed

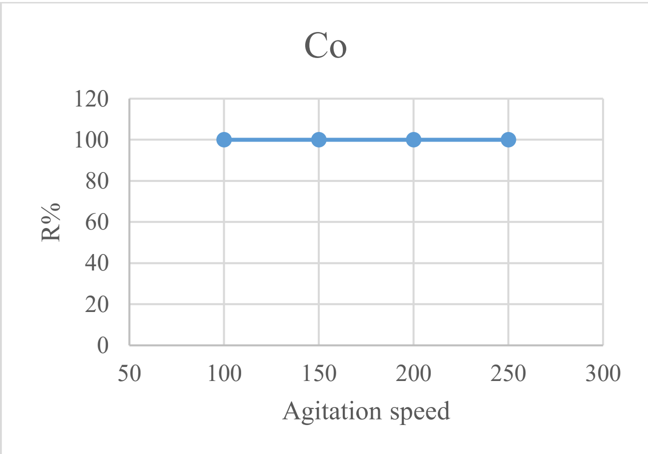
(g)


Cl
30
25
20
15
10
5
0
50
100
150
200
250
300
R%
Agitation speed

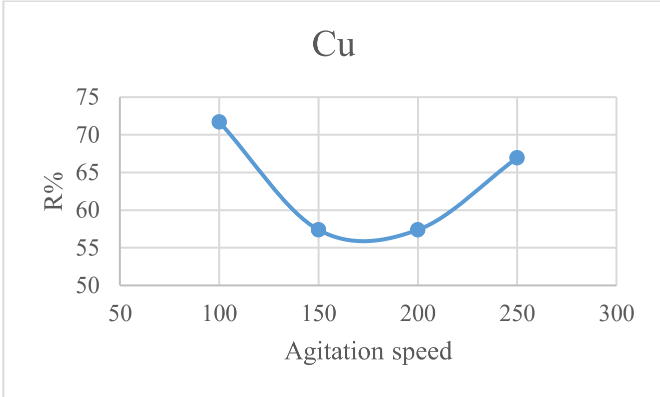
(h)



(i)



(j)



(k)

Figure 7. Effect of shaking speed (a) TDS, (b) DO, (c) BOD, (d) COD, (e) TOC%, (f) PO_4, (g) NO_3, (h) Cl, (i)TSS, (j) Co, (k) Cu

3.5 Discussion

The results obtained in this study demonstrate the high efficiency of FG, synthesized from orange peel using FJH, in removing a wide range of pollutants from hospital wastewater. The findings were compared with results reported in prior research to evaluate the performance of FG in relation to other adsorbents and treatment technologies.

Table 8 showed excellent removal efficiency of Flash graphene for BOD_5, achieving 100% removal within 90 minutes using only 1 gram of adsorbent. In comparison, conventional treatment systems reported in previous studies achieved only around 60% BOD_5 removal efficiency [3]. Similarly, COD was completely removed within just 15 minutes in this study, outperforming membrane bioreactor (MBR) systems that achieved approximately 75% COD reduction [9].

Table 8. Summary

Pollutant	This Study (FG from Orange Peel)	Previous Research & Method	Reported Removal Efficiency	Reference
BOD_5	100% in 90 min (1 g FG)	Conventional treatment	~60%	[3]
COD	100% in 15 min (0.5 g FG)	MBR	~75%	[9]
TOC	Full removal at 15 min	Graphene oxide-based	80–85%	[20]
Cu^{2+}	57.4% at 90 min	Graphene/Chitosan composite	~70%	[32]
Co^{2+}	Fully removed (15–60 min)	Not reported (rarely studied)	N/A	-

This study recorded notable removal efficiencies for several inorganic pollutants. Total dissolved solids (TDS) were reduced to acceptable levels at minimal contact time, and phosphate (PO_4^{3-}) removal was highly effective at pH 7.3. For nitrate (NO_3^-), optimal removal occurred at pH 8.5. These results align with, and in some cases exceed, previous studies that used FG synthesized from banana peels and plastic waste [21, 27].

In terms of heavy metals, copper (Cu^{2+}) and cobalt (Co^{2+}) were effectively removed, with up to 57.4% and full removal, respectively, under optimized batch conditions. Comparable results were reported using a graphene oxide/chitosan nanocomposite, although that system required higher adsorbent doses and longer contact times [32].

4. CONCLUSIONS

1. Compared to previously reported methods, the flash graphene synthesized from orange peel using FJH demonstrates equal or superior performance in pollutant removal. Its rapid synthesis, low cost, and environmentally friendly preparation process further support its viability as an alternative to conventional hospital wastewater treatment technologies. These findings emphasize the potential of FG as a scalable, sustainable solution for addressing complex pollutant loads in developing countries.
2. FJH enabled rapid and cost-effective synthesis of graphene from orange peel waste without solvents or purification. This method produced high-quality flash graphene with excellent surface properties suitable for adsorption.
3. Flash graphene showed high efficiency in removing a wide range of organic (BOD, COD), inorganic (TDS, PO_4^{3-}, NO_3^-), and heavy metals (Cu^{2+}, Co^{2+}), from real hospital wastewater under optimized conditions.
4. This approach offers a low-cost, sustainable solution by

converting agricultural waste into a valuable adsorbent. It reduces environmental impact, supports circular economy practices, and provides a practical alternative to conventional wastewater treatment methods.

5. This study suggests a potential alternative to the conventional wastewater treatment plant in hospitals with more economical and cost-effective nanomaterials.

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NOMENCLATURE

ml	Milliliters
g	Gram
rpm	Rotation per minute
t	Time
T	Temperature, ℃
Subscripts	
AC	Activated carbon
OP	Orange peel
FG	Flash graphene
FJH	Flash Joule heating